National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Obed Wild and Scenic River

Natural Resource Report NPS/OBED/NRR—2017/1554

ON THE COVER
The Obed River within OBRI
Photograph by: Saint Mary's University of Minnesota GeoSpatial Services

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November 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Please cite this publication as:

Benck, K. M., K. Allen, A. J. Nadeau, H. Hutchins, A. M. Davis, and A. Robertson. 2017. Natural resource condition assessment: Obed Wild and Scenic River. Natural Resource Report NPS/OBED/NRR—2017/1554. National Park Service, Fort Collins, Colorado.

NPS 179/141123, November 2017

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation characterizing the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Obed Wild and Scenic River (OBRI) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or ecological processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and ecological processes that are currently of the greatest concern to park management at OBRI. The final project framework contains 11 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each resource component in the framework to provide a summary of current condition and trend for each selected resources. When possible, existing data for the established measures of each component were analyzed and compared to a designated reference condition. A weighted scoring system was applied to calculate the current condition of each component. Weighted Condition Scores (WCS), ranging from zero to one, were divided into three condition categories: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by OBRI resource managers and/or NPS Appalachian Highlands Network (APHN) Inventory & Monitoring staff.

Existing literature, short- and long-term datasets, and input from NPS scientists were used to support the condition designation for each of the components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for two of the 11 components (18%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. One component (fish communities) was determined to be in good condition; however, a trend could not be established. Two components, landscape dynamics and freshwater invertebrates, were considered to

be of significant concern, and a declining trend was assigned to both components. The main concerns associated with the landscape dynamics component are the urbanization of the watersheds above the park, oil and gas development surrounding the park, and the private in-holdings within the park. The highest concerns for freshwater invertebrates are the apparent declines (based on survey data) in overall mussel abundance and listed mussel species abundance. The remaining six components (birds, cobble bars/river scour prairies, dark night skies, native forests/other plant communities, water quality and water quantity) were of moderate concern. Due to insufficient data, a trend could only be assigned to the dark night sky component. Detailed discussion of these designations are presented in Chapters 4 and 5 of this report.

Several park-wide threats and stressors influence the condition of these priority resources in OBRI. Those of primary concern include urban development/growth in the parks watershed, water quality, natural resource extraction, drought, non-native invasive species, regional climate change, and potential loss of habitat. Understanding these threats, and how they relate to the condition of park resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the park ecosystem, as well as its cultural landscape.

Acknowledgments

We acknowledge Obed Wild and Scenic River staff for the technical expertise provided during scoping, through multiple stages of review, and via phone and email; specifically, Tom Blount, Rebecca Schapansky, Etta Spradlin, Marie Tackett, Jason Fisher, and Chad Harrold. In addition, we would like to thank the APHN staff, in particular Brian Witcher, Robert Emmott, Jim Hughes and all network staff who provided critical review of interim documents. Special thanks to Dale McPherson, Southeast Region NRCA and Resource Stewardship Strategy (RSS) Coordinator for guidance, logistic coordination, reviews and overall assistance in the completion of this project. Thank you to all others who assisted the development of this document.

Acronyms and Abbreviations

%TAud – Percent Time Audible

µS/cm – Microsiemens per centimeter

AET – Actual Evapotranspiration

ALR – Anthropogenic Light Ratio

ANC – Acid neutralizing capacity

AOA – Area of Analysis

APHN – Appalachian Highlands Network

ARD – Air Resources Division

bbls – Barrels of Oil

BBS – Breeding Bird Survey

BCR – Bird Conservation Region

BISO – Big South Fork National River and Recreation Area

BLM – Bureau of Land Management

BSc – Biotic Score

BSc-G – Biotic Score at Genus Level

BSc-S – Biotic Score at Species Level

CAA – Clean Air Act

CBC – Christmas Bird Count

CCD – Charge-couple device

CDP – Census Designated Place

cfs – cubic feet per second

CL – Condition Level

cms – cubic meters per second

cps – cycles per second

CPUE – Catch per Unit Effort

Acronyms and Abbreviations (continued)

CWMA – Catoosa Wildlife Management Area

dB – decibel

dBA – A-weighted decibels

DEM – Digital elevation model

DO – Dissolved Oxygen

dv – deciviews

EAB – Emerald ash borer

EO – Element Occurrence

EPA – Environmental Protection Agency

EPT – Ephemeroptera/Plecoptera/Trichoptera

FHA – Federal Highway Administration

FNU – Formazin Nephelometric Unit

GAP – Gap Analysis Program

GIS – Geographic Information System

GPRA – Government Performance and Results Act

GPS – Global Positioning System

HUC – Hydrologic Unit Code

HWA – Hemlock woolly adelgid

Hz – Hertz

I&M – Natural Resources Inventory & Monitoring

IBA – Important Bird Area

IBI – Index of Biotic Integrity

IRMA – Integrated Resource Management Application

IUCN – International Union for Conservation of Nature and Natural Resources

Acronyms and Abbreviations (continued)

kg/ha/yr – kilograms/hectare/year

L_{50} – Median Existing Daytime Sound Levels

mag/arcsec^2 – V magnitudes per square arc second

mcd/m^2 – milli-candela per square meter

Mcf – Thousand cubic feet

mg/l – Milligrams per liter

Mgal/d –million gallons per day

MRLC – Multi-Resolution Land Characteristics Consortium

MSPA – Morphological Spatial Pattern Analysis

N – Nitrogen

NCBI – North Carolina Biotic Index

NFI – Noise Free Interval

NH_3 – Ammonia

NH_4 – Ammonium

NHIP – Natural Heritage Inventory Program

NLCD – National Landcover Dataset

NO_2 – Nitrite

NO_3 – Nitrate

NOAA – National Oceanic and Atmospheric Administration

NO_x – Nitrogen Oxides

NPS – National Park Service

NRCA – Natural Resource Condition Assessments

NRCS – Natural Resources Conservation Service

NSNSD – Natural Sounds and Night Skies Division

Acronyms and Abbreviations (continued)

NTU – Nephelometric Turbidity Unit

NVCS – National Vegetation Classification Standard

NWIS – National Water Information System

O_3 – Ozone

OBRI – Obed Wild and Scenic River

ONRWs – Outstanding Natural Resource Waters

P – Phosphorus

PAD-US – Protected Areas Database of the United States

PET – Potential Evapotranspiration

PIF – Partners in Flight

PO_4 – Phosphate

ppb – parts per billion

ppm-hrs – parts per million-hours

ROW – Right-of-Way

RSS – Resource Stewardship Strategy

S – Sulfur

SERGoM – Spatially Explicit Regional Growth Model

SL – Significance Level

SMUMN GSS – Saint Mary's University of Minnesota GeoSpatial Services

SO2 – sulfur dioxide

SOP – Standard Operating Procedure

SpC – Specific conductance

SPL – Sound pressure level

SQM – Sky Quality Meter

Acronyms and Abbreviations (continued)

STORET – Storage and Retrieval Data Warehouse

TAA – Time Above Ambient

TAud – Time Audible

TDEC – Tennessee Department of Environment and Conservation

TGS – Tennessee Geological Survey

TNC – The Nature Conservancy

TN-IPC – Tennessee Invasive Plant Council

TR-G – Taxa Richness at Genus Level

TR-S – Taxa Richness at Species Level

TVA – Tennessee Valley Authority

TWRA – Tennessee Wildlife Resources Agency

TWQB – Tennessee Water Quality Board

U.S. – United States

USFWS – U.S. Fish and Wildlife Service

USGS – United States Geological Survey

VOC – Volatile Organic Compound

WCS – Weighted Condition Score

WNS – White-nose Syndrome

ZLM – Zenithal Limiting Magnitudes

1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

> ***NRCAs Strive to Provide…***
>
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas;[5] and
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.
Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[6]An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation

In October 1968, the United States (U.S.) Congress passed the Wild and Scenic Rivers Act in order to protect the remarkable ecosystems and free-flowing stretches of several rivers and watersheds in the U.S. The Wild and Scenic Rivers Act states:

> *It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations* (PL 90-5421).

The Obed Wild and Scenic River (OBRI) contains a unique convergence of rare and threatened ecosystems, primal landscapes, and wildlife resources (NPS 2015d). The park supports one of the world's most biologically diverse riverine systems that provides habitat for many rare and unique species (NPS 2015d). There are also a wide variety of geologic structures preserved within OBRI including high bluffs, waterfalls, overhanging cliffs, natural stone arches, and cobble bars (NPS 2015d). In order to protect these wild features, and the free-flowing river system of the Obed River and its tributaries, the U.S. Congress passed an amendment to the Wild and Scenic Rivers Act on 12 October 1976 establishing a portion of the Obed River system in eastern Tennessee as a National Wild and Scenic River. The area that was established as OBRI in the amendment to the Act included:

> *The segment from the western edge of the Catoosa Wildlife Management Area to the confluence with the Emory River; Clear Creek from the Morgan County line to the confluence with the Obed River, Daddy's Creek from the Morgan County line to the confluence with the Obed River; and the Emory River from the confluence with the Obed River to the Nemo Bridge as generally depicted and classified on the stream classification map dated December 1973* (PL 94-486 Title III).

2.1.2. Geographic Setting

OBRI is located primarily in Morgan County, Tennessee, with a small part of the park located in Cumberland County (Figure 1). The park protects approximately 64.4 river km (40 river mi) of the Obed and Emory Rivers, as well as Clear Creek and Daddy's Creek (Forester et al. 1998, p. 70) (Figure 1). The total area of the park is 2,238.2 ha (5,530.6 ac), part of which is public land owned or managed by the Tennessee Wildlife Resources Agency (TWRA) (NPS 2016b). Much of the southern and western portions of OBRI border the Catoosa Wildlife Management Area (CWMA) (Figure 1), managed by the TWRA. Partnership agreements between the TWRA and the NPS are in place that allow management of the CWMA in such a way as to protect the wildlife resources and character that are critical to the OBRI area (NPS 2015b).

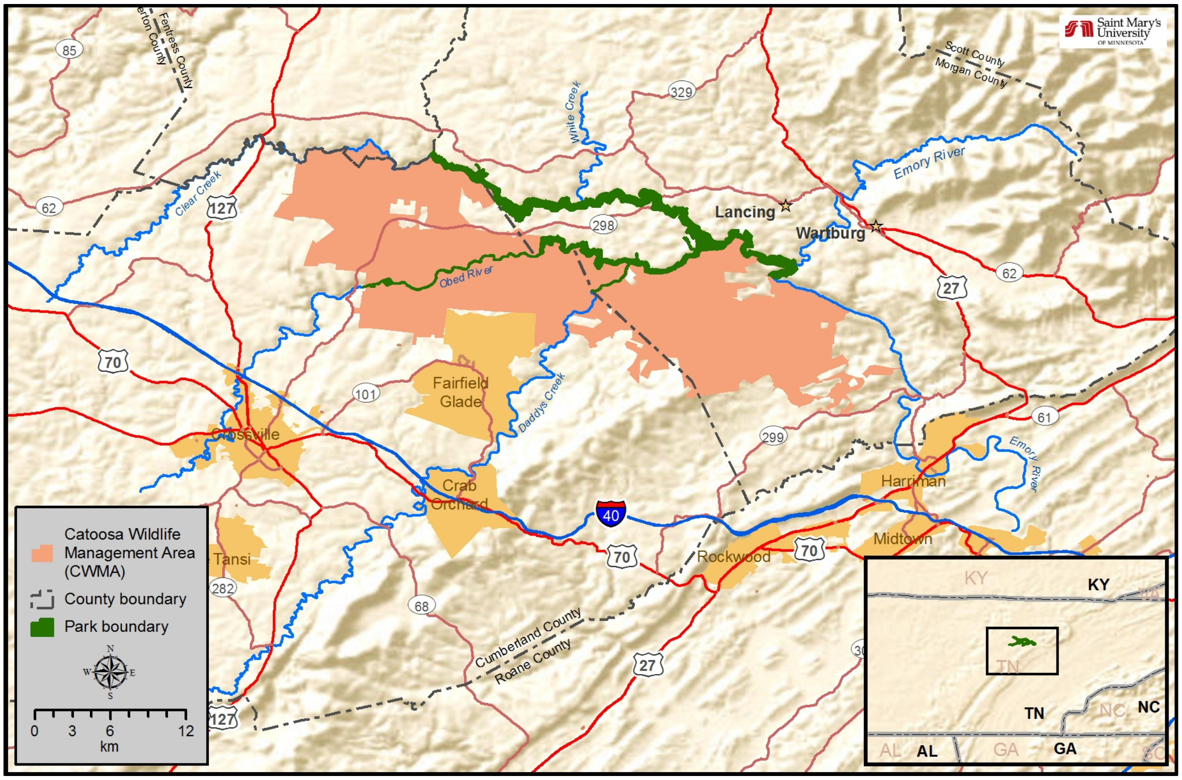

Figure 1. The location of the Obed Wild and Scenic River and the Catoosa Wildlife Management Area within Morgan and Cumberland Counties near Wartburg and Lancing, Tennessee.

OBRI is located on the Cumberland Plateau in eastern Tennessee within the southwestern Appalachian Mountains. This region is characterized by a mild, humid, subtropical climate with hot and humid summers and mild winters (Wiken et al. 2011). The nearest weather station is about 3.2 km (2 mi) north of the park in Lancing, TN (Figure 1). Mean annual temperature for Lancing, TN is 12.8 °C (55.1 °F), according to data collected from 1981 to 2010 (NCEI 2015). The lowest temperatures in the area occur between November and March (Table 1) (NCEI 2015). On average, the annual rainfall in Lancing is 137.1 cm (54.0 in) and is generally evenly distributed throughout the year with slightly lower average monthly rainfall occurring in October (Table 1) (NOAA 2016).

Table 1. 30-year climate normals (1981–2010) for Lansing 6NW (Station ID GHCND:USC00405040) (NOAA 2016).

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C) Max	7.4	9.7	14.7	19.9	24.2	28.1	29.7	29.5	26.3	21.1	15.0	8.8	19.5
Average Temperature (°C) Min	-4.2	-2.7	0.6	5.6	9.8	14.7	16.9	16.1	12.0	5.7	1.6	-2.8	6.1
Average Precipitation (cm) Total	11.1	10.4	11.1	12.9	12.7	12.8	13.8	10.4	10.1	7.9	11.0	13.0	137.1

2.1.3. Visitation Statistics

Visitation records are available from the NPS for the period 1987–2015 (Figure 2). Over this 29-year period, average visitation was 187,252 recreational visitors per year (NPS 2016a). During this period, the lowest number of recreational visitors occurred in 1987, when just 6,722 visitors entered the park (NPS 2016a). The highest visitation recorded was in 1997 with 298,642 visitors (NPS 2016a). In the last year in this record, 2015, visitation was 214,411, slightly above the period of record average (Figure 2).

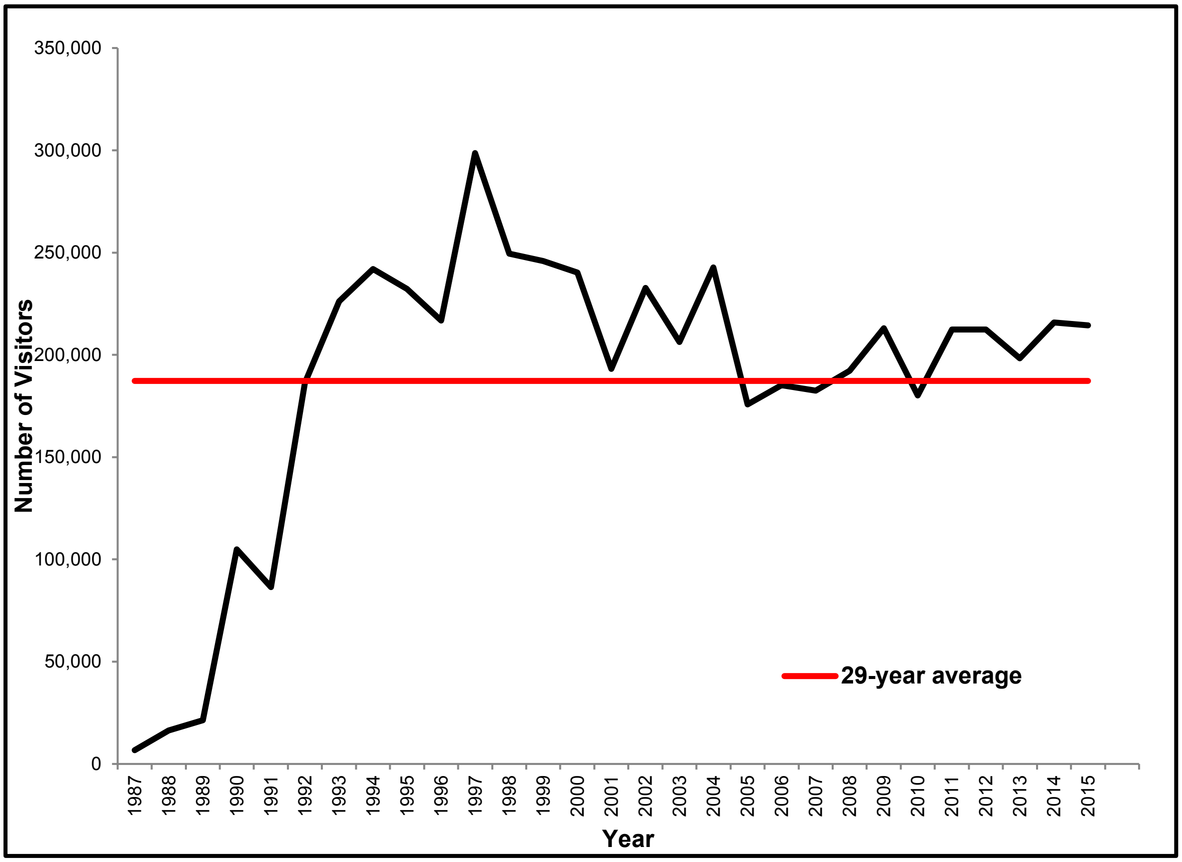

Figure 2. Number of visitors each year between 1987 and 2015; the horizontal, red line represents the 29 –year annual visitation average at OBRI (NPS 2016a).

Many of the park's visitors are attracted to the tremendous scenery present in OBRI. In a recent study, over half (55%) of visitors cited this reason (Begly et al. 2013). Many also visit OBRI for the opportunity to rock climb (47%) and hike (33%) (Begly et al. 2013). Other popular activities include fishing, bird watching, camping, and whitewater paddling.

Rock climbing at OBRI has been an attraction since the park was established (NPS 2002b). Climbers visit OBRI due to the quality of the rock, the relative safety of established routes, and the unique challenges offered by overhanging cliff faces (NPS 2002b). Bouldering, perhaps the most popular form of rock climbing at OBRI, involves short, sequential moves on rocks that are relatively close to the ground, allowing the climber to free-climb (NPS 2002b). Other types of climbing in the park include sport, traditional, and scrambling (NPS 2002b).

Hiking is another popular attraction at the park, with seven designated trails and several scenic overlooks in the park (NPS 2016c). Trails vary in difficulty, allowing visitors to take a short walk or spend the entire day hiking through rugged terrain. Cultural and natural history are incorporated into the hiking trails and overlooks. There are also ranger-led programs for visitors to learn about plants, animals, recreation activities, and the oral history of OBRI and the surrounding area (NPS 2016d).

Kayaking and canoeing are very popular at OBRI, as there are whitewater runs ranging from Class II to IV (Photo 1) (Forester et al. 1998). However, conditions are such that this activity should only be undertaken by visitors who are prepared and have some knowledge of the conditions that can be experienced at the park (Forester et al. 1998). Potentially dangerous conditions include fast rising rivers that can flood without much warning, and the capacity for the current to carrying large debris (Forester et al. 1998).

Photo 1. Kayaking on Daddy’s Creek at OBRI (NPS photo).

2.2. Natural Resources

2.2.1. Ecological Units and Watersheds

OBRI is located within the Environmental Protection Agency (EPA) Level III Southwestern Appalachian Ecoregion (Figure 3) and Level IV Cumberland Plateau Ecoregion (Figure 4). According to the EPA (2016), the Southwestern Appalachian Ecoregion contains “a mosaic of forest and woodland with some cropland and pasture.”

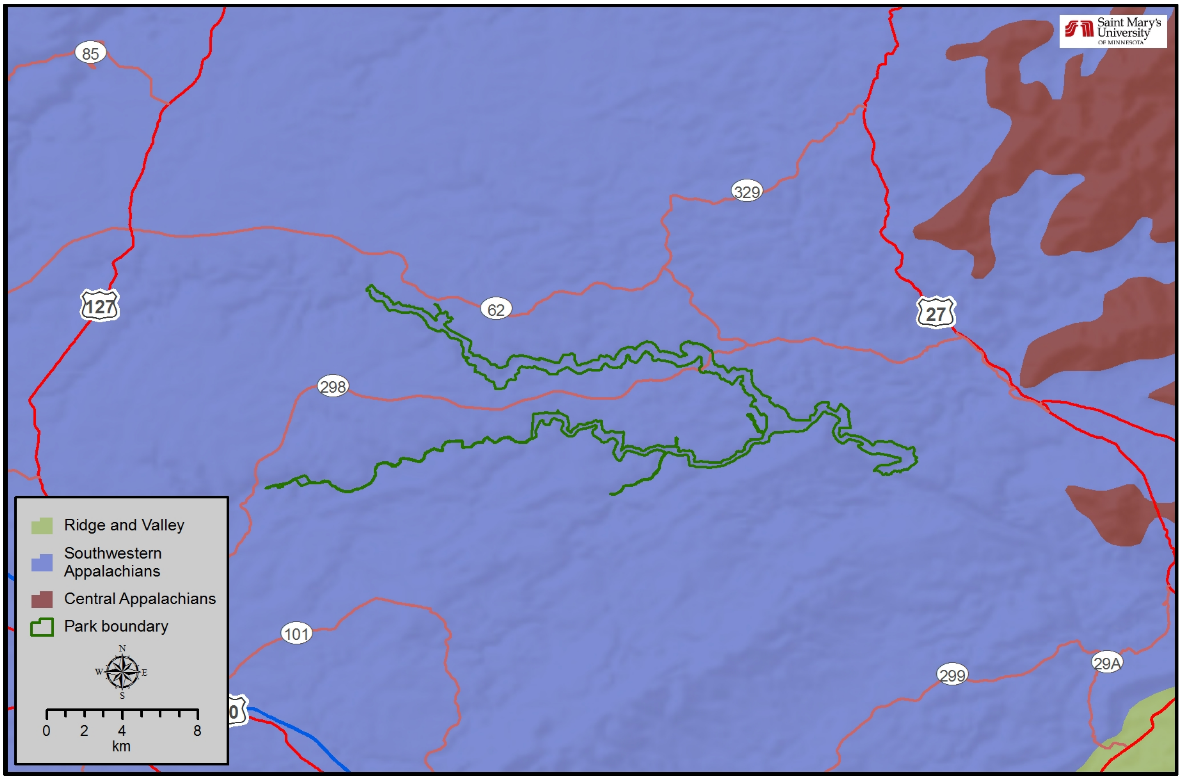

Figure 3. EPA Level III Ecoregions in Morgan and Cumberland Counties (EPA 2010).

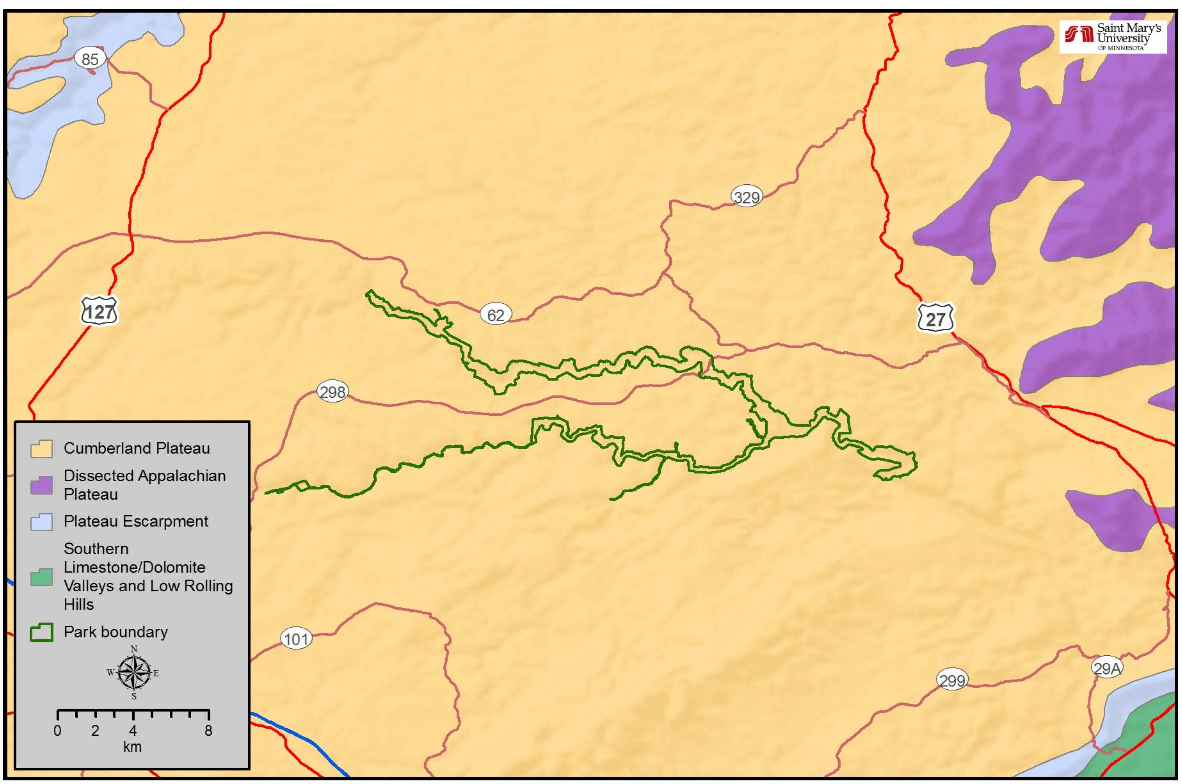

Figure 4. The Level IV Ecoregions in Morgan and Cumberland Counties (EPA 2010).

The Cumberland Plateau Level IV Ecoregion is described as open and low mountains that are:

> *…about 1,000 feet higher than the Eastern Highland Rim [Level IV Ecoregion] to the west, and receive slightly more precipitation with cooler annual temperatures than the surrounding lower-elevation ecoregions… Elevations are generally 1,200–2,000 feet, with the Crab Orchard Mountains reaching over 3,000 feet. Pennsylvanian-age conglomerate, sandstone, siltstone, and shale is [sic] covered by mostly well-drained, acid soils of low fertility. The region is forested, with some agriculture and coal mining activities* (EPA 2016).

The Cumberland Plateau stretches from north central Alabama through Tennessee and Kentucky. The plateau is characterized by rugged terrain that is relatively flat when viewed from above (NPS 2002a). In aerial views, the landscape resembles a flat-topped tableland formation that has been carved into a dramatic landscape of gorges, canyons, cliffs, arches, chimneys, waterfalls, and rock shelters by various rivers and streams (NPS 2002a). Within OBRI, the ravines and escarpment slopes are dominated by mesophytic forests of maple (*Acer* spp.), beech (*Fagus* spp.), ash (*Fraxinus* spp.), basswood (*Tilia* spp.), sweetgum (*Liquidambar styraciflua*), and oak trees (*Quercus* spp.), while upland forests are predominantly mixed oaks, hickory (*Carya* spp.), and shortleaf pine (*Pinus echinata*) (Wiken et al. 2011). The Cumberland Plateau is capped with sedimentary rocks deposited over 350 million years ago by an ancient sea in layers that are thousands of feet thick (NPS 2002a). The plateau was uplifted slowly, and the depositional sequence of rocks can be seen on the canyon walls and cliffs (NPS 2002a).

Based on U.S. Geological Survey (USGS) hydrologic unit codes (HUC), OBRI is located within four HUC 10 watersheds of the HUC 8 Emory River sub-basin: the Obed River, Daddy's Creek, Clear Creek and Emory River watersheds (Figure 5). The majority of OBRI falls within the Obed River and Clear Creek watersheds, with only a small portion of the park falling within the Daddy's Creek watershed.

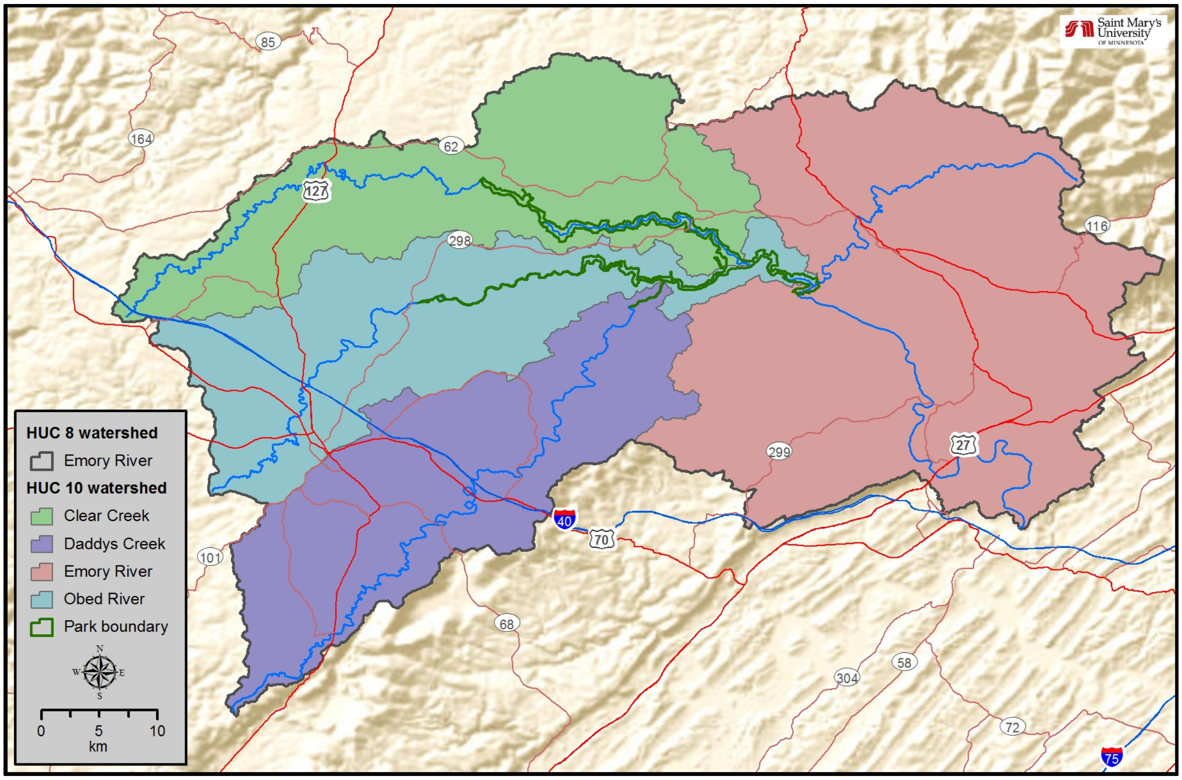

Figure 5. HUC 8 and 10 watersheds associated with OBRI.

2.2.2. Resource Descriptions

Flora

Many species of flora have been documented within OBRI, with over 750 species of vascular plants occurring in the park (NPS 2015d). There are two federally-listed threatened plant species in OBRI, Cumberland rosemary (*Conradina verticillata*) and Virginia spiraea (*Spiraea virginiana*) (NPS 2002a, Emmott et al. 2005, NPS 2015c). There are also 19 state-listed rare, threatened, or endangered plant species, most of which occur in riparian communities (Emmott et al. 2005). Many species have evolved within this riverine system, and their survival depends on periodic scouring events to maintain their habitat (Wolfe et al. 2007, Murdock et al. 2013). In addition to the sensitive floral species in OBRI, there are four species in the park that are considered an exploitation concern by the NPS; pink lady's slipper (*Cypripedium acaule*), greater yellow lady's slipper (*Cypripedium parviflorum* var. *pubescens*), American ginseng (*Panax quinquefolius*), and goldenseal (*Hydrastis canadensis*) (NPS 2015c).

Birds

There are 159 species of birds present or probably present within the park (NPS 2015d). These NPS designations of park occurrence are defined in Table 2. OBRI has a highly diverse Neotropical migrant community, due largely to the park's undisturbed forests. Several members of the OBRI Neotropical migrant community are considered high priority bird species, including the Swainson's warbler (*Limnothlypis swainsonii*), cerulean warbler (*Setophaga cerulea*), wood thrush (*Hylocichila mustelina*), and Acadian flycatcher (*Empidonax virescens*) (Watson 2005). There are no federally-listed threatened or endangered species of birds occurring in the park. The red-cockaded woodpecker (*Picoides borealis*) previously occurred in the area, but has since been extirpated from OBRI (Watson 2005).

Table 2. Definitions for species occurrence in park. Table reproduced from NPS (2013).

Park Occurrence	Definition	Comments
Present in Park	Species occurrence in park is documented and assumed to be extant.	Extremely high confidence that the species occurs in the park for all or part of the year. Evidence, in the form of a current, verifiable reference, voucher or observation, is included in NPSpecies (preferred) or is readily available.
Probably Present	Documented occurrences of the species in the park and/or in the adjoining region of the park give reason to suspect that it probably occurs within the park.	Very high confidence that the species occurs in the park. Evidence may exist in NPSpecies, but may not be considered current or reliable enough to elevate the status to Present in Park. Efforts should be made to obtain current, verifiable evidence to elevate the status to “Present in Park.” If reasonable efforts to obtain current, verifiable evidence are unsuccessful, then the Occurrence should be changed to Unconfirmed or Not in Park, as applicable.
Unconfirmed	Attributed to the park based on weak ("unconfirmed record") or no evidence, giving minimal indication of the species' occurrence in the park.	Verifiable evidence is not considered sufficient enough to elevate the status to “Probably Present,” nor current enough to elevate the status to “Present in Park.” Efforts should be made to obtain current, verifiable evidence in NPSpecies to elevate the occurrence value to “Present in Park.” If reasonable efforts to obtain current, verifiable evidence are unsuccessful, status should be changed to Not Present.

<u>Mammals</u>

An assortment of mammal species occurs in OBRI, with a total of 50 species present or probably present within the park (NPS 2015d). There are an additional seven unconfirmed species and three species that have been extirpated from the area (NPS 2015c). This total includes nine species of bats that are present in the park and three species that are listed as either probably present or unconfirmed (NPS 2015c). The federally-listed gray myotis (*Myotis grisescens*) is one of four state- or federally-listed bat species present along with the proposed federally-listed northern long-eared bat (*Myotis septentrionalis*) (Emmott et al. 2005, NPS 2015d). Extirpated species include the black bear (*Ursus americanus*), marsh rice rat (*Oryzomys palustris*), and southern red-backed vole (*Clethrionomys gapperi*) (NPS 2015c). There continue to be reports of black bear in and around the park, and it is likely that this species does occur periodically within OBRI’s boundaries. Bear reintroduction efforts in nearby areas with suspected low populations have taken place, although there is currently no estimate of a regional population size. There are several species of mice, voles, rats (Cricetidae), squirrels (Sciuridae), and shrews (Soricidae) in the park (NPS 2015c). Other common mammals include white-tailed deer (*Odocoileus virginianus*), common raccoons (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), eastern cottontail rabbits (*Sylvilagus floridanus*), southern flying squirrels (*Glaucomys volans*), and eastern chipmunks (*Tamias striatus*) (NPS 2015c).

Amphibians and Reptiles

OBRI has 21 reptile species listed as present in the park by NPSpecies (NPS 2015c). NPSpecies lists an additional 17 reptile species as probably present in OBRI, with another six species listed as unconfirmed and two that are extirpated (NPS 2015c). Extirpated species are the northern pine snake (*Pituophis melanoleucus melanoleucus*) and the eastern six-lined race-runner (*Cnemidophorus sexlineatus sexlineatus*) (NPS 2015c). Common reptiles include eastern box turtles (*Terrapene carolina carolina*; Photo 2), ground skinks (*Scincella lateralis*), five-lined skinks (*Eumeces fasciatus*), eastern fence lizards (*Sceloporus undulatus*), common garter snakes (*Thamnophis sirtalis sirtalis*), northern water snakes (*Nerodia sipedon sipedon*), midland rat snakes (*Elaphe spiloides*), northern ringneck snakes (*Diadophis punctatus edwardsii*), northern black racers (*Coluber constrictor constrictor*), northern copperheads (*Agkistrodon contortrix mokasen*), and eastern worm snakes (*Carphophis amoenus amoenus*) (NPS 2015c).

Photo 2. An eastern box turtle (NPS photo by Alicia Lafever).

In addition to the reptile species present in OBRI, NPSpecies lists 23 amphibian species as present in the park (NPS 2015c). An additional five species are listed as probably present, with nine species listed as unconfirmed (NPS 2015c). Common amphibians in OBRI include red-spotted newts (*Notophthalmus viridescens viridescens*), northern slimy salamanders (*Plethodon glutinosus*), longtail salamanders (*Eurycea longicauda longicauda*), southern two-lined salamanders (*E. cirrigera*), seal salamander (*Desmognathus monticola*), dusky salamanders (*D. fuscus*), and green frogs (*Rana clamitans melanota*) (NPS 2015c). The Cumberland dusky salamander (*Desmognathus abditus*), while considered rare throughout the Tennessee Cumberland Plateau, can be found in the park (Meade 2005, NPS 2015c).

Fish

There are over 50 species of fish present in the park, with an additional 26 species that are currently listed as unconfirmed (NPS 2015c). There are many species of shiners (*Notropis* spp.) and darters (*Etheostoma* spp. and *Percina* spp.), and a few sunfish (Centrarchidae) and catfish species (*Ameiurus* spp. and *Ictalurus* spp.) (NPS 2015c). Species considered abundant in park watersheds include the largescale stoneroller (*Campostoma oligolepis*), whitetail shiner (*Cyprinella galactura*), warpaint shiner (*Luxilus coccogenis*), Tennessee shiner (*Notropis leuciodus*), telescope shiner (*Notropis telescopus*), and redline darter (*Etheostoma rufilineatum*) (NPS 2015c). The federally-threatened spotfin chub (*Erimonax monachus*) is present in OBRI waters (Emmott et al. 2005).

Aquatic Invertebrates

The free-flowing rivers and streams within OBRI are a management focus for park resource managers (Hughes 2008). The quality of these waters are threatened by resource extraction, urban development, and water withdrawals occurring upstream of OBRI (Hughes 2008). Aquatic invertebrate species are an important component of the park's aquatic ecosystems, particularly in regards to being an indicator of overall water quality (Hughes 2008, Cook and Hutton 2009).

A number of freshwater mussel species are found within the waters of OBRI. The presence or absence of mussels, number of species present, and abundance are often used to determine overall health of an aquatic ecosystem, which is why they have been identified as a Vital Sign by the APHN (Emmott et al. 2005, USFWS 2010). As of 2015, there are 12 mussel species present in the park, two species probably present, and 14 species that are unconfirmed (NPS 2015c). Two of the species that are present in the park are federally-listed as endangered: the purple bean (*Villosa perpurpurea*) and the Alabama lamp mussel (*Lampsilis virescens*) (NPS 2015c). Prior to recent surveys and monitoring of mussel populations inside OBRI, the mussel fauna in the area was considered scarce and unknown (NPS 2015d). Mussels are dependent upon fish hosts to carry out their life cycle, and healthy fish populations are crucial to their survival (Emmott et al. 2005, USFWS 2010). Specific to the Cumberland Plateau, mussel populations tend to be scattered and small, due to the calcium-poor waters (NPS 2015d). Currently, the only species listed as abundant is a non-native species, the Asian clam (*Corbicula fluminea*), which is considered a management priority (NPS 2015c).

Included among the aquatic invertebrate taxa are several crayfish species. These species play important ecological roles in both the aquatic and terrestrial ecosystem, and contribute to the aquatic macroinvertebrate community biodiversity in the park's freshwater rivers and creeks (Reynolds et al. 2013). The park lists several species of native crayfish, including a group of highly endemic crayfish species (NPS 2006). There are eight species of native crayfish present in the park (hairyfoot crayfish [*Cambarus crinipes*], boxclaw crayfish [*C. distans*; Photo 3], mountain midget crayfish [*C. parvoculus*], beautiful crayfish [*C speciosus*], triangleclaw crayfish [*C. spheniodes*], hay crayfish [*C. stiatus*], blackbarred crayfish [*C. unestami*], and placid crayfish [*Orconectes placidus*]) (NPS 2015c). One unconfirmed native species (Obey crayfish [*C. obeyensis*]) and one non-native species (rusty crayfish [*O. rusticus*]) are found in waters adjacent to the park (NPS 2015c). The abundance and distribution of these two crayfish species are unknown.

Photo 3. Boxclaw crayfish (NPS photo by Chris Lukhaup).

Other aquatic macroinvertebrates found within OBRI consist mainly of aquatic insects. Due to their sensitivity to factors associated with declining water quality, they are often used to assess the health of freshwater ecosystems (Hughes 2008, Cook and Hutton 2009), and are listed as a Vital Sign by the APHN (Emmott et al. 2005). Measures of species richness, diversity, and relative abundance are used to calculate indices of biotic integrity (IBI) for particular streams and rivers (Emmott et al. 2005). The IBI results provide a means to identify changes in water quality. A recent comprehensive aquatic macroinvertebrate inventory for OBRI collected 5,931 organisms, representing 182 taxa (Cook and Hutton 2009). Of this total, 176 taxa were aquatic insects (Cook and Hutton 2009). The most abundant insect orders collected by Cook and Hutton (2009) were Diptera (true flies, 52 taxa), Trichoptera (caddisflies, 41 taxa), Ephemeroptera (mayflies, 34 taxa), Coleoptera (beetles, 22 taxa), Plecoptera (stoneflies, 12 taxa), and Odonata (dragonflies and damselflies, 10 taxa). Other aquatic insect Orders represented were Hemiptera (two taxa), Megaloptera (two taxa), and Lepidoptera (one taxon).

2.2.3. Resource Issues Overview

Development of the land around OBRI has had impacts on the park such as habitat fragmentation, contaminated mine drainage, and river channel geomorphological changes (Emmott et al. 2005). Additional threats to the park's natural resources include invasive species introductions, resource extraction, altered fire regimes, and agricultural land use (Emmott et al. 2005). These all contribute to water and air quality degradation, changes to the landscape, and global climate change (Emmott et al. 2005).

Habitat Fragmentation

Both land cover and land use change are a concern, since these often result in habitat fragmentation and can have long term, permanent impacts on terrestrial and aquatic biota, including losses in biodiversity and in the abundance of sensitive resident species of OBRI (Fahrig 2003). Increasing human population density and changes in housing development are associated with increased invasive species introductions, altered migration pathways, and loss of critical habitat buffers (i.e., decreased habitat patch sizes and loss of patch edge areas) (Emmott and Murdock 2008). There are numerous gas and oil wells established around the park, particularly within the Clear Creek watershed. An oil spill and fire at one of these wells in 2002 resulted in extensive damage to riparian vegetation and soil along Clear Creek and White Creek (OBRI NRC 2008).

Water-related Threats

Water quality in OBRI represents one of the top priorities for the park, largely due to OBRI's designation as a Wild and Scenic River. The Wild and Scenic Rivers Act, as amended on 12 October 1976, established OBRI as a unit of the National Wild and Scenic River system. In Section 3[b] of the Wild and Scenic Rivers Act the primary purpose of the National Wild and Scenic River System is to:

> *…include rivers with outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values and shall be preserved in free-flowing condition, and that their immediate environs shall be protected for the benefit and enjoyment of present and future generations* (Public Law 90-542; 16 U.S.C. 1271).

It is NPS policy to comply with Tennessee State Laws and Regulations for managing aquatic resources. According to the rules of the Tennessee Water Quality Board (TWQB), certain waterbodies may be designated as Outstanding Natural Resource Waters (ONRWs) if they are high quality waters that are an outstanding natural resource such as waters within the National Park System or waters of ecological or exceptional recreational significance (TDEC 2007). Under the above regulation, the portion of the Obed River within the boundaries of OBRI has an Outstanding Natural Resource Waters designation as assigned by the TWQB (Emmott et al. 2005, Laster et al. 2014). The regulations of the TWQB also allow for the designation of Exceptional Tennessee Waters, as waters that are within a national park, or a Federal Wild and Scenic Rivers (TDEC 2007). Under this regulation, the Daddy's Creek and Clear Creek, which are both within the boundaries of OBRI, are designated as Exceptional Tennessee Waters.

Threats to these designations are present within the park's watershed. These include contaminated drainage from abandoned mines, sedimentation and erosion from lands cleared for urban development or mineral extraction, contaminants associated with both mineral extraction and land development, and water withdrawals for municipal and industrial use (Emmott et al. 2005). Currently, much of the Obed River within the park is listed as 303(d) waters for total nitrogen (N) and total phosphorus (P) concentrations (TDEC 2016). Additionally, a search is underway to identify a regional water supply by the Cumberland Plateau Regional Water Authority. If this search results in the determination that it is necessary to withdraw water from the Obed River for drinking water needs the Obed River would then be designated as an Exceptional Tennessee Water (Laster et al. 2014). A ccombinations of these and other threats, coupled with excessive nutrient concentrations have played a major role in the extirpation of sensitive aquatic species and a general decline in biodiversity in the Obed River (Ahlstedt et al. 2001, Emmott et al. 2005, Dinkins and Faust 2015).

Invasive Exotic Plants

A total of 68 species of non-native plants are present in the park with an additional 83 non-native species that NPSpecies lists as unconfirmed (NPS 2015c). Of the 68 non-native plants in the park, 25 are considered a management priority (NPS 2015c). Invasive plants are considered a major threat to the ecological health of the park, especially in areas where vegetation alliances are prone to invasion or have communities of threatened plants (Emmott et al. 2005, Nordman 2010). The river scour prairies/cobble bar communities are considered prone to invasive plant infestations and have been suggested as a management priority in OBRI (Nordman 2010). Invasive plants are a threat to local flora (and fauna) because of their ability to outcompete and eventually replace native species (Nordman 2010). According to Nordman (2010), who conducted a plant inventory in the park from 2003–2005, there were 14 invasive plant species present that are considered a severe threat to OBRI's ecosystem health. Additionally, there were six invasive plant species considered to be a significant threat (Nordman 2010). Threat levels are determined by the Tennessee Invasive Plant Council (TN-IPC) and are defined as follows:

> *Severe Threat*: possess invasive characteristics; spread easily in native plant communities and displace native vegetation.

> *Significant Threat*: possess invasive characteristics; not presently considered to spread as easily into native plant communities as "Severe Threat" species (TN-IPC 2009).

The aquatic plant hydrilla (*Hydrilla verticillata*) is among the invasive species that are considered a severe threat to the park (Photo 4). Extensive infestations of hydrilla have been documented in the park (Estes et al. 2010). Hydrilla (an aquatic macrophyte species) reached Tennessee sometime in the 1990s, and its presence at OBRI was confirmed in 2007 (Simmons 2007, USGS 2007, Netherland 2015). Hydrilla is originally from southern India and is listed as a federal noxious weed (USDA 2014). Hydrilla was likely introduced through castaway fragments from recreational boats (e.g., motors, trailers, and live wells) (Jacono et al. 2015). This noxious weed can quickly establish extensive, lateral growths and readily adapts too many aquatic environmental gradients (Jacono et al. 2015). Hydrilla presents a major concern for the unique aquatic macroinvertebrate, fish, and rare plant communities within the park. Estes et al. (2010) suggested immediate action in determining the distribution of hydrilla in the park, In addition to this, an assessment of potential impacts within the aquatic ecosystem is needed to understand how this invasive will affect native biota.

Photo 4. Hydrilla growing in a stream within OBRI (Photo from Wofford et al. 2008).

Another invasive plant species listed as a severe threat by the TN-IPC (2009) is the tree of heaven (*Ailanthus altissima*). During a survey conducted between 2007 and 2008. A single plant was observed, and was flagged for removal to prevent it from spreading (Wofford et al. 2008). Autumn olive (*Elaeagnus umbellata* var. *parvifolia*) is also listed as a severe threat to the park ecosystems (Wofford et al. 2008, TN-IPC 2009). It is widespread throughout the park, especially in areas that are adjacent to Catoosa WMA (Evan Raskin, APHN Assistant Data Manager/Biologist, written communications, November 2016).

Other invasive species that are considered to be a severe threat include Chinese lespedeza (*Lespedeza cuneata*), Japanese honeysuckle (*Lonicera japonica*), Japanese stiltgrass (*Microstegium vimineum*), princess tree (*Paulownia tomentosa*), multiflora rose (*Rosa multiflora*), and Japanese meadowsweet (*Spiraea japonica*) (Wofford et al. 2008). Chinese lespedeza was observed by Wofford et al. (2008) at 17 locations in the park, with one infestation estimated to contain about 1,500 individuals (Wofford et al. 2008). Three other locations had counts of 30, 50, and 100 individuals, respectively (Wofford et al. 2008). The remaining 13 sites each contained fewer than 25 plants with many having fewer than 15 individuals (Estes et al. 2010). The locations observed by Wofford et al. (2008) were mainly associated with cobble bar habitats, except for two locations where it was observed in sandbar and scrub/shrub habitats, respectively.

Japanese stiltgrass is a perennial species that was observed at six locations in the park (Wofford et al. 2008). One patch discovered by vegetation surveyors covered a large area in a 6 m by 6 m (20 ft by 20 ft) clump, while most of the other patches were small enough for to be manually removed by surveyors while conducting the vegetation survey (Wofford et al. 2008).

Two species of invasive plants classified as significant threats were also detected in the park: Queen-Anne's lace (*Daucus carota*) and oriental lady's thumb (*Persicaria longiseta*). Only a single Queen-Anne's lace plant was discovered and removed during the Wofford et al. (2008) survey. However, oriental lady's thumb was observed in several areas throughout the park, primarily on mud-flats and along sandy banks (Wofford et al. 2008).

Air Quality

In the Clean Air Act (CAA), Congress set a national goal to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value (42 U.S.C. §7470(2)). This goal applies to all units (both Class I and Class II) of the National Park System. OBRI is considered a Class II park (Emmott and Porter 2008), meaning that it is still protected under the CAA, but has less stringent protection guidelines on air quality than Class I parks (IMPROVE 2015).

An increase in air pollution can affect everything from ecological to human health, along with visibility (e.g., scenic views) and overall visitor enjoyment (Emmott and Porter 2008). Due to the combination of the height and physical structure of the Southern Appalachian Mountains and the predominant weather patterns, air pollutants tend to be trapped or concentrated at lower elevations inside the mountainous terrain (Emmott and Porter 2008). According to Emmott and Porter (2008), ozone (O_3), wet deposition of N and sulfur (S), and visibility are the greatest concern for the APHN. Despite an overall decrease in sulfur dioxide (SO_2) emissions throughout the nation, levels have been increasing in and around the Southern Appalachians, causing decreases in air quality and visibility. Ground-level O_3 is created when nitrogen oxides (NO_x) from automobiles and factories combine with hydrocarbons and sunlight. This pollution is not necessarily created inside the parks, but due to prevailing winds, the pollution travels inside park boundaries and can damage plant communities (especially at higher elevations) and human health as a respiratory irritant (NPS 2015d). In 2005, O_3 exposures had caused significant injury to at least 30 native plant species in the Southern Appalachians (Emmott et al. 2005).

According to NPS Air Resources Division (ARD) (2015a), 2009–2013 estimated values of air quality conditions can provide insight into the overall air quality for OBRI. Ozone pollution inside the park is of moderate concern for both human health (69.2 parts per billion [ppb]) and vegetation health (W126 metric of 8.9 parts per million-hours [ppm-hrs]), based on the air quality index values in Table 3. The W126 metric is a biologically-relevant metric that focuses on plant response to O_3 exposure during daylight hours over the growing season (NPS 2015a). Wet deposition of S and N are of significant concern for OBRI (3.8 and 4.0 kilograms per hectare per year [kg/ha/yr], respectively) due to high levels of acidification and nutrient-enrichment affecting ecosystem health (based on the air quality index values in Table 3). Average visibility for OBRI also warrants significant concern (9.5 deciview [dv]) (NPS 2015a).

Table 3. National Park Service Air Resources Division air quality index values for wet deposition of nitrogen (N) or sulfur (S), ozone (O_3), and visibility (NPS 2015a).

Condition Level	Wet Deposition of N or S (kg/ha-yr)	Human Health Risk from O_3 (ppb)	Vegetation Health Risk from O_3 (ppm-hrs)	Visibility (dv*)
Significant Concern	>3	≥71	>13	>8
Moderate Concern	1–3	55–70	7–13	2–8
Good Condition	<1	<55	<7	<2

*A unit of visibility proportional to the logarithm of the atmospheric extinction; one deciview represents the minimal perceptible change in visibility to the human eye.

Local climate variations and weather patterns are important factors in measuring air quality (Emmott and Porter 2008). Climate variations may differ significantly within short distances, in addition to prevailing winds and precipitation directly impacting air quality measures (Flaherty 2008). The Natural Resources Conservation Service (NRCS) provides wind rose plots, based on 30 years of hourly wind data, for different locations throughout the U.S. These wind rose plots are available from weather stations located in Bristol, Chattanooga, Knoxville, Memphis, and Nashville, Tennessee (NRCS 2010). Even though these locations are at least 32 km (20 mi) away, they can provide a general understanding of the wind direction, speed, and overall wind pattern for the park. For Chattanooga, Tennessee, located approximately 97 km (60 mi) southwest of OBRI, the wind rose plot from April (Figure 6) shows the majority of wind coming from the south. This trend tends to be fairly consistent throughout the year (NRCS 2010). The April wind rose plots for Knoxville, Tennessee (Figure 7), located approximately 32 km (20 mi) east of OBRI, shows the majority of the wind coming from the southwest. This trend also tends to be fairly consistent throughout the year (NRCS 2010).

Due to the variant topography and predominant weather patterns in the APHN parks, local air quality data is most desired for accurate representation. Due to a lack of OBRI-specific air quality data (Emmott et al. 2005), air quality conditions are not accurate or clear. Monitoring of air quality inside OBRI could provide park managers and staff information that could help determine the proper measures needed to reduce potential ecosystem damages.

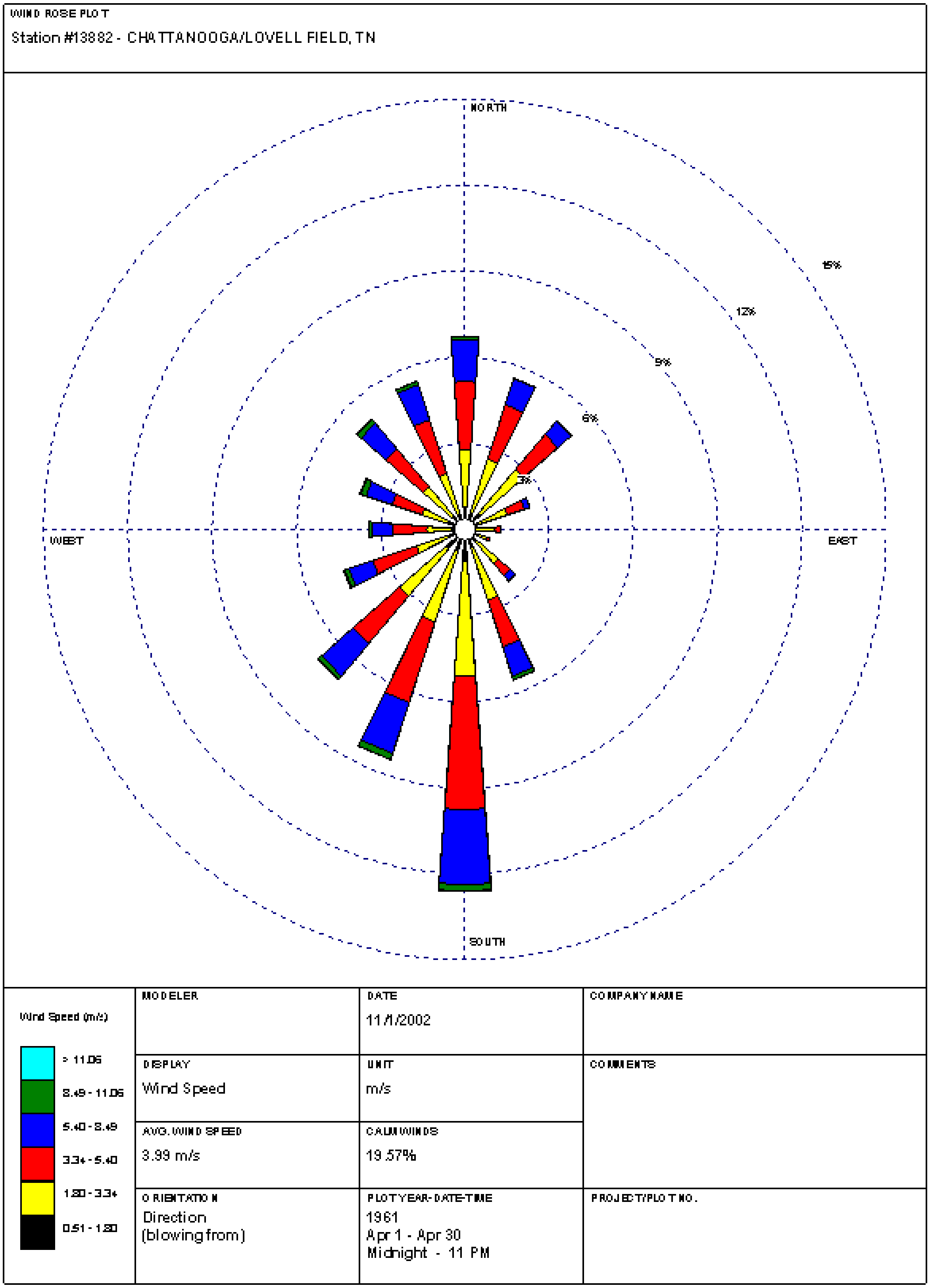

Figure 6. Wind rose plot for Chattanooga, Tennessee in April articulates wind direction and speed based on 30 years of hourly wind data (NRCS 2010).

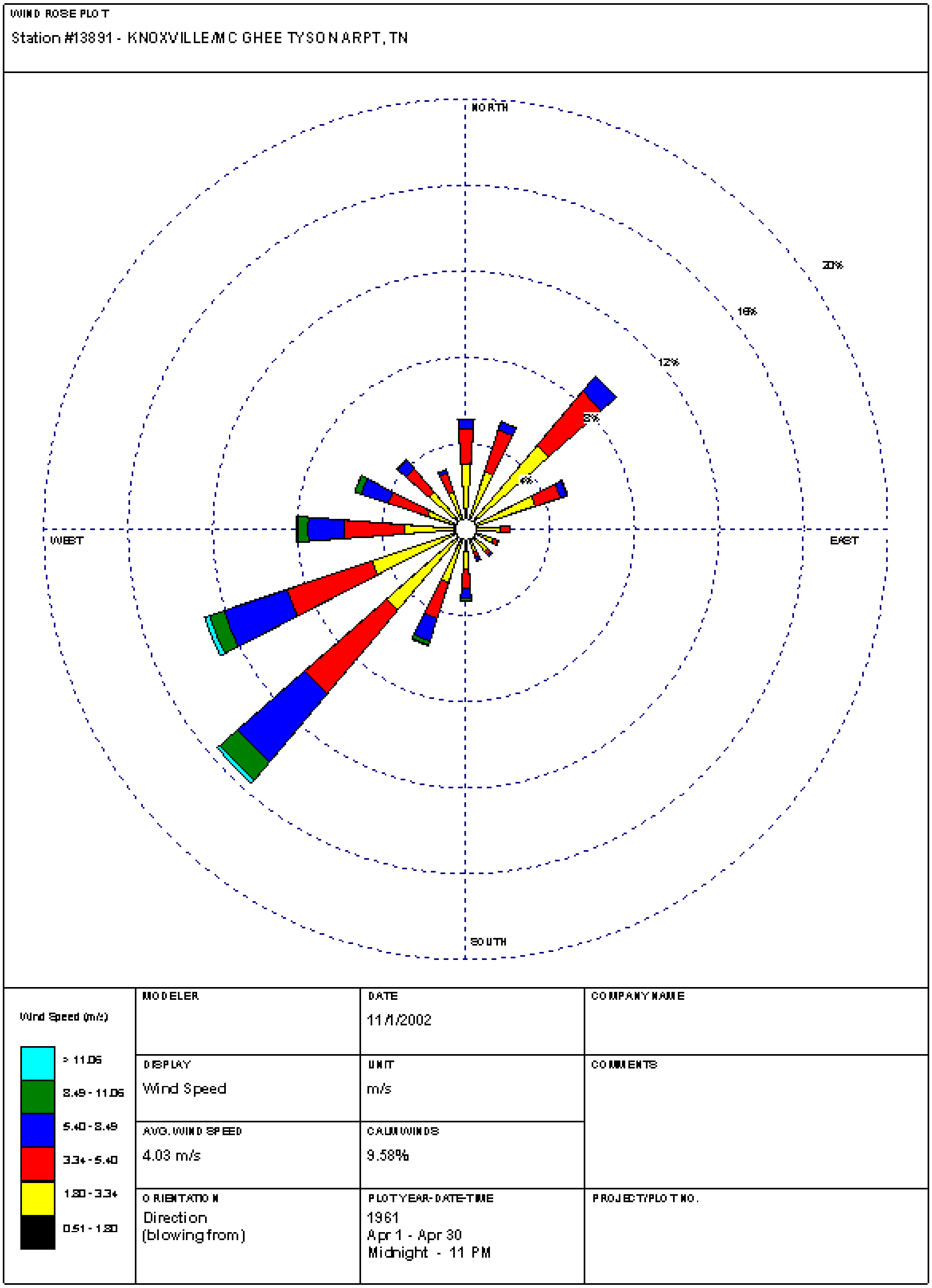

Figure 7. Wind rose plot data for Knoxville, Tennessee in April articulates wind direction and speed based on 30 years of hourly wind data (NRCS 2010).

Altered Fire Regimes

The role of fire and its influence on the vegetative communities and ecosystems of OBRI is poorly understood. Natural fires can have large-scale influences and drive major changes on natural systems (Emmott et al. 2005). Fire exclusion across the landscape has resulted in major changes to ecological components, patterns, and processes and is considered a stressor (Emmott et al. 2005). Emmott et al. (2005) suggests that the fire-adapted communities and associated species are rapidly disappearing from the OBRI region. One example of the disappearance of a fire-adapted species is the red-cockaded woodpecker. This species depends on fire-modified old pine habitats, and hollows out cavities in living pines that have been weakened by heartwood rot.

OBRI managers do not currently use prescribed burns, nor are there plans to use this management tool in the immediate future. This is due to the park's linear nature, limited acreage of terrestrial property, and the verticality of the gorges, making it difficult to effectively manage prescribed burns. Fire is not completely absent from the OBRI area. Wildfires are not uncommon in the park, although many may be due to arson (Rebecca Schapansky, OBRI Resource Management Specialist, written communication January 2017). In 2002 there was a major oil well explosion and fire directly adjacent to the park. This spill and subsequent fire primarily impacted the Clear Creek watershed, and its effects have been monitored and studied since 2005 (Emmott et al. 2005).

Climate Change

Global climate change is expected to affect the entire U.S. during this century, and the expected changes vary across landscapes and geographic scales (i.e., microclimates, topographic position, terrain) (Davey et al. 2007). Due to APHN parks experiencing unique weather patterns and climate trends from mountainous terrain and air currents, their environments can change over short distances (Davey et al. 2007). According to the APHN, climate change could impact OBRI's ecological systems by disrupting soil-water relationships, plant-soil processes, and nutrient cycling at various rates and intensities (Emmott et al. 2005).

Since 1951, the regional climate around OBRI has shown little change, occurring at rates of less than 1% (PRISM Group 2007). Overall, both mean annual precipitation amounts and temperature values slightly increased over this period (Figure 8, Figure 10). Out of all four seasons, mean precipitation amounts had the highest increase during the summer months (June-August, 0.3%; Figure 9; PRISM Group 2007), while mean temperature values increased the most during the winter (December-February, > 0.1%; Figure 11; PRISM Group 2007). On the contrary, predicted climate characteristics throughout the next century around OBRI could provide different scenarios. Predictions show an increase in mean annual precipitation around OBRI (≈ 7% by 2100; Figure 12; Maurer et al. 2007), with the spring season (March-May) showing the largest increase (≈ 9% by 2100) (Figure 13; Maurer et al. 2007). Annual mean temperature is also expected to increase 2.2–2.8 °C (4–5 °F) by 2050 (Figure 14) and 3.9–4.4 °C (7–8 °F) by 2100 (Figure 15) (Maurer et al. 2007). Fall (September-November) temperatures are expected to show the largest increase (2.2–2.8 °C [4–5 °F]) by 2050, while summer (June-August) temperatures are predicted to increase by 3.9–4.4 °C (7–8 °F) by 2100 (Maurer et al. 2007). These predictions are based off the A2 (high) emissions scenario (Maurer et al. 2007).

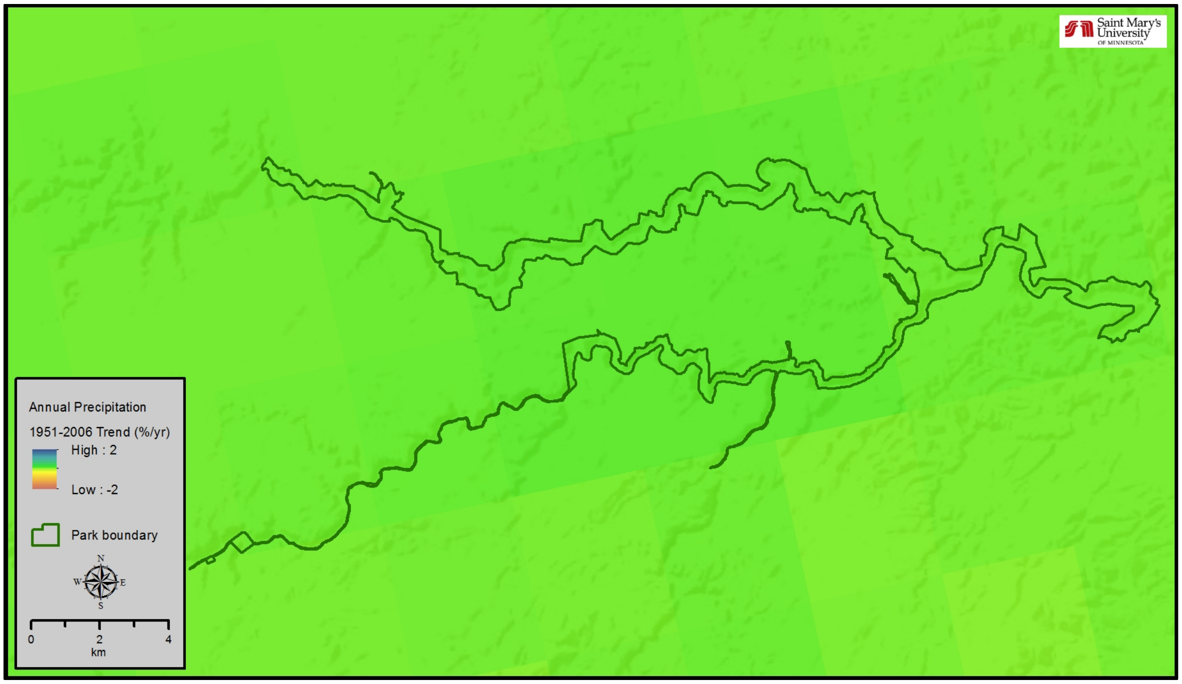

Figure 8. Change in mean annual precipitation in the OBRI region between 1951 and 2006 (PRISM Group 2007).

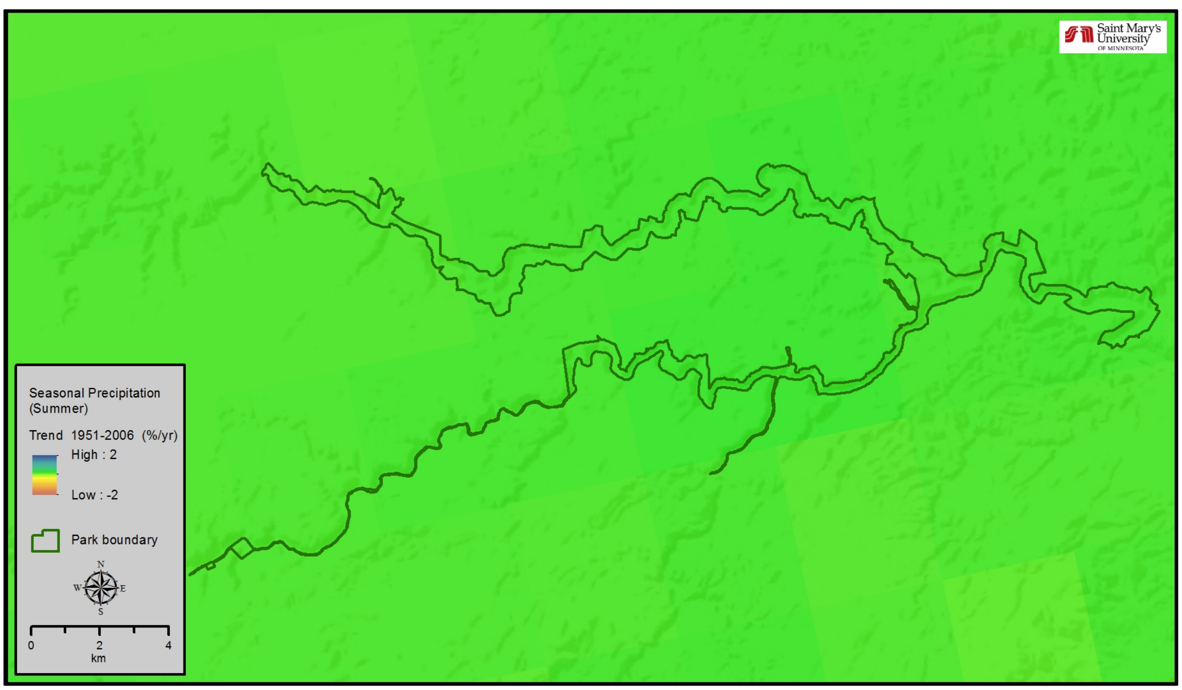

Figure 9. Change in mean summer (June-August) precipitation in the OBRI region between 1951 and 2006 (PRISM Group 2007).

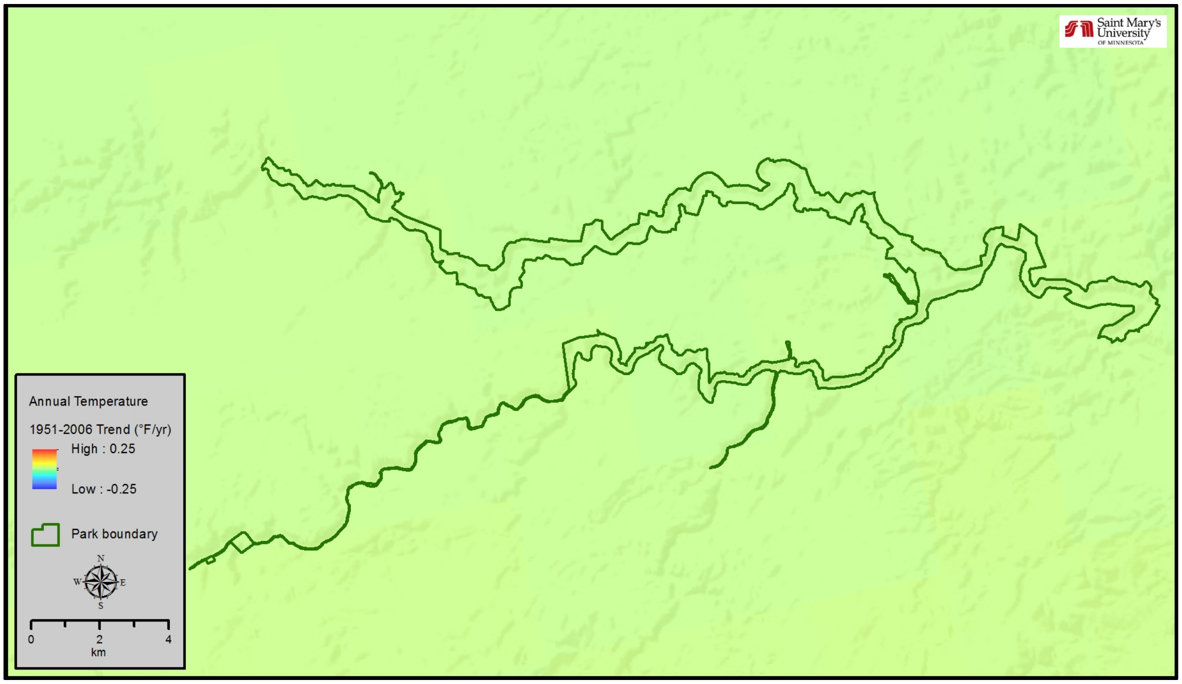

Figure 10. Change in mean annual temperature in the OBRI region between 1951 and 2006 (PRISM Group 2007).

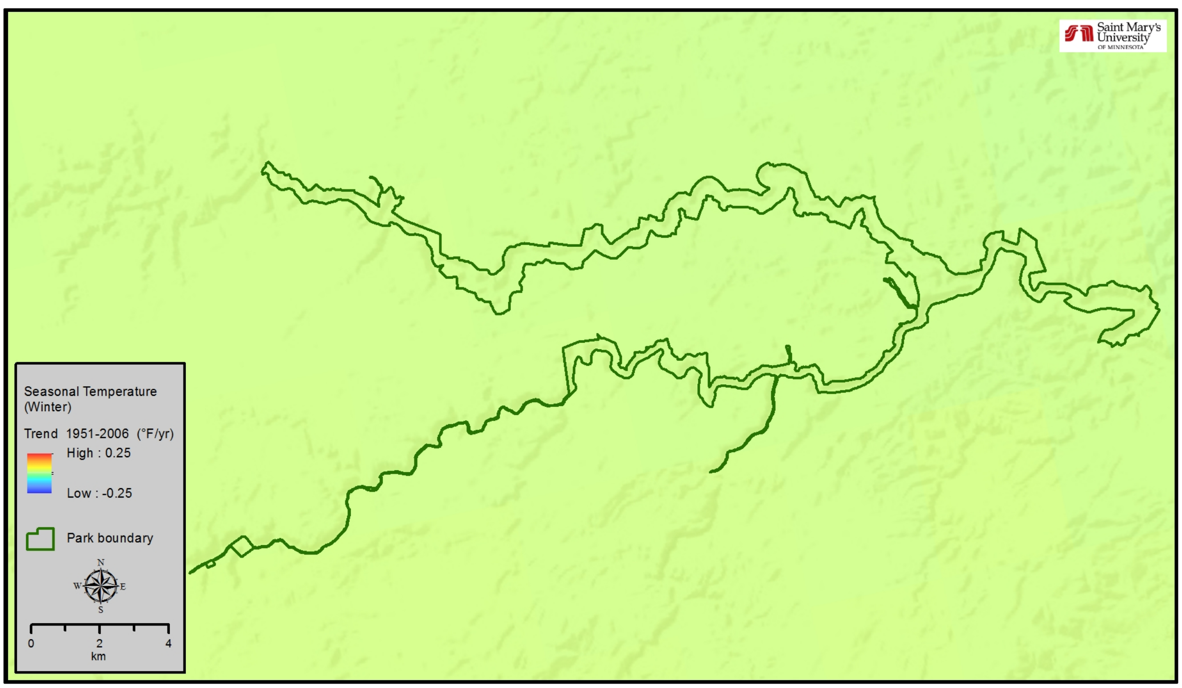

Figure 11. Change in mean winter (December-February) temperature in the OBRI region between 1951 and 2006 (PRISM Group 2007).

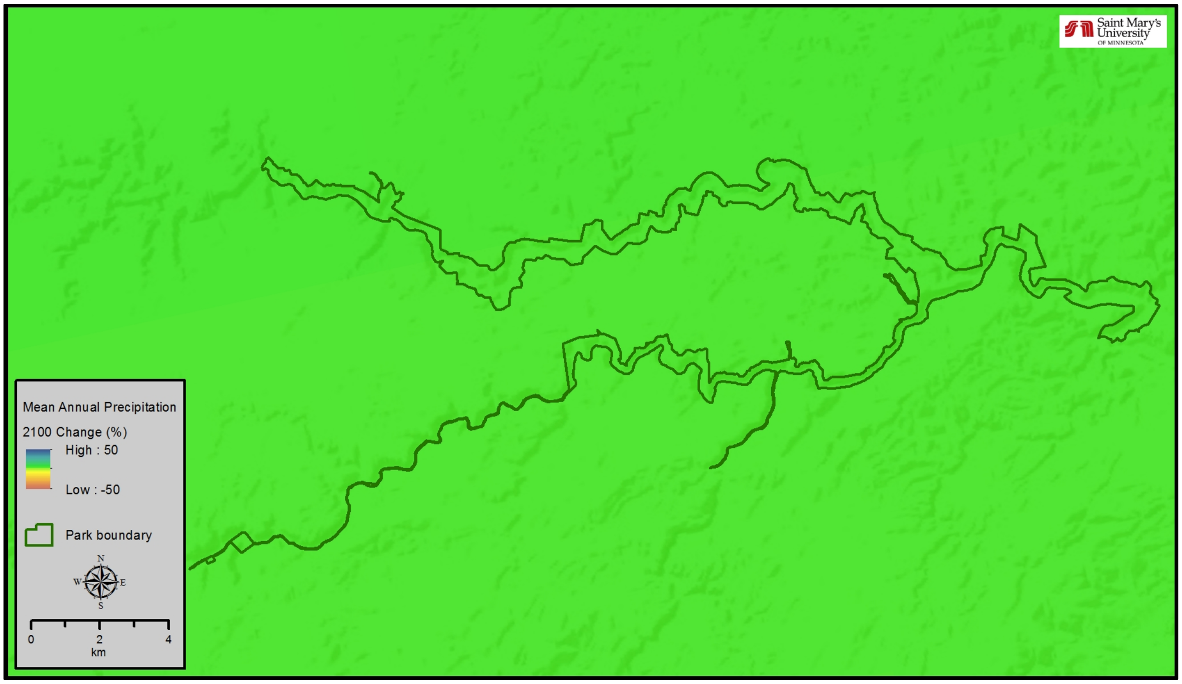

Figure 12. Projected change in mean annual precipitation by 2100 (≈ 7% increase) in the OBRI region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

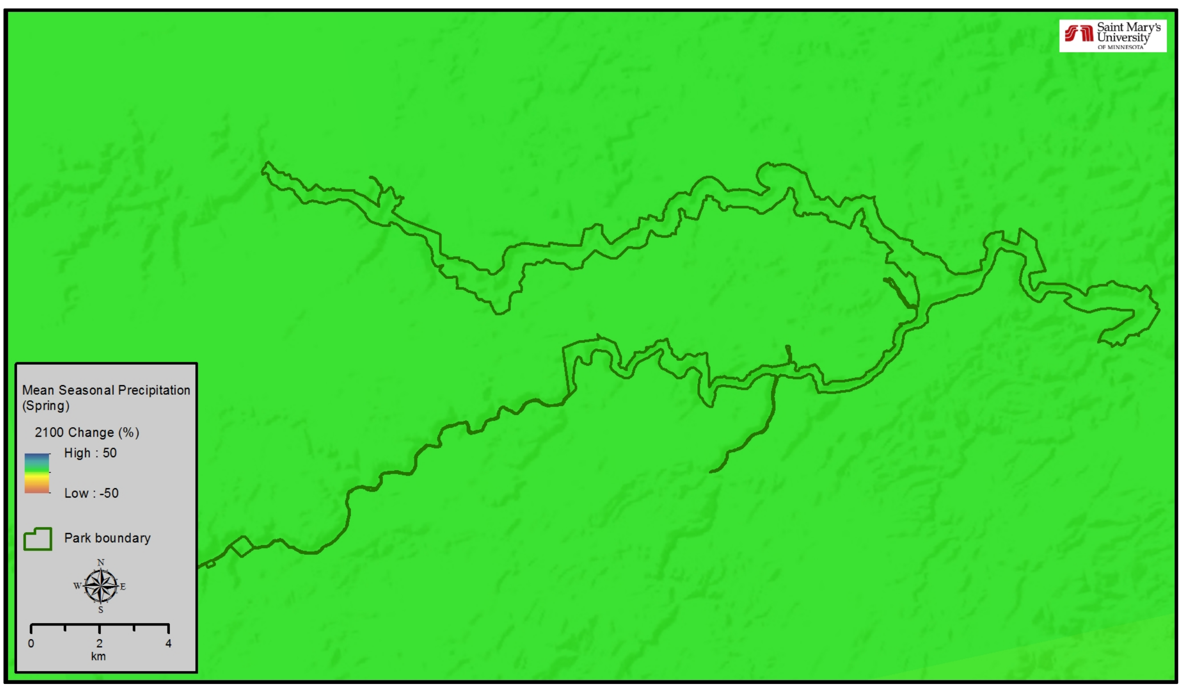

Figure 13. Projected change in mean spring (March-May) precipitation by 2100 (≈ 9% increase) in the OBRI region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

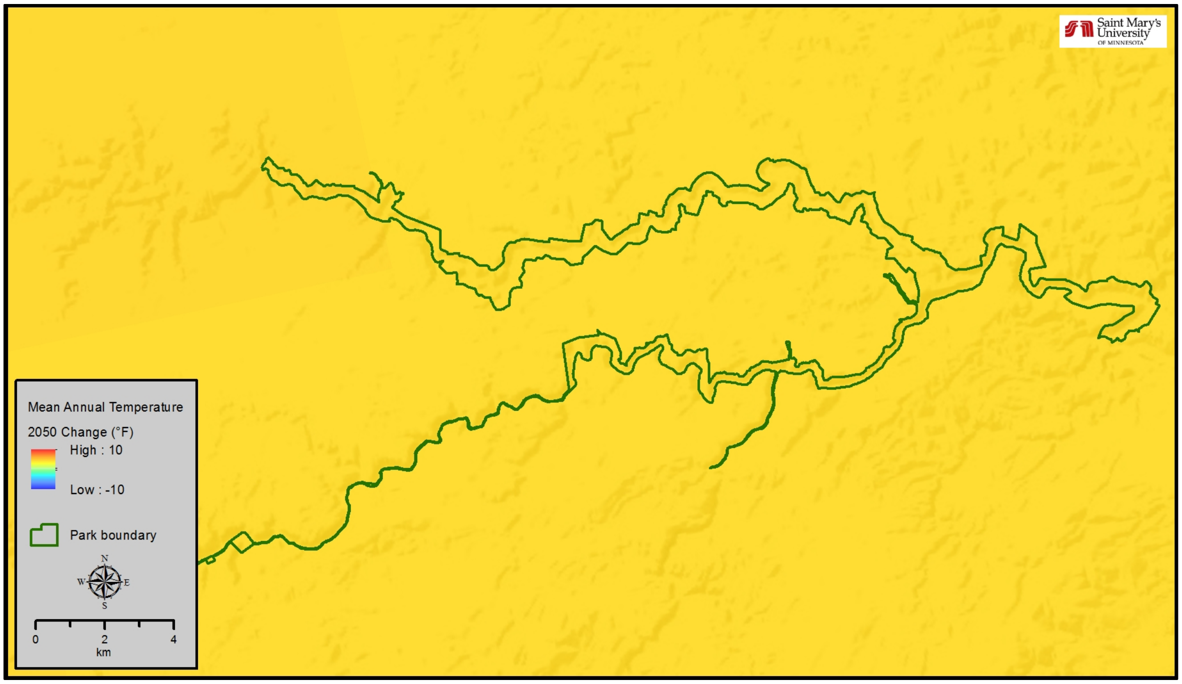

Figure 14. Projected change in mean annual temperature by 2050 (2.2–2.8 °C [4–5 °F]) in the OBRI region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

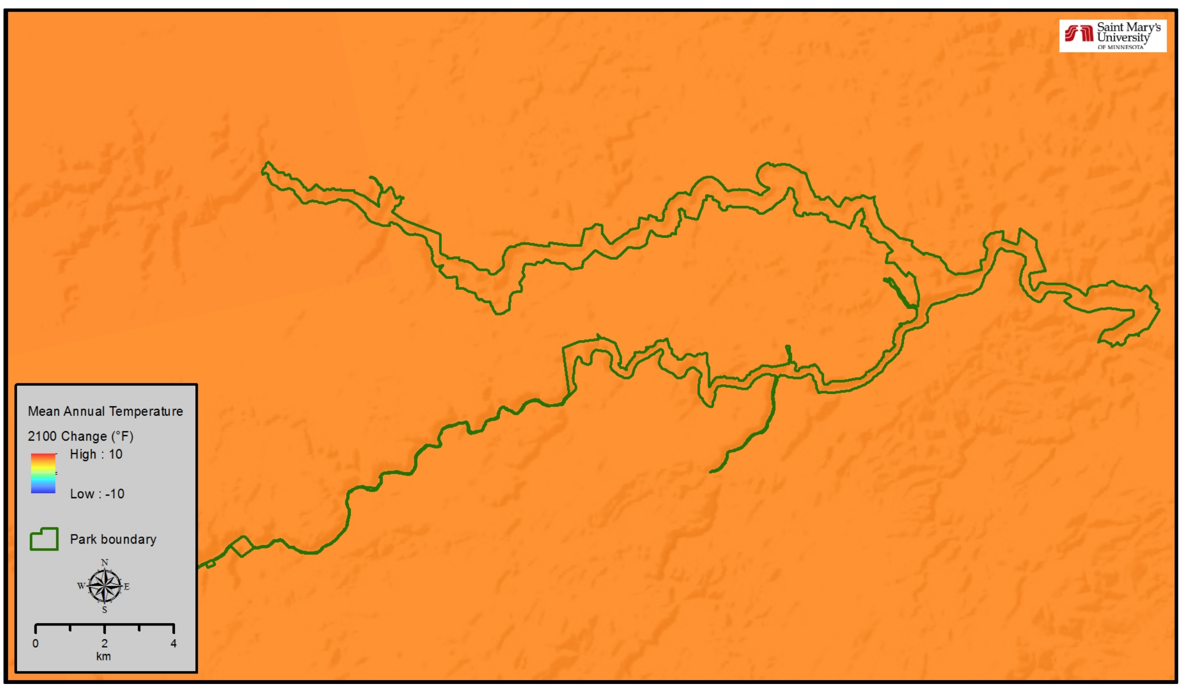

Figure 15. Projected change in mean annual temperature by 2100 (3.9–4.4 °C [7–8 °F]) in the OBRI region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

Precipitation is an important variable in balancing terrestrial and aquatic systems in OBRI; processes like soil and fuel moisture, primary production, stream flow, pollutant concentrations, and oxygen carrying capacity in the riparian systems are all important to the ecosystem (Davey et al. 2007). The predicted warmer temperatures, even with higher precipitation values, combine to produce the potential for drought and overall climate aridity (Figure 16) in OBRI to increase, thus altering natural processes (e.g. flooding events that drive succession and nutrient inputs) that the OBRI ecosystem depends on (Davey et al. 2007). As climate trends can provide insight into future ecosystem health, monitoring climate and weather patterns can help NPS staff make informed decisions on how to achieve adaptive management of OBRI's natural resources (Davey et al. 2007).

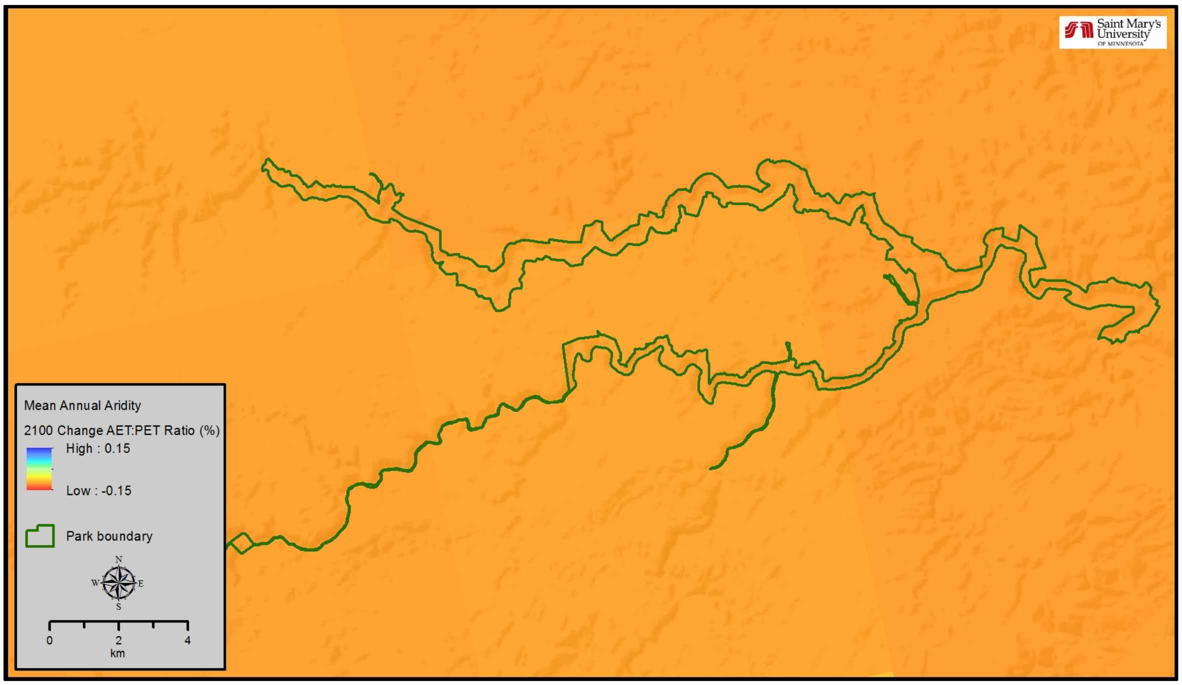

Figure 16. Projected change in mean annual aridity (≈ 10% increase) by 2100, as predicted by the change in the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) (Maurer et al. 2007). Projections based on an estimate average (E-50) circulation model and the A2 (high) emissions scenario.

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

The Wild and Scenic Rivers Act of 1968 (Section 3[d]) states that

> *…the Federal agency charged with the administration of each component of the National Wild and Scenic Rivers System shall prepare a comprehensive management plan for such [sic] river segment to provide for the protection of the river values.*

In accordance with the mandate outlined in the Wild and Scenic Rivers Act, OBRI is managed following the park's 1995 General Management Plan (NPS 1995). The objectives of this plan are:

- To achieve and maintain the highest water quality, using current State water quality standards as a minimum, and a free flowing condition where both quality and quantity provide optimal conditions for the preservation of the river system's naturally diverse and native aquatic life and also for swimming.
- To protect the natural systems, cultural resources, landscape character, and biodiversity of the Wild and Scenic River area.
- To maintain the natural abundance and diversity of native wildlife populations (NPS 1995, p. 8).

Additional management objectives outlined NPS (1995) that specifically pertain to visitor experience in the park include:

- To provide the opportunity and means to learn about, experience, and enjoy the special values of OBRI (essentially primitive, unpolluted, and generally inaccessible) while assuring the protection of those values.
- For the "Wild" river areas (≈ 71.3 river km [≈ 44.3 river mi]): To provide the user the opportunity to experience the primitive nature of the resource between existing public bridge crossings.
- For the "Recreational" river areas (≈ 1.6 river km [≈ 1 river mi]): To provide the user the opportunity for outdoor recreation experiences in a natural setting (NPS 1995, p. 10).

NPS (1995, p. 10) defined management objectives for development in the park as "to provide the following types of access and development with minimal resource degradation in concert with the river classification". Finally, the access and development goals, as outlined by NPS (1995, p. 10) were to:

> *Provide vehicular access and minimal public use facilities along the river, only at existing bridge crossings; hiking trails, scenic overlook experiences, and allow for and manage primitive camping.*

There are additional special mandates that OBRI must adhere to in regards to the park's wild and scenic river designation and in regards to land acquisition limitations/requirements. Examples of these provisions include that OBRI must permit hunting and fishing to occur on all lands and waters of the park, and that the lands within OBRI that are also part of the CWMA are to be managed and owned by the State of Tennessee and the TWRA.

More recently, a purpose statement identified in OBRI's 2015 Foundation Document (NPS 2015b, p. 4) states the purpose of the park as:

> *The Obed Wild and Scenic River, Tennessee's only wild and scenic river, protects and enhances one of the last free-flowing river systems in the Eastern United States. This system is characterized by rugged terrain and exceptional waters and provides opportunities to experience a dramatic river gorge of the Cumberland Plateau much as it has been throughout human history.*

2.3.2. Status of Supporting Science

The APHN, which includes OBRI, has developed a Vital Signs Monitoring Plan as a strategy to conduct long-term ecological monitoring of key resources within network parks (Emmott et al. 2005). Selection of key resources, or Vital Signs, is individualized for each APHN park. The APHN Vital Signs selected for monitoring in OBRI are listed in Table 4.

Table 4. APHN Vital Signs selected for monitoring in the OBRI (Emmott et al. 2005).

Category	APHN Vital Sign	Sampling Protocol Status
Air and Climate	Ozone	Under development
	Wet and dry deposition	Under development
	Visibility and particulate matter	Under development
	Weather and climate	Under development
Water	Water quality	Under development
	Aquatic macroinvertebrates	Under development
Biological Integrity	Cumberlandian cobblebars	Completed
	Freshwater mussels	Under development
	Rare fish	Under development
Landscapes (Ecosystem Pattern and Processes)	Landscape change	Under development

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3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the OBRI resource management team and APHN staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1. Preliminary Scoping

A preliminary scoping meeting was held on 10–11 March 2015. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to OBRI managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by OBRI resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources, identified and agreed upon by the project team. Project findings will aid OBRI resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: OBRI resource staff, the NPS Integrated Resource Management Application (IRMA) website, APHN Vital Signs program, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.
- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.

- Clearly identify “management critical” data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.
- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.
- Utilize “gray literature” and reports from third party research to the extent practicable.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS, in the NRCA process a “framework” is developed for a park or preserve. This framework provides a means to organize, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are the key resource components, and the measures, stressors, and reference conditions used to assess them.

“Resource components” in this process are defined as natural resources (e.g., birds, plant communities), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more “measures” that best define the current condition of the component being assessed in the NRCA. Measures are defined as those values or characterizations that can be evaluated and quantified in terms of the state of ecological health or integrity of a component. In addition to measures, the current condition of a component may be influenced by certain “stressors”. These stressors are identified and considered during assessment of each component. A “stressor” is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the NRCA scoping process, key resource components were identified by NPS staff and are represented as “components” in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in OBRI. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A “reference condition” is a benchmark to which current values of a given component’s measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as "pre-fire suppression." In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Key resources for the park were adapted from the APHN Vital Signs Monitoring Plan (Emmott et al. 2005). This initial framework was presented to park resource staff to stimulate meaningful dialogue about the key resources that should be included in this assessment.

Significant collaboration between SMUMN GSS analysts and NPS staff resulted in a focused scope for the NRCA project and a final complete framework of the key resources to be assessed. The NRCA framework was finalized in April 2015 following acceptance from NPS resource staff. This framework contains a total of 11 components (Figure 17) and was used to drive analysis in this NRCA. The framework in Figure 17 outlines the components (resources), the appropriate measures, known or perceived stressors and threats to the resources, and the reference condition for each component for comparison to current conditions used to develop the OBRI NRCA.

OBRI NRCA Framework

Natural Resource Condition Assessment

	Component	*Measures*	*Stressors*	*Reference Condition*
Biotic Composition				
Landscape and Ecosystem Processes				
	Landscape Dynamics	Land cover/land use change, total population, population density, housing development, change in edge habitat size, change in habitat patch size, land ownership, number of oil and gas wells	Loss of connectivity with public/protected lands, conversion of habitat types, development (commercial, industrial, agricultural and residential), population growth, mineral resources extraction	Mature forest as described by Braun (1950)
Ecological Communities				
	Native Forests/Other Plant Communities	Number of plant species, percent nativity, total area of non-native species, trends in Element Occurrences, hemlock mortality, distribution of emerald ash borer	Climate change, commercial poaching, visitor impacts, other forest insects and disease, extreme weather events, fire suppression, non-native plants	Mature forest as described by Braun (1950)
Mammals				
	Mammals	Species richness, annual harvest numbers, bear abundance	Habitat loss, white nose syndrome, poaching, invasive/exotic species	Park/network completed surveys of community
Birds				
	Birds	Species richness, trends in Neotropical migrants, annual turkey harvest statistics	Habitat loss, hemlock woolly adelgid, hunting, domestic cats, non-native species, brood parasites	Undefined

Figure 17. Obed Wild and Scenic River natural resource condition assessment framework.

OBRI NRCA Framework
Natural Resource Condition Assessment

	Component	Measures	Stressors	Reference Condition
Biotic Composition				
Freshwater Biota				
	Fish Communities	Species diversity, abundance, density, age class distribution/recruitment, Index of Biotic Integrity, trends in rare fish spatial distribution	Drought, water quality, water quantity, oil and gas development, historic mining waste, non-native fish species	Park/network completed baseline surveys of community
	Cobble bars/River Scour Prairies	Percent cover of large shrubs and trees, percent cover of grasses and herbs, number of Cumberland rosemary clumps, overall coverage of Cumberland rosemary, trends in Element Occurrences	Frequency, timing and volume of flood events, presence of non-native species	Park/network completed surveys of community
	Freshwater Invertebrates	Species diversity, Abundance, listed species abundance, listed species density, listed species shell size, Index of Biotic Integrity	Drought, water quality, water quantity, oil and gas development, historic mining waste, non-native mussel species, hydrilla, researcher/monitoring impacts	Park/network completed surveys of community

Figure 17 (continued). Obed Wild and Scenic River natural resource condition assessment framework.

OBRI NRCA Framework

Natural Resource Condition Assessment

	Component	*Measures*	*Stressors*	*Reference Condition*
Environmental Quality				
	Water Quality	Water temperature, pH, dissolved oxygen, conductivity, turbidity, acid neutralizing capacity, nutrients	Urban development, increased water demand, agriculture, drought, climate change, oil and gas development, mining, sedimentation	Water quality conditions for Clear Creek watershed
	Water Quantity	Annual peak discharge, annual minimum discharge, annual number of significant runoff events, annual changes in precipitation amount/patterns, changes in water demand/effluent volume	Urban development, increased water demand, agriculture, drought, climate change, oil and gas development, mining, sedimentation	Historic flow patterns from USGS gages on Obed and Emory Rivers and precipitation normal from Crossville Experimental Station
	Dark Night Skies	Average natural sky luminance, average anthropogenic light dome, horizontal illuminance, maximum vertical illuminance, Sky Quality Meter/Bortle Class	Light trespass from nearby cities or development, lack of involvement in local communities planning or development, air transparency	Absence of anthropogenic light as defined by NPS NSNSD
Physical Characteristics				
Geologic and Hydrologic				
	Acoustical Environment	Sound pressure levels, duration of sounds	railway, oil and gas drilling, chainsaws and residential noise (lawn mower), generators in campground, vehicles (transportation noises), visitor use/recreation outside of park	Ambient sound level that would exist in the absence of human-caused noise

Figure 17 (continued). Obed Wild and Scenic River natural resource condition assessment framework.

3.2.2. Reporting Area

With the exception of the landscape dynamics, fish communities, water quality, and water quantity components, the current condition summaries describe the condition of each resource component within the boundaries of OBRI. The fish communities, water quality, and water quantity resource components were assessed in terms of the parks watershed. Specifically, these components was assessed individually for the Clear Creek, Daddy's Creek, Obed River, and Emory River watersheds. The area encompassed by these watersheds is based on HUC-10s designations as delineated by the USGS. The current condition of the individual watersheds was combined to determine an overall condition score for the component. The landscape dynamics component was also assessed at this same watershed level, however, individual watershed conditions were not determined. Additionally, the oil and gas development measure of this component was assessed in terms of an area within 0.8 km (0.5 mi) of the park's current boundary.

3.2.2. General Approach and Methods

This study involved gathering and reviewing the existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition (when possible).

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time OBRI staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. Spatial (GIS) data were also provided by NPS staff. Additional data (spatial and tabular) and literature to supplement this initial data mining effort, were acquired through online bibliographic literature searches and inquiries on various state and federal government websites. All data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality in terms of the resource component to which they applied.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework. This process depended largely on the amount of information and data available for the component, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from OBRI and the APHN. The specific approaches to data development and analysis that were undertaken are found within the respective component assessment sections in Chapter 4 of this report.

Scoring Methods and Assigning Condition

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A "Significance Level" represents a numeric categorization (integer scale from 1–3) of the importance of each measure in assessing the component's condition; each

Significance Level is defined in Table 5. This categorization allows measures that are more important for determining condition of a component (higher Significance Level) to be more heavily weighted in calculating an overall condition. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 5. Scale for a measure's Significance Level in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a Condition Level for each measure on a 0–3 integer scale (Table 6). This assignment is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 6. Scale for Condition Level of individual measures.

Condition Level (CL)	Description
0	Of **NO** concern. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **HIGH** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

Weighted Condition Score

After the Significance Levels (SL) and Condition Levels (CL) are assigned, a Weighted Condition Score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: good condition (WCS = 0.0–0.33); condition of moderate concern (WCS = 0.34–0.66); and condition of significant concern (WCS = 0.67–1.0). Tables 7 and 8 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles that a resource is in good condition. White circles are used to represent situations in which SMUMN GSS analysts and park staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a “snapshot-in-time” of current resource conditions. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5–10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A horizontal arrow indicates an unchanging condition or trend, and an arrow pointing down indicates deterioration in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. In situations where the trend of the component’s condition is currently unknown, no arrow is given.

Table 7. Description of symbology used for individual component assessments.

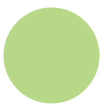
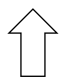
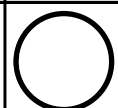
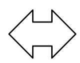
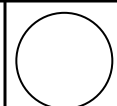
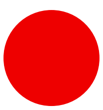
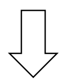
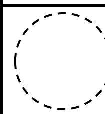
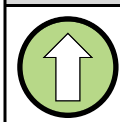
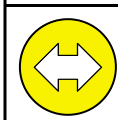
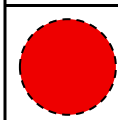
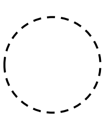
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table 8. Examples of how the symbols should be interpreted:

Symbol Example	Description of Symbol
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and OBRI and APHN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or e-mail conversation with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts within the park and network for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the feedback from resource experts reviews to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by OBRI resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and outside resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description

This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology or it may be a resource that is of high management priority. Also emphasized are interrelationships that occur among the featured component and other resource components included in the NRCA.

Measures

Resource component measures are initially defined in the framework scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values

This section explains the reference condition determined for each resource component as it is defined in the framework. An explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods

This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component is presented and interpreted in this section.

Threats and Stressor Factors

This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were identified in the framework scoping process. The identified threats and stressors are outlined in the NRCA framework, however, they are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps

This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the *Current Condition and Trend* section. The *Overall Condition* section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited

This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices are referenced in the *Literature Cited* section of the component in Chapter 4 were the appendix is referenced.

3.3.3. Literature Cited

Emmott, R. G., N. Murdock, P. Flaherty, and J. Ranney. 2005. Appalachian Highlands Inventory and Monitoring Network: Vital Signs Monitoring Plan. National Park Service, Appalachian Highlands Network, Asheville, North Carolina.

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 31 January 2013).

The H. John Heinz III Center for Science, Economics, and the Environment. 2008. The state of the nation's ecosystems 2008: Measuring the land, waters, and living resources of the United States. Island Press, Washington, D.C.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267-1276.

4. Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 11 key resource components in the project framework (Figure 17). The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components in Chapter 4 follows the project framework (Figure 17):

4.1. Landscape Dynamics

4.2. Native Forests/Other Plant Communities

4.3. Mammals

4.4. Birds

4.5. Fish Communities

4.6. Cobble Bars/River Scour Prairies

4.7. Freshwater Invertebrates

4.8. Water Quality

4.9. Water Quantity

4.10. Dark Night Skies

4.11. Acoustical Environment

4.1. Landscape Dynamics

4.1.1. Description

Landscape change is one of the Vital Signs for the APHN (Emmott et al. 2005), and changes in a landscape can be quantified through landscape dynamics. Landscape dynamics is a broad assessment methodology that utilizes a variety of metrics and data to describe the characteristics of a landscape and how it changes over time (Emmott et al. 2005, Worsham et al. 2013). This methodology is very flexible in that it can be applied at a variety of spatial scales (or area of analysis [AOA]) ranging from a localized buffered area, to a watershed, or a region. Regardless of the spatial scale used, the assessment incorporates the context of the AOA. This process can then be repeated at different temporal scales, and comparing these time scales can produce a measurement of change.

The landscape context of a park has a direct effect on the condition of its natural resources and the public's perceived value or importance of those resources (Gross et al. 2009). Changes at the landscape scale have the potential to cause localized effects, and vice versa, local changes over time can have a cumulative effect at the landscape scale. All APHN parks have experienced the effects of external development, and there is an interest within the NPS to use remotely sensed data to gain a better understanding of the types of external change, where change is occurring, and where change could potentially occur in the future (Emmott et al. 2005). Over time, these external land uses and land use changes have the potential to impact the park's natural resources in a number of ways. For instance, urban development can result in habitat fragmentation, habitat loss, or the introduction of invasive species (Emmott et al. 2005). Changes in the vegetation associations that comprise land cover can result in loss of ecological functions, such as erosion control or nutrient transformation, loss of biodiversity, and fragmented habitats.

OBRI's watershed is comprised of four 10-digit HUCs as delineated by the USGS. The majority of the park is located in three main watersheds; the Obed River watershed (HUC 0601020803), the Clear Creek watershed (HUC 0601020801), and Daddy's Creek watershed (HUC 0601020802). A small portion of the park is also located within the Emory River watershed (HUC 0601020804) (See Figure 5, Chapter 2). These areas are relatively rural, but several urban areas are located in the upper reaches of the Obed River, Daddy's Creek, and Clear Creek watersheds. These include the cities of Crab Orchard and Crossville, the unincorporated communities of Bowman and Clarkrange, and the retirement/resort communities of Fairfield Glade and Lake Tansi (Figure 1). Several other communities are located within the Emory River watershed, but only Wartburg is located in the portion of the watershed upstream of the park (Figure 1).

Natural disturbances within the park's watershed may alter landscapes in a number of ways; however, these effects are often temporary and the natural habitat normally returns (Gross et al. 2009). In contrast, anthropogenic disturbances within this same area have the potential to permanently degrade the park's flora, fauna and aquatic resources, including the rare plant and animal species found within the park (The H. John Heinz III Center for Science 2008, Gross et al. 2009). The primary concern over changes in land use in the watershed is in regard to the implications to the park's water resources (Emmott et al. 2005). Specifically, urban development in areas upstream from OBRI can directly influence the quality and quantity of waters within the park

(Emmott et al. 2005). For this reason, the park is working with local utility districts in the development of a long-term regional water supply strategy that would allow the districts to meet the area's growing water needs without withdrawing unsustainable quantities of water from the park's watersheds (Emmott et al. 2005).

External development within the park's watershed would lead to habitat fragmentation and habitat loss, which would be especially detrimental to the Cumberland Plateau region around OBRI. The Cumberland Plateau area is known as "the world's longest hardwood-forest plateau" and is considered to be one of the most biologically rich regions on Earth (TNC 2016). Mature hardwood (deciduous) forests historically covered the Cumberland Plateau (NPS 2015f). Remnants of this historic landscape can still be found on the Cumberland Plateau, and conservation efforts are ongoing to preserve this landscape. In one such effort to protect the natural resources on the Cumberland Plateau, The Nature Conservancy (TNC), in collaboration with the State of Tennessee, purchased and placed nearly 52,610 ha (130,000 ac) of land on the Cumberland Plateau under protection from further development (TNC 2016). This effort resulted in connecting nearly 26,710 ha (66,000 ac) of existing public lands, including OBRI (TNC 2016). This effort was undertaken in an attempt to preserve the high level of biodiversity and the rugged and remote wilderness character of the Cumberland Plateau (TNC 2016).

Within the boundaries of OBRI, a large diversity of vegetation communities and species are present. In total, 34 unique vegetation communities have been identified (NPS 2015f). These communities are comprised of over 750 vascular plant species, along with nearly 100 different species of mushrooms and lichens (NPS 2015f). The NPS has partnered with the TWRA to manage the lands within the CWMA so as to protect the primitive character of the area and the wildlife resources present on these lands (NPS 2015f).

An additional pressure is the presence of several private inholdings within the park's boundary, some with oil and gas well development. To date, over 1,300 wells are located within the park's watershed (Etta Spradlin, NPS Environmental Protection Specialist, written communication, 29 August 2016).

4.1.2. Measures

- Land cover/land use change
- Total population
- Population density
- Housing development
- Change in edge habitat size
- Change in habitat patch size
- Land ownership
- Number of oil and gas wells

4.1.3. Reference Conditions/Values

The reference condition for the landscape dynamics component is defined in terms of the landscape context that existed in the historic mature hardwood (deciduous) forests which covered the Cumberland Plateau (NPS 2015f). This forest was described by Braun (1950) as a mixed mesophytic climax forest community. These mature forests provided important ecological services to the free-flowing and wild rivers and streams, the rugged and primitive terrain, and the rare and threatened ecosystems that are now preserved by the park (NPS 2015f). Historically, this area was a primitive, undeveloped landscape of rugged wilderness, devoid of urban settings or other anthropogenic development such as mineral or oil and gas exploration or extraction. The specific composition of OBRI's hardwood forests can be found in the Chapter 4.2 of this assessment (Native Forest/Other Plant Communities).

4.1.4. Data and Methods

NPScape Methodology and Measures

The NPS has created a series of metrics and data products that can be used to provide landscape-scale information to document land use change, collectively known as NPScape (Gross et al. 2009). The goal of NPScape is to provide park resource managers with the relevant landscape-scale information necessary to effectively manage the natural resources within parks (Gross et al. 2009). NPScape also provides resource managers with detailed standard operating procedures (SOPs) which allows users to manipulate the data and products to address specific natural resource needs (Gross et al. 2009).

NPScape was developed with a focus on large-scale factors that can be represented by consistently available data for the conterminous U.S. (Gross et al. 2009). It has a conceptual framework that links the measurable aspects of a given landscape to resources within a park unit (Gross et al. 2009). NPScape provides a suite of metrics and measures that represent "Vital Sign" indicators that are an important part of gaining an understanding of natural resource conservation in a landscape context (Monahan et al. 2012, NPS 2014). Currently, NPScape metrics fall into seven measure categories: human population, housing, roads, land cover, pattern, climate, and conservation status (NPS 2014). In general, these measures address the human drivers, natural systems, and conservation context of national parks and neighboring lands (NPS 2014). A process has been outlined for each measure on how they can be quantified based on a set of metrics. A subset of those measures was selected for inclusion in this component.

The importance of landscape attributes to a park's natural resources can vary with scale or spatial extent (Monahan et al. 2012). NPScape recommends that several different AOAs be used as the spatial extent in its analysis: the area within the park boundary, areas immediately adjacent to the park (e.g., 1 3 km [0.6–1.9 mi]), the local region around the park (15–4 0 km [9.3–24.9 mi]), watersheds upstream of the park, or ecoregions (Monahan et al. 2012). Each of these AOAs are relevant for some or all of the measures and metrics employed by NPScape (Monahan et al. 2012). The NPScape methodology provides basic guidance to resource managers on when and how to select the appropriate AOA (Monahan et al. 2012). Additionally, the methodology allows resource managers to consider and select other AOAs that may be more relevant to specific park issues or resources (Monahan et al. 2012). Unless otherwise noted, the AOA selected for this analysis is the four 10-digit HUC watersheds that the park is situated within. This AOA was selected as it captures the relevant information on influences and changes occurring beyond the park boundary that can directly impact hydrology, water chemistry, and the aquatic biota of the park.

Land Cover/Land use Change

NPScape provides a set of GIS tools that can be used to quantify land cover in terms of cover (or habitat) type (Gross et al. 2009). For this assessment, the NPScape tools that analyze land cover in terms of habitat area and natural versus converted cover were used. These tools produce land cover-derived raster datasets and summary tables stored within a file geodatabase (NPS 2015c). Both tools use the National Land Cover Dataset (NLCD) as the primary data input. The NLCD, produced by the Multi-Resolution Land Characteristics Consortium (MRLC), provides a land cover classification scheme that consists of 16 classes (Homer et al. 2015). This land cover classification has been applied consistently across the U.S. at a spatial resolution of 30 m (approximately 98.4 ft). More importantly, this classification and spatial resolution have been used to create land cover datasets representing 2001, 2006, and 2011, allowing for analysis of change over time (Homer et al. 2015). NLCD data is available through the MRLC website at http://www.mrlc.gov/finddata.php.

Natural and converted cover was calculated using the Natural-Converted Area per Category Tool within the NPScape Land Cover Toolbox. The tool was used to create data outputs for each of the three NLCD datasets. The tool reclassifies the NLCD dataset into two main classes: natural and converted (Monahan et al. 2012). When expressed as a ratio (converted area/natural area), these data can provide an indication of the amount of anthropogenic disturbance within an AOA (O'Neil et al. 1988, Monahan et al. 2012); referred to as the U-Index (O'Neil et al. 1988). The breakdown of how each NLCD class is reclassified to either natural or converted land cover is outlined in Table 9. The natural and converted cover metric provides a simple representation of overall biotic condition (Monahan et al. 2012). One limitation of this analysis is that it is uninformative in regards to specific habitats (Monahan et al. 2012). This generalization of output into two categories must be recognized when interpreting data, as disproportionate conversion of small high-value habitats could lead to misinterpretation of the results (Monahan et al. 2012).

Table 9. Aggregated NLCD land cover classes into generic categories of natural and converted land. Table was reproduced from Gross et al. (2009).

Cover Category	NLCD Classification
Converted	Low intensity developed, Medium intensity developed, High intensity developed, Open space developed, Cultivated crops, Hay/pasture
Natural	Grassland/herbaceous, Shrub/scrub, Mixed forest, Evergreen forest, Deciduous forest, Barren land, Perennial ice/snow*, Woody wetlands, Emergent herbaceous wetlands, Open water

*Not present within the OBRI AOA.

Habitat area was calculated using the Generic Area per Category Tool within the NPScape Land Cover Toolbox. Data outputs were created for each of the three NLCD datasets. The tool calculates habitat area in terms of the land cover classifications in the input data (NPS 2015c). Habitat area is an important indicator of landscape condition, and is especially relevant in terms of wide-ranging generalist species (Monahan et al. 2012). While data on the area of cover by habitat type are a basis for many analyses, they do have limitations (Monahan et al. 2012). For instance, the data do not provide information concerning patch attributes or pattern and "habitat" must be defined (Monahan et al. 2012).

Total Population and Population Density

NPScape provides a set of tools for determining select population statistics within a user-defined AOA (NPS 2015e). The tools use census data summarized at the census block as their data inputs. The tools extract the census block polygons within the AOA, and calculate the total population, population density, and many other attributes (NPS 2015e). Areas where people are not likely to live (e.g., parks or protected lands) and known water areas were removed from the census datasets prior to finalizing the total population or population density results (NPS 2015e). The Protected Areas Database of the United States (PAD-US) data were used to identify and remove public and protected lands from the total population and population density datasets produced by the NPScape tools. The PAD-US contains inventories of protected areas dedicated to the preservation of biological diversity and other resources (NPS 2015e). This data repository is maintained and published by the USGS Gap Analysis Program (GAP) (NPS 2015e). The PAD-US data includes the geographic boundaries of lands under public ownership by federal, state, and local government agencies, along with privately held conservation areas (NPS 2015e). The PAD-US geodatabase can be downloaded through the NPScape website (http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm?tab=3) or directly from the USGS (http://gapanalysis.usgs.gov/padus/data/download/).

For the purposes of this assessment, U.S. Census data were analyzed for 1990, 2000, and 2010 population surveys. Census data was downloaded from the IRMA website (https://irma.nps.gov/DataStore/Reference/Profile/2208959). Projections of future population were also obtained from the IRMA website (http://irmafiles.nps.gov/Reference/Holding/492345).

Housing Development

NPScape provides a set of tools that analyze housing development in terms of housing density at the county level (Gross et al. 2009, Monahan et al. 2012). The NPScape Housing Density Tool categorizes housing density data into 11 standardized categories (Table 10). These categories allow for a finer resolution analysis, especially in low-density areas such as those that typically surround national parks (Gross et al. 2009). These categories can also be grouped and analyzed in terms of the broader categories of rural, exurban, suburban, and urban.

Table 10. Housing density classifications (NPS2015b).

Grouped Housing Density Classification	Housing Density Classification
Rural	Private undeveloped
	< 1.5 units / square km
	1.5–3 units / square km
	4–6 units / square km
Exurban	7–12 units / square km
	13–24 units / square km
	25–49 units / square km
	50–145 units / square km
Suburban	146–494 units / square km
	495–1,234 units / square km
Urban	1,235–2,470 units / square km
	> 2,470 units / square km
Commercial/industrial	Commercial/industrial
Urban-Regional Park	Urban-Regional Park

Housing density data can provide a sense of other effects from anthropogenic development (road density, impervious surfaces); however, since the tool output for future conditions is based on data that have been derived from models based on a set of assumptions of future growth patterns, the results may not reflect actual growth (Monahan et al. 2012). The NPScape housing density tools use U.S. Census data (1970–2010) to determine housing density for each 10-year census. The Spatially Explicit Regional Growth Model (SERGoM) version 3 dataset is used by the NPScape housing density tools to create the future projections of housing density.

Based on U.S. Census housing data, SERGoM methods use housing data, along with land ownership and road density data, to produce a representation of housing development locations over a landscape at decadal intervals up to the year 2100 (NPS 2015b). The model uses a supply-demand-allocation approach with the assumption that for each 10-year period, future growth will be similar to what occurred in the previous decade (Theobald 2005). These data are used to generate housing density raster datasets and statistics for the period 2020–2100. As noted above, the projected housing densities are predictions based on socioeconomic forecasting, which could easily change in the near to distant future (NPS 2015b). Changes to the economy and geographic patterns in development can vary a great deal over this length of time, resulting in the actual future conditions differing from the projected conditions (NPS 2015b).

Landscape Pattern

The spatial configuration and composition of land cover types on a landscape have an effect on the ecological functions present and how they are performed (Turner 1989, Turner et al. 2001). These factors also have a role in determining the biodiversity of the landscape (Ostapowicz et al. 2008). NPScape provides metrics that can be used to address landscape pattern, in terms of patch characteristics (Monahan et al. 2012). The most common patch characteristics used to assess landscape pattern include patch size and edge habitat (Gross et al. 2009).

Edge habitat represents the boundary (or transition zone) between two different patch types, while patch size is determined by the areal extent of a cover type. These two aspects of landscape pattern are inter-related. The amount of edge habitat is determined by the shape and size of a patch. Edge habitat can either increase or decrease as patch size changes. The type of change is dependent on changes to the shape and/or size of a patch. Habitat fragmentation, however, results in a decrease in patch size and an increase in edge habitat density (Monahan et al. 2012).

NPScape provides land pattern metrics through the use of Morphological Spatial Pattern Analysis (MSPA) using the NLCD as the data input (Monahan et al. 2012). MSPA is a pixel-level analysis of land cover that uses image segmentation to classify individual pixels into a set of pattern types (Monahan et al. 2012). Pattern types are listed in Table 11. Within the MSPA pattern types, "core" and "edge" classifications represent patch size and edge habitat respectively (NPS 2015d). The NPScape Pattern Morphology Tool produces output based on the forest and grassland cover types (NPS 2015d). The tool produces output for two separate edge definitions, 1-pixel width (30m [98.4 ft] in the NLCD) and 5-pixel widths (150 m [492.1 ft]) of core areas (Gross et al. 2009). Increasing the edge width results in more core areas being included in the edge habitat, but studies have shown the proportion of edge to core habitat not to be significant (Ostapowicz et al. 2008). An edge width of 30 m (98.4 ft) was used in this analysis, as previous studies on deciduous forests in the Eastern U.S. have shown that edge factors generally occur within 5 m (16.4 ft) to 50 m (160 ft) of the core patch (Ranney 1977, Matlack 1993). The advantages to using the MSPA are its ability to be applied over large spatial extents and to identify change at the pixel level (Gross et al. 2009). Limitations to this model include sensitivity to pixel level changes, the computational time required to complete large areas, and the fact that it is a relatively new process, with few scientific studies linking results to specific ecological attributes (Monahan et al. 2012).

Table 11. MSPA classifications and definitions (Soille and Vogt 2009, Riitters 2011).

Pattern Type	Definition
Core	Foreground* pixels whose distance to the background is greater than the edge width
Islet	Cluster of foreground pixels that is too small to contain core, and is not a connector or branch
Perforated	The interior perimeter around a hole (inclusion) in a cluster of core pixels
Edge	The exterior perimeter around a cluster of core pixels
Bridge	Cluster of pixels linking two or more edge pixels, or two or more perforated pixels
Loop	Cluster of pixels connected to one edge pixel or one perforated pixel of the same type
Branch	Cluster of pixels connected to one edge pixel or one perforated pixel

* "Foreground" is the analyzed cover type (forest, shrubland, grassland) and "background" is the complement (i.e., if foreground in forest, the background in shrubland and grassland).

Land Ownership

Land ownership was evaluated for parcels that were within the administrative boundary of the park. OBRI provided GIS data that represented the status of the park's administrative boundary as of January 2016 (NPS 2016). This vector dataset also identified parcels that are inholdings within the administrative boundary of OBRI (NPS 2016).

Number of Oil and Gas Wells

The number (per year) of active, plugged, or abandoned wells within 0.8 km (0.5 mi) of the park's boundary was assessed in this measure. A spatial query was used to select all wells from the point GIS data representing well locations that met the distance criteria. The point GIS dataset was created by the Tennessee Department of Environment and Conservation (TDEC) and was obtained by park staff for use in this assessment. In terms of this assessment needs, the dataset is not complete as it does not have information on well type, well status, or well status date for every well. To supplement the GIS data, additional information was queried from the TDEC online database of oil and gas well permits (TDEC 2016b) and from well log information from the Tennessee Geologic Survey (TGS) (TGS 2012). Even with this supplemental information, complete data for well type, well status, and well status date were not available for all the wells selected by the spatial query. In cases where status information could not be located, it was assumed that the wells are still active. Due to this incompleteness of data, this measure is considered a partial data gap.

4.1.5. Current Condition and Trend

Land Cover/Land Use Change

Based on the standardized classification as assigned in the 2011 NLCD (Jin et al. 2013), natural land cover types are dominant within the AOA, comprising nearly 80% of the area (Figure 18, Table 12). This category includes all lands within the OBRI boundary in addition to over 44,110 ha (109,000 ac) of land under Federal, State, or Private Conservation Group ownership (Figure 19). Much of the converted land is concentrated around the population centers of Crossville, Crab Orchard, Lake Tansi, and Fairfield Glade (Figure 20). Comparison of the NLCD between 2001 and 2011 reveals only a small portion of the AOA was converted from natural cover. During this period, less than 0.2% of the AOA was converted to some type of anthropogenic land cover/land use (Table 12). The majority of this change occurred from 2001–2006, with only 0.05% of the change occurring between 2006 and 2011 (See Appendix A for data for all 3 years). While this is a small percentage, it did result in a net loss of 360 ha (889.6 ac) of natural cover between 2001 and 2011 (Table 12).

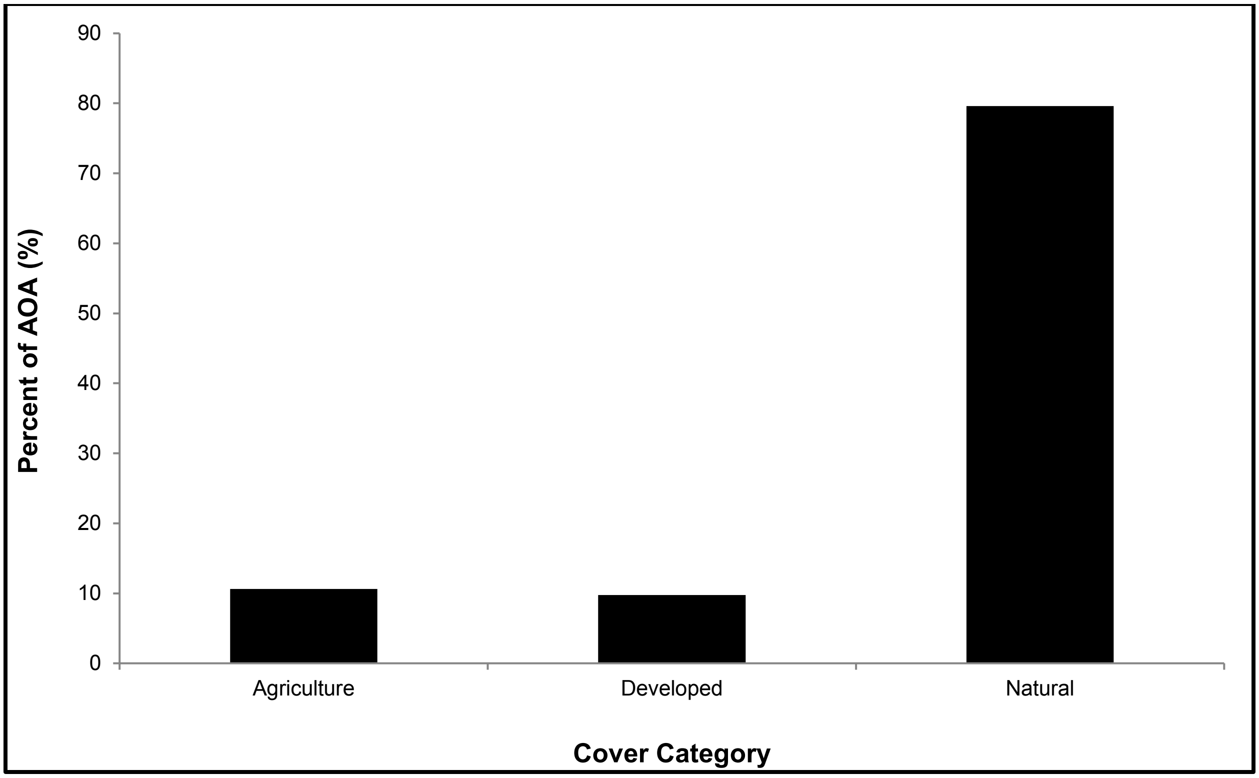


Figure 18. Percentage of area within the AOA for the main cover categories based on 2011 NLCD (Homer et al. 2015).

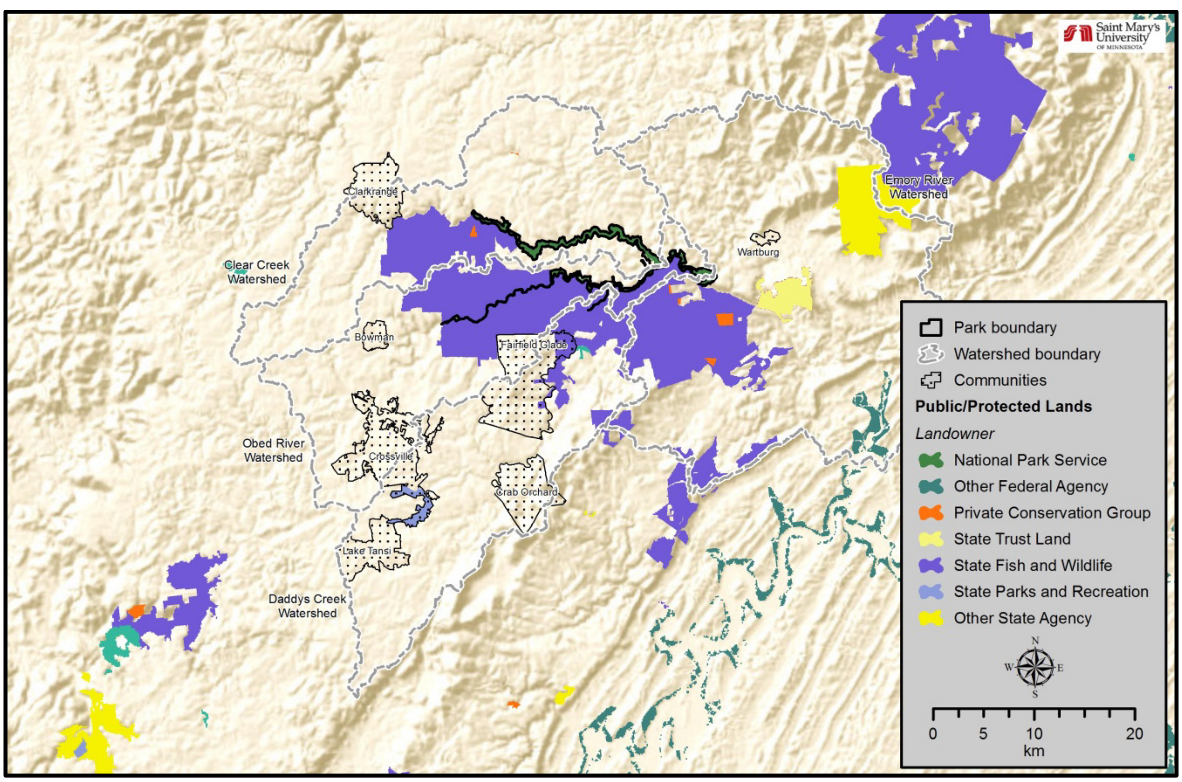


Figure 19. Public/protected lands within the AOA (USGS 2012).

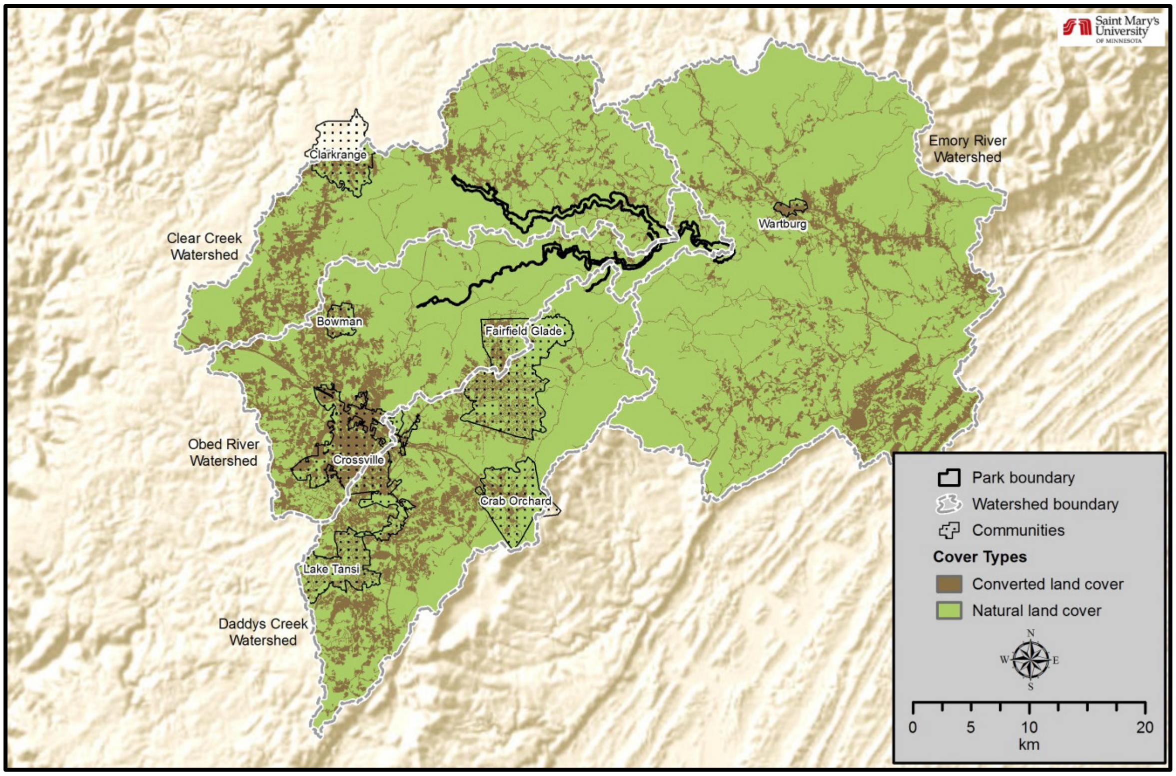


Figure 20. Natural vs. converted land cover based on the 2011 NLCD cover classifications (Homer et al. 2015).

Table 12. Change in land cover category from 2001 to 2011 for the OBRI AOA (Homer et al. 2007, Homer et al. 2015). Results were calculated using NPScape tools and NLCD data for 2001 and 2011. Total area differs slightly from Table 13 due to rounding.

	2001		2011		Change	
Cover Category	**Total Area (ha)**	**Percent of AOA (%)**	**Total Area (ha)**	**Percent of AOA (%)**	**Total Area (ha)**	**Percent of AOA (%)**
Converted	45,496	20.2	45,856	20.4	360	0.2
Natural	179,540	79.8	179,180	79.6	-360	-0.2

Within the OBRI AOA, deciduous and mixed forests are the dominant land cover, based on the classifications used by the NLCD (Figure 21). In 2011, just over two-thirds of the AOA was comprised of forested area, with deciduous forests being the dominant forest type (Figure 22). Agricultural land use and developed areas each comprise about 10% of the AOA (Figure 18). Urban development is mainly centered on the Crossville to Crab Orchard area, and the connecting road corridor (Figure 21). The Clear Creek watershed has the smallest amount of development (Figure 21). Between 2001 and 2011, developed lands showed the largest increase in area, with an increase of approximately 936 ha (2,313 ac), with nearly half of the change being in open space development (Table 13). Lands classified as open space development are areas with some buildings present and vegetation consisting mainly of lawn grasses (Homer et al. 2015). Impervious surfaces are present, but typically comprise <20% of total cover (Homer et al. 2015). This classification generally represents parks, golf courses, and other vegetated areas used for recreation, but can also include large-lot single family dwellings (Homer et al. 2015). Low intensity and moderate intensity development showed some increase (207 ha [511.5 ac] and 213 ha [526.3 ac] respectively), with high density development increasing by around 10% (Table 13). Low and moderate intensity developed areas typically include single-family housing units (Homer et al. 2015). These areas have a mixture of constructed areas and vegetation, with the main difference being the amount of impervious surface present (Homer et al. 2015). In low density developed areas, impervious surfaces account for 20–49% of total ground cover, while in medium intensity developed areas impervious surfaces account for 50–79% of total ground cover (Homer et al. 2015). High intensity developed areas have impervious surfaces accounting for 80–100% of total cover (Homer et al. 2015). Multi-family dwellings, commercial, and industrial properties are normally associated with high density developed areas (Homer et al. 2015). Deciduous forested areas within the AOA exhibited the highest level of net loss of area between 2001 and 2011 (Table 13). Total area of deciduous forests within the AOA declined by 3,761 ha (9,293.6 ac) during the period and mixed forest areas declined by 1,099 ha (2,715.7 ac) over the same period (Table 13). However, evergreen forests showed an increase in area of 1,623 ha (4,010.5 ac) during this period. Other habitat types that increased in areal extent include: scrub/shrub (+2,792 ha [6,899.2 ac]), herbaceous/grassland (+516 ha [1,275.1 ac]), and emergent herbaceous wetlands (+37 ha [91.4 ac]) (Table 13). The complete breakdown for all three years (2001, 2006, 2011) can be found in Appendix B.

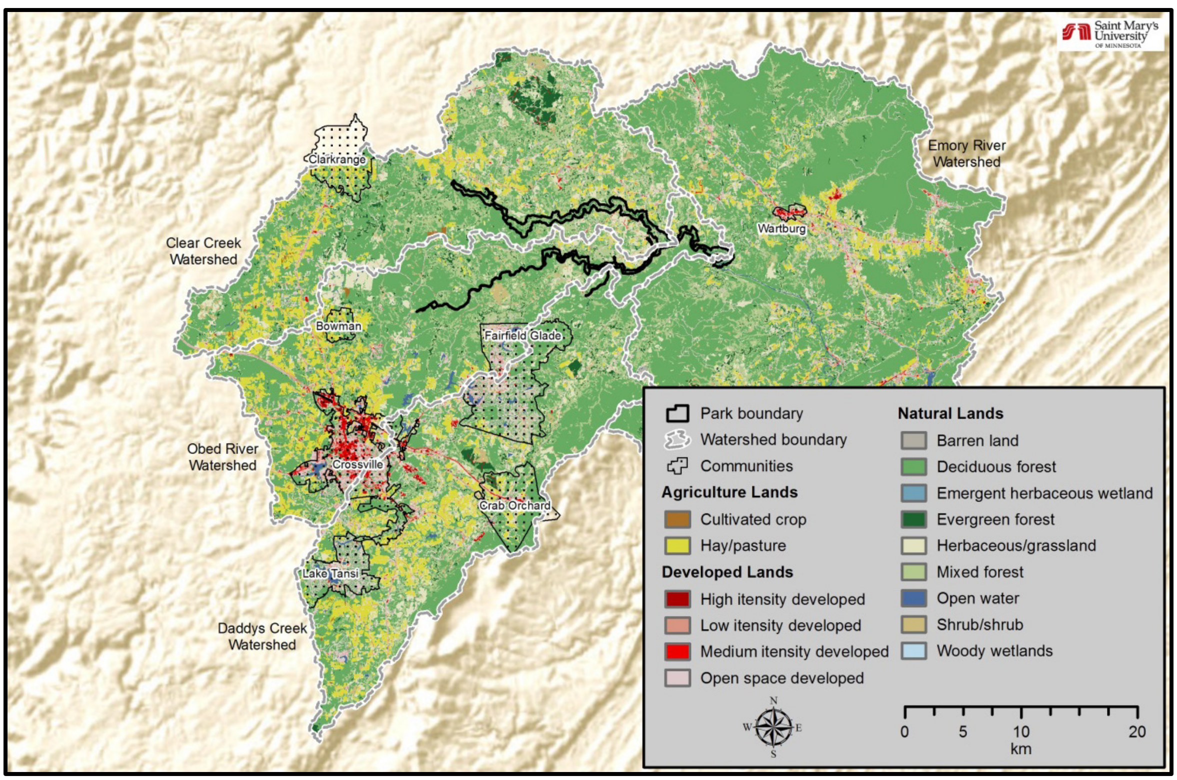


Figure 21. Land cover/land use based on the 2011 NLCD cover classifications (Homer et al. 2015).

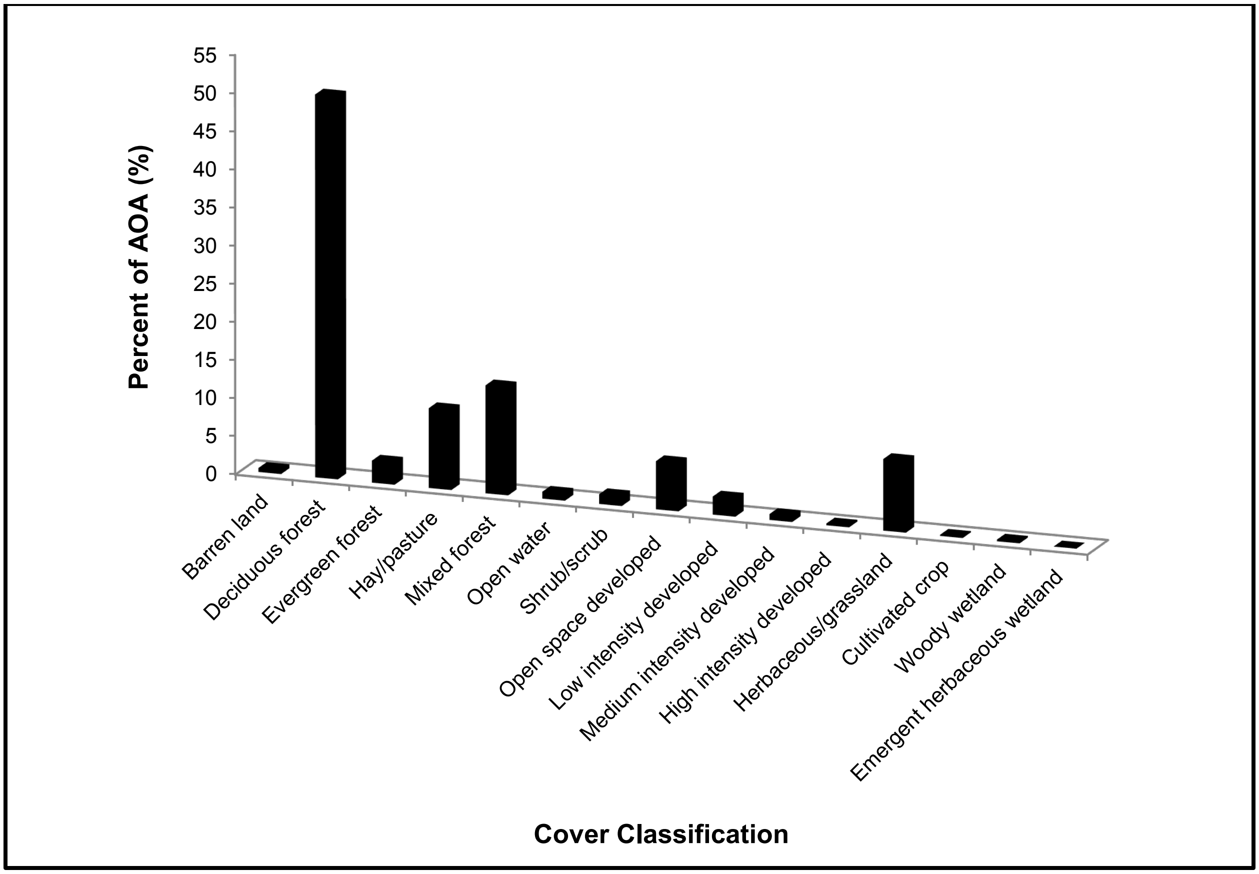


Figure 22. Percentage of area for all cover categories found within the AOA, based on 2011 NLCD (Homer et al. 2015).

Table 13. Change in land cover types from the 2001 to 2011 for the OBRI AOA (Homer et al. 2007, Homer et al. 2015). Results were calculated using NPScape tools and NLCD data for 2001 and 2011. All area values are in hectares. Total area differs slightly from Table 12 due to rounding.

Cover Type	2001 Area	2011 Area	Change
Agriculture	*24,486*	*23,910*	*-576*
Cultivated crop	297	331	34
Hay/pasture	24,189	23,579	-610
Developed	*21,010*	*21,946*	*936*
Low intensity developed	5,153	5,360	207
Medium intensity developed	1,547	1,760	213
High intensity developed	423	525	102
Open space developed	13,887	14,301	414
Natural	*179,539*	*179,180*	*-359*
Open water	2,082	2,037	-45
Emergent herbaceous wetland	3	40	37
Woody wetland	487	481	-6

Table 13 (continued). Change in land cover types from the 2001 to 2011 for the OBRI AOA (Homer et al. 2007, Homer et al. 2015). Results were calculated using NPScape tools and NLCD data for 2001 and 2011. All area values are in hectares. Total area differs slightly from Table 12 due to rounding.

Cover Type	2001 Area	2011 Area	Change
Herbaceous/grassland	20,744	21,260	516
Shrub/scrub	96	2,891	2,795
Deciduous forest	116,616	112,855	-3,761
Mixed forest	32,994	31,895	-1,099
Evergreen forest	4,916	6,539	1,623
Barren land	1,601	1,183	-418

Total Population

Total population within the AOA during the last census (2010) was estimated to be approximately 105,447 people (USCB 2015). This represented an approximate 40% increase since the 1990 census (Table 14). The rate of increase was greatest between the 1990 and 2000 census, while the rate of population growth slowed by 4% between 2000 and 2010 (Table 14). Population totals are highest in the census blocks that comprise the Crossville, Bowman, Fairfield Glade, Crab Orchard and Lake Tansi areas (Figure 23). Due to differences in the census track and census block boundaries between the census years, a comparison of population change at a more finite scale is not possible.

Table 14. Change in total population within the OBRI AOA. Results are based on data from the U.S. Census Bureau for the 1990, 2000, and 2010 census (USCB 2012a, b, 2016).

Census Year	Total Population	Change from Previous Census	Percent Change from Previous Census (%)	Percent Total Change (%)
1990	75,718	–	–	–
2000	90,946	15,228	20.1	20.1
2010	105,447	14,501	15.9	39.3

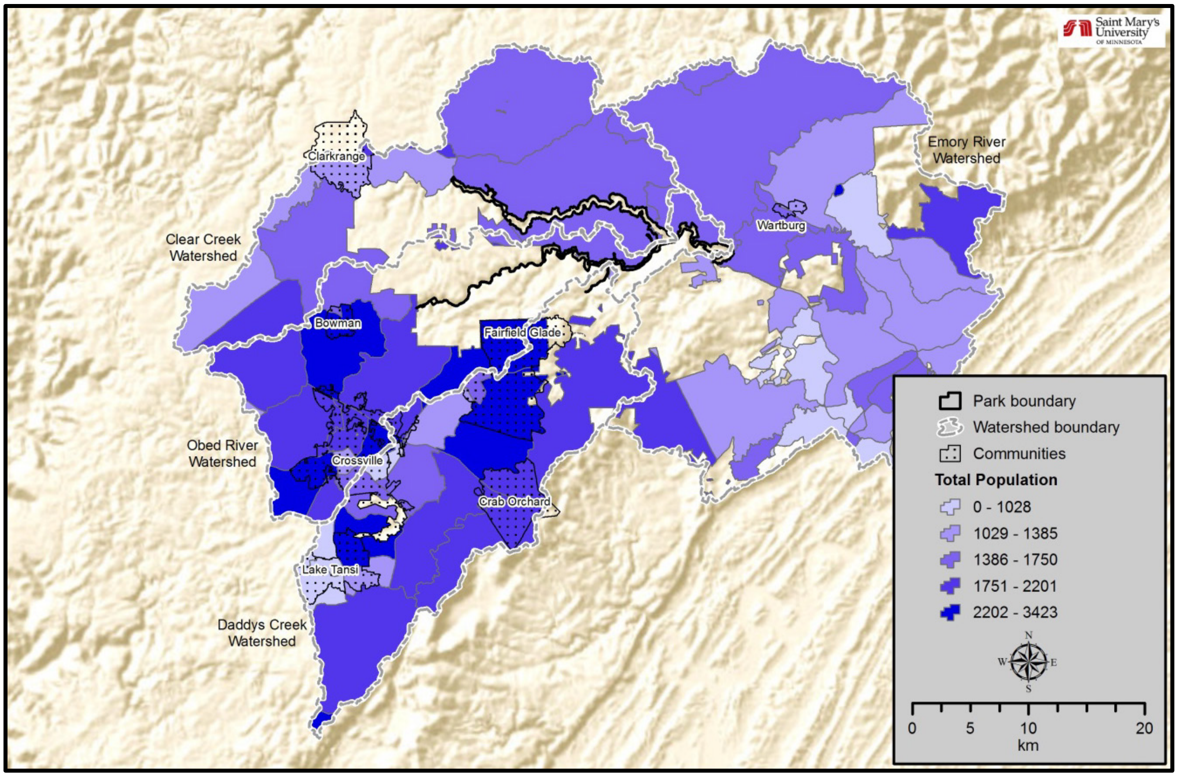


Figure 23. Population totals by census block groups within the AOA (USCB 2016). Public lands and water areas have been erased from the census blocks.

Several communities and census-designated places (CDPs) are within the upper reaches of the watersheds associated with the AOA (Figure 23). The population counts from the last two census surveys and an estimated population as of 1 July 2014 for these populated places are given in Table 15. The largest population centers are the City of Crossville and the CDPs of Fairfield Glade and Lake Tansi (Table 15). The City of Crossville is the largest populated place within the AOA, with an estimated population of 11,330 as of 1 July 2014 (USCB 2015). The populations of Fairfield Glade CDP and Lake Tansi CDP were 7,754 and 3,934, respectively, as of 1 July 2014 (USCB 2015). The highly-populated census block located to the east-northeast of Wartburg in Figure 23 represents the Morgan County Correctional Complex. Fairfield Glade and Lake Tansi have both increased in population by at least 50% over the period of 2000–2014 (Table 16). Only Crab Orchard has experienced a decline in population since the 2000 census; however, Wartburg and Bowman, while showing overall growth since 2000, have declined in population during the period 2010–2014 (Table 16). All of the populated places within the AOA exhibited lower rates of growth during the period of 2010–2014 than for the period of 2000–2010 (Table 16).

Table 15. Population of the communities and census designated places within the AOA for the 2000 and 2010 census and estimated population as of 1 July 2014 (USCB 2012b, USCB 2015, 2016)

Community	Census Designation	2000 Census	2010 Census	2014 Estimate
Crossville	City	8,981	10,795	11,330
Fairfield Glade	CDP	4,885	6,989	7,754
Lake Tansi	CDP	2,621	3,803	3,934
Wartburg	City	890	918	906
Crab Orchard	City	838	752	759
Clarkrange	CDP	461	575	618
Bowman	CDP	203	302	254

Table 16. Changes in population for the communities and census designated places within the AOA for the periods 2000–2010, 2010–2014, and 2000–2014 (USCB 2012a, USCB 2015, 2016)

Community	Change 2000–2010	Change 2010–2014	Change 2000–2014
Crossville	1,814 (20%)	535 (5%)	2,349 (26%)
Fairfield Glade	2,104 (43%)	765 (11%)	2,869 (59%)
Lake Tansi	1,182 (45%)	131 (3%)	1,313 (50%)
Wartburg	28 (3%)	-12 (-1%)	16 (2%)
Crab Orchard	-86 (-10%)	7 (1%)	-79 (-9%)
Clarkrange	114 (25%)	114 (7%)	157 (34%)
Bowman	99 (49%)	-48 (-16%)	51 (25%)

The majority of the AOA is located within Cumberland and Morgan Counties in Tennessee (Figure 1). Small portions of the watersheds upstream of OBRI are located within Bledsoe and Fentress Counties. The extreme upper headwaters of Daddy's Creek are in Bledsoe County and a small portion of the Clear Creek watershed is located in Fentress County. A portion of the Emory River watershed is located in Roane County; however, the contributing area for this watershed is downstream from OBRI. Projected population counts for all these counties are available through NPScape for the years 2020 and 2025. The two main counties associated with the AOA established for this assessment, Morgan and Cumberland Counties, are both projected to increase in population by the year 2025; however, population growth within Morgan County is projected to increase only 1% (Table 17). Cumberland County is projected to have a population increase of 22% by the year 2025 (Table 17). The largest projected increase in population for the counties associated with the AOA is for Bledsoe County (Table 17). This may lead to future issues with water quality for Daddy's Creek, as its headwaters are located in this county (Figure 1). Fentress County also is projected to increase in population by 17% by the year 2025 (Table 17). Parts of the Clear Creek watershed are located within this county, and currently Clear Creek is considered to have excellent water quality (see Chapter 4.8). The Clear Creek watershed is predominantly comprised of natural lands and agricultural land use, and population increases in the county could have an impact on future water quality in Clear Creek

Table 17. Population growth projections compared to the 2010 Census (USCB 1991, 2007, 2011).

County	Population Totals			Population Growth		
	2010	2020	2025	2010–2020	2020–2025	2010–2025
Bledsoe County	14,416	17,150	18,316	19%	7%	27%
Cumberland County	54,059	61,922	66,119	15%	7%	22%
Fentress County	18,838	20,968	21,961	11%	5%	17%
Morgan County	20,257	20,476	20,559	1%	<1%	1%
Roane County	57,042	61,836	63,942	8%	3%	12%

Population Density

Population density in the lands surrounding OBRI and for the AOA in general, has increased since 1990 (Table 18) (USCB 1991, 2007, 2011). Historically, population density in this area has been relatively low. Based on the analysis conducted in this assessment, this trend seems to be continuing (USCB 1991, 2007, 2011, NPS 2015f). Population density from the 2010 census for each census block group within the AOA is represented by Figure 24. Population density is not uniformly distributed within the AOA, and as expected, the highest densities are associated with the larger population centers (Figure 24). Population density also tends to decrease with distance from population centers (Figure 24). Between the 1990 and 2010 census years, population density increased by just over 38% (Figure 24) (USCB 1991, 2007, 2011). The highest population density in the AOA is associated with the census block group that covers the Morgan County Correctional Complex, located to the east-northeast of Wartburg.

Table 18. Population density and percent change in population density within the OBRI AOA. Results are based on data from the U.S. Census Bureau for the 1990, 2000, and 2010 census years (USCB 1991, 2007, 2011).

Census Year	Population Density (people/km^2)	Percent Change from Previous Census (%)
1990	29.6	–
2000	35.5	19.8
2010	40.9	15.4
1990–2010	–	38.25

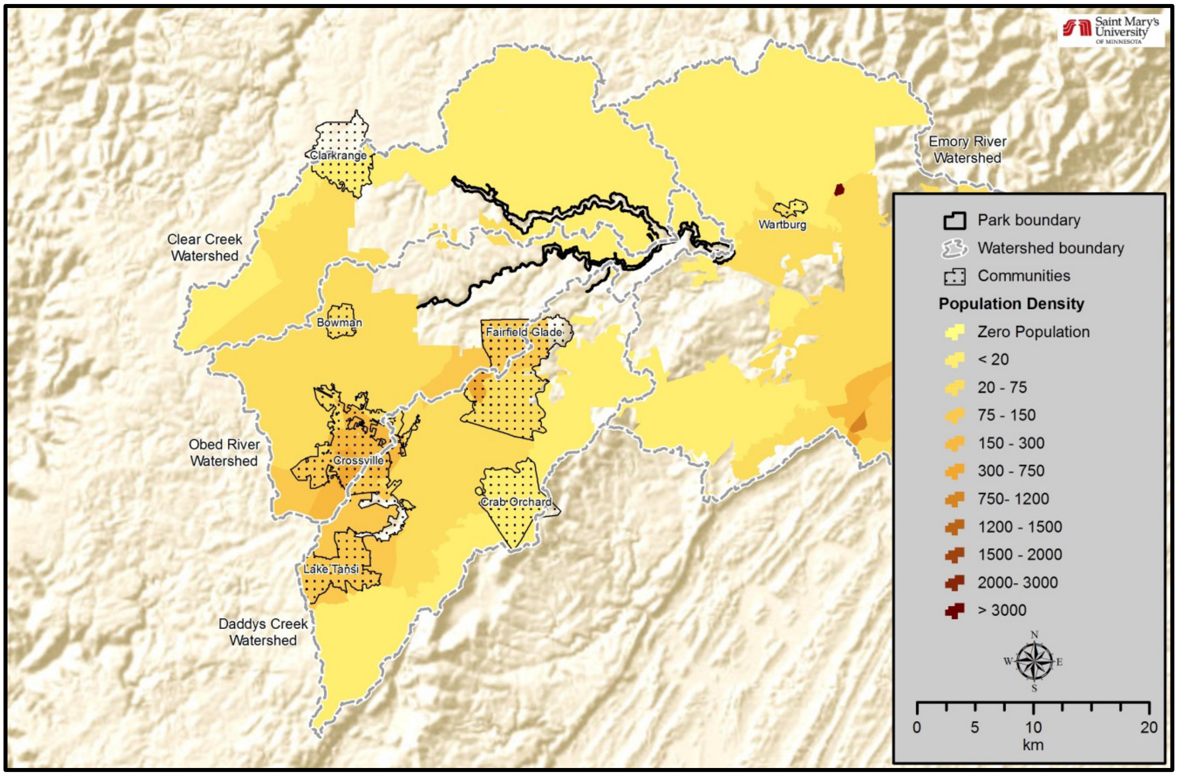


Figure 24. Population density by census block groups within the AOA (USCB 2016). Population density is represented as number of persons/km2. Public lands and water areas have been erased from the census blocks.

Housing Development

Population and housing development are highly correlated (Gross et al. 2009). This can be seen in Figure 25, as the urban areas within the AOA have higher housing densities. Even with the high densities in urban areas, the majority of the AOA has a housing density of less than 12 units/km^2 (31.1 units/mi^2) (Figure 25, Table 19). Since 1970, population growth and housing demand has contributed to a net loss of approximately 53, 330 ha[1] (131,780.8 ac) of land whose housing density was previously designated as rural, specifically in those areas classified as private undeveloped or as <1.5 units/km^2 (<3.9 units /mi^2) (Table 19). The losses in these two rural categories were offset by increases in the classifications within the exurban category and the 4–6 units/km^2 (10.4–16.8 units /mi^2) classification within the rural category (Table 19). Impacts from this rapid expansion of housing are contributing to high levels of water quality degradation in the upper reaches of the Obed River, although conservation and monitoring efforts have resulted in some improvement to the Obed's water quality (Forester et al. 1998, NPS 2015f).

[1] 1 square kilometer (km^2) is equal to 100 hectares (ha)

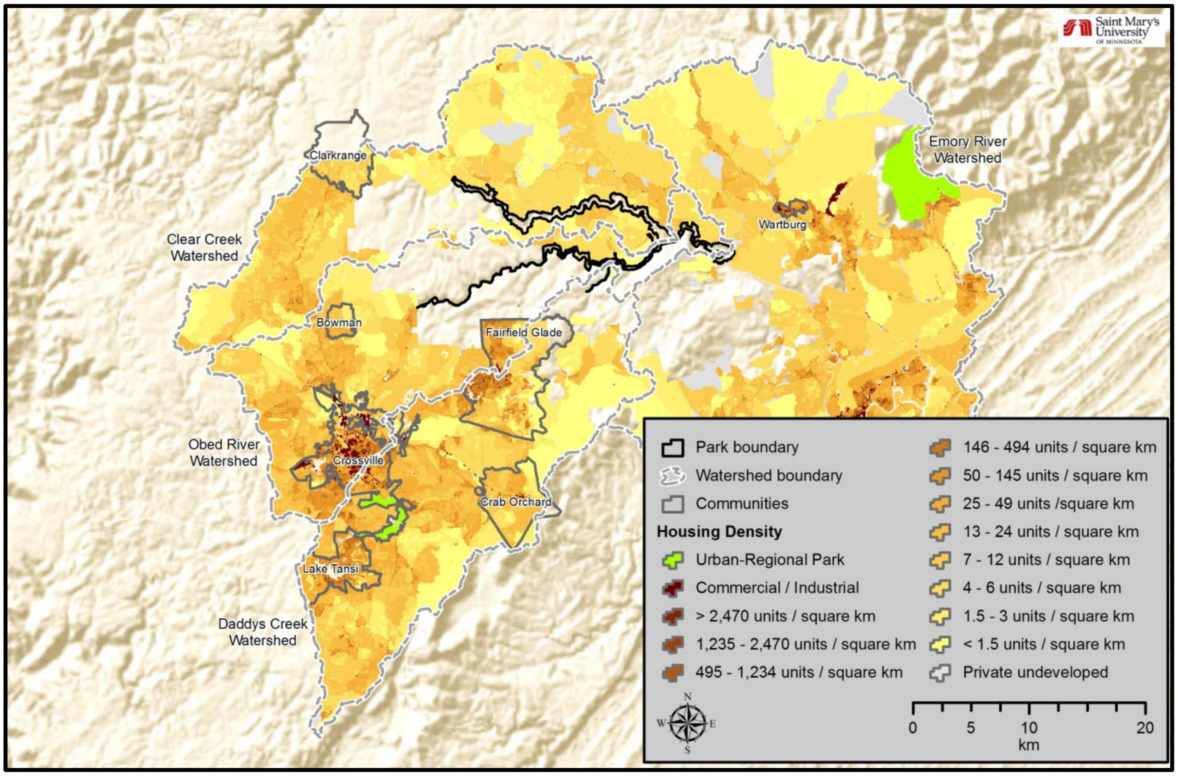


Figure 25. Housing density within the OBRI AOA for 2010 (USCB 2016).

Table 19. Distribution and change of density classifications within the AOA as predicted by the NPScape Housing Density tools (Theobald 2005, USCB 2016). Total area and percent area for the grouped classifications were calculated separately and any difference in the sum of value classes and individual classes is due to rounding.

	1970		2010	
Density Classification	**Area (km^2)**	**Percent AOA (%)**	**Area (km^2)**	**Percent AOA (%)**
Rural	*1,579.8*	*85.7*	*1046.5*	*56.7*
Private undeveloped	302.0	16.4	65.5	3.6
< 1.5 units/km^2	778.7	42.2	314.6	17.0
1.5–3 units/km^2	308.3	16.7	325.1	17.6
4–6 units/km^2	190.9	10.3	341.2	18.5
Exurban	*213.9*	*11.6*	*718.0*	*38.9*
7–12 units/km2	116.2	6.3	290.3	15.7
13–24 units/km2	56.4	3.1	225.0	12.2
25–49 units/km2	25.6	1.4	125.0	6.8
50–145 units/km2	15.7	0.8	77.8	4.2
Suburban	*5.1*	*0.3*	*35.0*	*1.9*
146–494 units/km^2	4.3	0.2	29.7	1.6
495–1,234 units/km^2	0.8	< 0.1	5.3	0.3

Table 19 (continued). Distribution and change of density classifications within the AOA as predicted by the NPScape Housing Density tools (Theobald 2005, USCB 2016). Total area and percent area for the grouped classifications were calculated separately and any difference in the sum of value classes and individual classes is due to rounding.

Density Classification	1970 Area (km^2)	1970 Percent AOA (%)	2010 Area (km^2)	2010 Percent AOA (%)
Urban	*0.2*	*< 0.1*	*1.3*	*0.1*
1,235–2,470 units/km^2	0.1	< 0.1	1.0	0.1
> 2,470 units/km^2	0.1	< 0.1	0.2	< 0.1
Commercial/industrial	14.0	0.8	14.0	0.8
Urban-Regional Park	31.4	1.7	31.4	1.7

Change in Edge Habitat Size

The NPScape tools provide edge habitat data for forest and grassland patches. Edge size, based on the 30 m (98.4 ft) edge definition, along with all MSPA class types for forested and grassland patches within the AOA, are given in Table 20. Forest edge habitat remained relatively constant between 2006 and 2011, even though there was a slight decrease in the amount of core forest habitat within the AOA (Figure 26). In contrast, there was an increase of just over 140% in the area of grassland edge habitat over the same time period (Table 20). Core grassland habitat also increased by nearly 250% during this time period (Table 20). Grassland edge habitat has increased throughout the AOA and appears to be more closely associated with the areas where natural lands have been converted. Relatively small changes in forest edge cover occurred in several areas of the AOA; however, the driving factors behind this change are not readily apparent.

Table 20. MSPA class types for forest and grassland patches within the AOA as derived by the NPScape analysis of 2006 and 2011 NLCD (Homer et al. 2007, Fry et al. 2011).

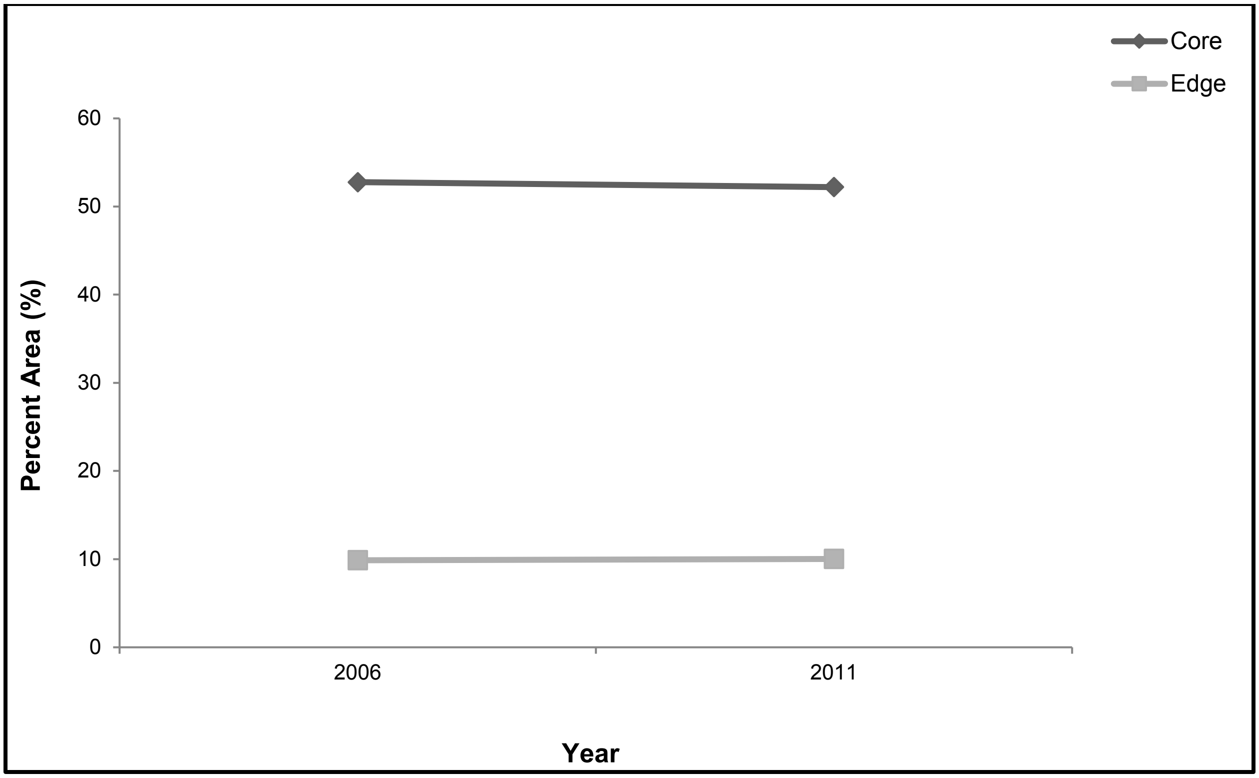
Patch	Pattern Type	2006 Area (km^2)	2006 Percent Area (%)	2011 Area (km^2)	2011 Percent Area (%)
Forest patches	Core	1,187.5	52.8	1,174.7	52.2
	Islet	15.9	0.7	15.6	0.7
	Perforated	25.0	1.1	27.6	1.2
	Edge	222.2	9.9	225.5	10.0
	Bridge	9.8	0.4	10.6	0.5
	Loop	8.1	0.4	8.8	0.4
	Branch	54.2	2.4	54.9	2.4
	Background*	727.7	32.3	732.7	32.6

* "Background" pattern is any other vegetated habitat

Table 20 (continued). MSPA class types for forest and grassland patches within the AOA as derived by the NPScape analysis of 2006 and 2011 NLCD (Homer et al. 2007, Fry et al. 2011).

Patch	Pattern Type	2006 Area (km^2)	2006 Percent Area (%)	2011 Area (km^2)	2011 Percent Area (%)
Grassland patches	Core	52.2	2.3	181.9	8.1
	Islet	65.3	2.9	39.8	1.8
	Perforated	0.3	0.0	1.5	0.1
	Edge	61.2	2.7	148.6	6.6
	Bridge	8.7	0.4	14.3	0.6
	Loop	5.3	0.2	5.8	0.3
	Branch	42.3	1.9	56.6	2.5
	Background*	2,015.1	89.5	1,802.0	80.1

* “Background” pattern is any other vegetated habitat



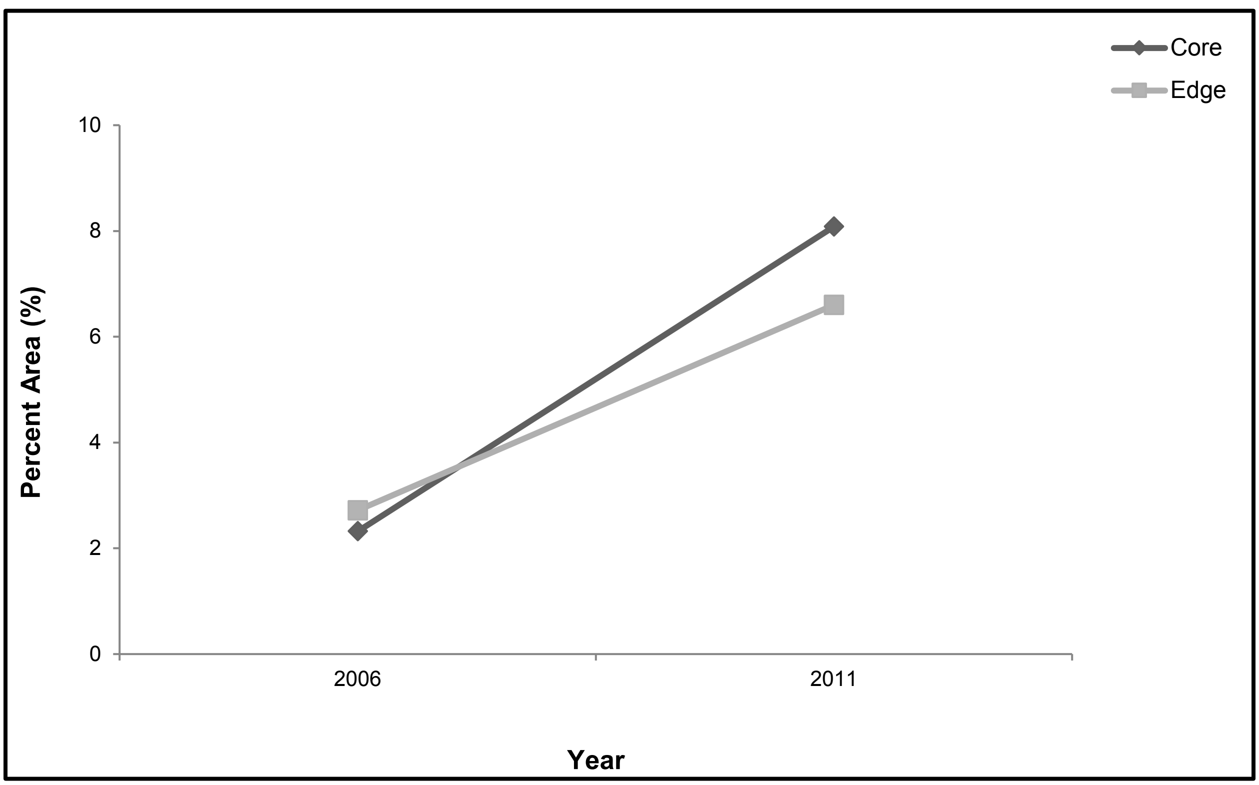


Figure 26. Changes in forest edge habitat (top) and grassland edge habitat (bottom) between 2006 and 2011 (Homer et al. 2007, Homer et al. 2015).

Change in Habitat Patch Size

Habitat within OBRI, and for the AOA, is predominantly forested. Core forested patches (those areas not influenced by edge effects) within the AOA have remained relatively stable in terms of percent of the AOA area, with a decrease of just over 0.5% between 2006 and 2011 (Table 20). However, this percentage does represent a loss of 1,276 ha (3,153.1 ac) within the AOA. In comparing the number of patches and average patch size, there were more core forest patches present in 2011 than in 2006 (Table 21). Coupled with this was a net loss in average core forest patch area of 1 ha (2.47 ac) (Table 21). This change, in conjunction with increases in the relative proportions of edge, bridge, loop, and branch pattern types (Table 20), indicate that 2011conditions reflected a slightly more fragmented forested landscape within the AOA compared to 2006.

Table 21. Changes in average patch size and number of patches within the AOA between 2006 and 2011 (Homer et al. 2007, Fry et al. 2011, Homer et al. 2015).

Year	Number of Patches	Average Patch Size (ha)
2006	3,173	259.8
2011	3,235	258.8

Land Ownership

Private ownership of lands within the administrative boundary is one of, if not the largest, issue facing OBRI's resource managers (Niki Nicholas, OBRI Superintendent, verbal communication, 10 March 2015). Based on the 2016 park boundary GIS data, a total of 54 parcels, covering approximately 470 ha (1,161.4 ac) within the park's legislative boundary are privately owned (Table 22). These inholdings are scattered throughout the park and comprise approximately 21% of the area within the park boundary (Figure 27, Table 22). At the time of this writing, five of these privately held parcels (1.2 ha [2.9 ac]) were in the process of being returned to NPS ownership, pending a land swap agreement (NPS 2016).

With the exception of three parcels that are easements for highway right-of-way (ROW) or railroad ROW, the remaining area within the park boundary is either federally- or state-owned (Table 22). The easements are located at the extreme eastern end of the park (Figure 27) and represent 0.6% of the park's total area (Table 22). There are parcels within the park boundary (corresponding to the footprints of the Obed River and various streams within the park) that are under ownership by the State of Tennessee. Lands under Federal ownership include several parcels that were purchased in order to protect the viewshed in the park (Chad Harrold, OBRI GIS Specialist, personal communication, 13 March 2016).

Table 22. Land ownership of parcels within the park boundary (NPS 2016). Area values are in hectares with acre equivalents given in parenthesis.

Land Ownership	Parcels	Area	Percent Area
Private	*54*	*470 (1,164.4)*	*21%*
Public	*99*	*1,754.6 (4,335.7)*	*78.4%*
Federal	89	1,534 (3,790.7)	68.5%
State	10	220.6 (545)	9.9%
Easements	*3*	*13.6 (33.5)*	*0.6%*
Railroad ROW	1	12.1 (29.9)	0.5%
Road ROW	2	1.5 (3.6)	0.1%

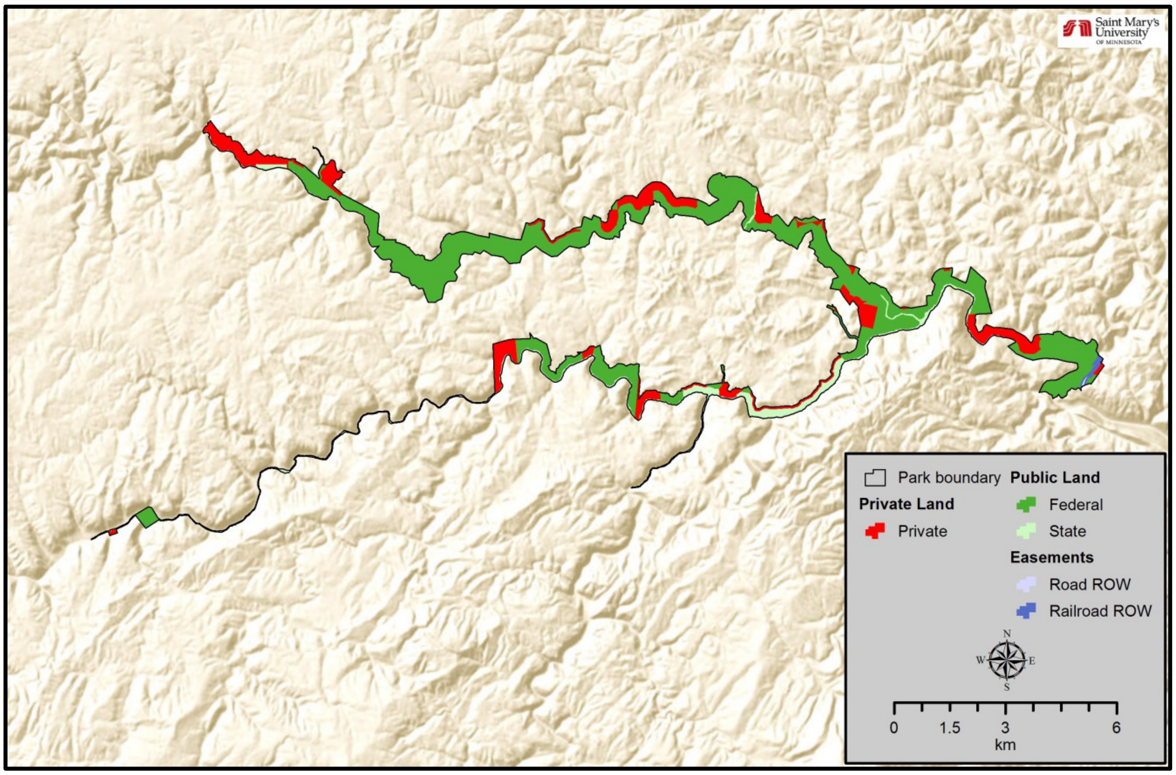


Figure 27. Land ownership within the current boundary of OBRI (NPS 2016).

<u>Number of Oil and Gas Wells</u>

The underlying geology of OBRI is comprised of Pennsylvanian sandstone, siltstone, and shale, along with some conglomerates and coal (NPS 2015f). In addition to coal, these geologic formations also contain pockets of oil and gas (NPS 2015f). Mineral extraction has been part of the region's economy dating back to before the Civil War and continues to the present day (Berwind 1987, BLM 2008, NPS 2015f). A recent study completed for the Bureau of Land Management (BLM) identified 25 counties within Tennessee that had active or historic production of oil and/or natural gas (BLM 2008). In 2006, nine counties had active natural gas production and 12 counties had active oil production (BLM 2008). In 2005, Morgan County was second in the state in production for both oil and gas (Table 23).

Table 23. 2005 Crude oil and natural gas production by county. Oil production is in barrels of oil (bbls) and gas production is given in terms of thousand cubic feet (Mcf). Table was reproduced from BLM (2008).

County	Oil	Gas
Overton	154,507	9,865
Morgan	51,814	401,522
Scott	35,191	219,858
Fentress	25,669	42,899
Pickett	21,786	–
Claiborne	13,917	231,678
Campbell	9,044	201,895
Anderson	8,427	813,297
Hancock	4,946	291,477
Clay	785	–
Cumberland	224	–
Franklin	168	–
Roane	–	1,027

The earliest commercial production of oil in Tennessee can be traced to 1866 from the Spring Creek field in southwest Overton County (Berwind 1987). During the years 1900 to 1960, a large number of wells were drilled within the state. However, a large percentage of these were dry wells (Berwind 1987). The State of Tennessee did not begin regulation of the oil and gas industry until 1968 (Berwind 1987). Moderate drilling continued through the 1970s until 1979, when activity increased significantly due to a number of major discoveries (Berwind 1987). Beginning in 1979 and continuing through 1983, there was a major upsurge in oil and gas well drilling activity (Berwind 1987). These trends are exhibited in the number of oil and gas wells located within 0.8 km (0.5 mi) of the park's boundary (Figure 28). TDEC oil, well log, and well data records show that the first well within this buffer area was drilled in November 1972 (TDEC 2016a). Two more wells were drilled in 1973, seven in 1974, three in 1977, two in 1978, and four in 1979 before the large increase between 1980 and 1982 (Figure 28) (TDEC 2016a). TDEC (2016a) records indicate the last well to be drilled within the buffer areas was in June 2014.

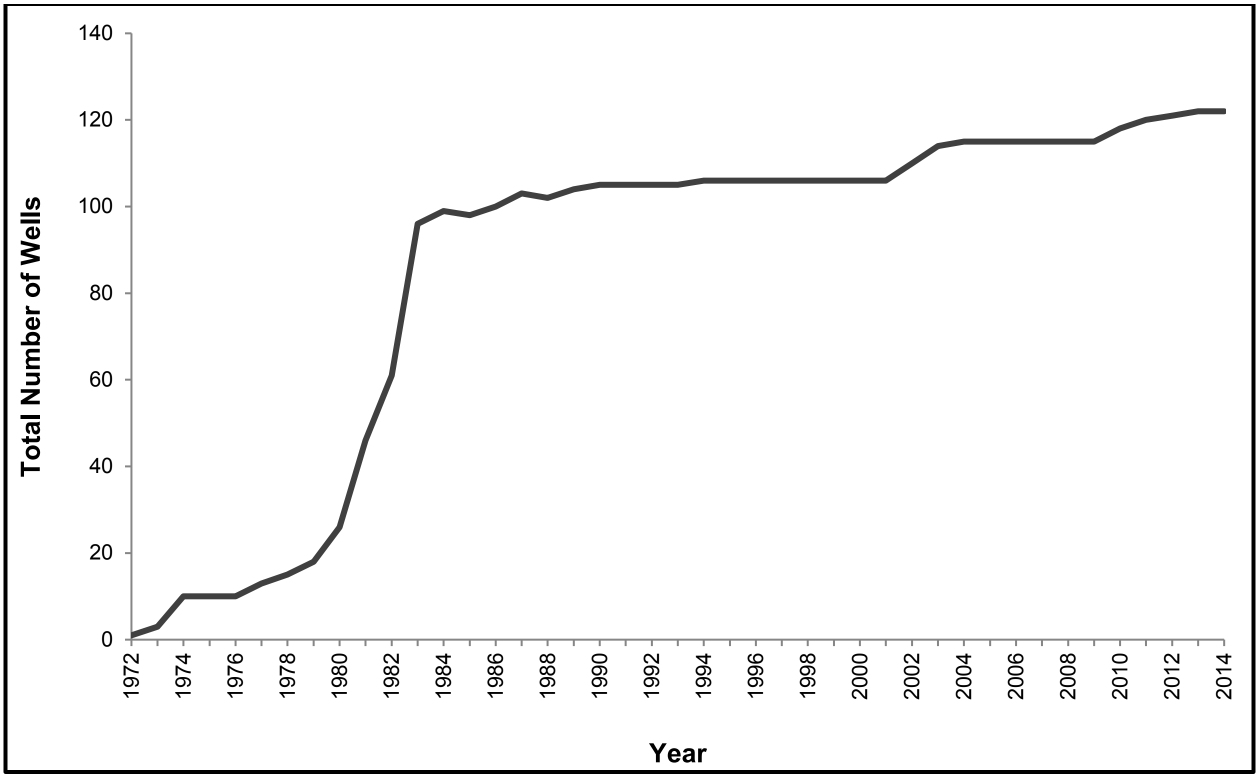


Figure 28. Total number of oil and gas wells present (by year) within 0.8 km (0.5 mi) of the OBRI boundary (TDEC 2016a).

Data from the State of Tennessee's Division of Geology indicate that there are 1,374 oil and gas wells (active and inactive) within the Emory River and Obed River watersheds (TDEC 2016a). Spatial queries on this dataset identified 140 wells within 0.8 km (0.5 mi) of the park's current boundary, with the majority of these wells located in the Clear Creek watershed (TDEC 2016a) (Figure 29). GIS data provided by park staff identified 11 oil and gas wells (four active and seven plugged) located within the park's legislative borders (NPS 2011) (Figure 29). The park GIS data were used to identify wells within the park's boundary, as these locations have been verified by park staff. In regards to the wells located on federally-owned lands, four are still active and three have been plugged (Spradlin, written communication, 29 August 2016). The other plugged wells are located on lands not yet acquired by the NPS but within the current park boundary (Forester et al. 1998).

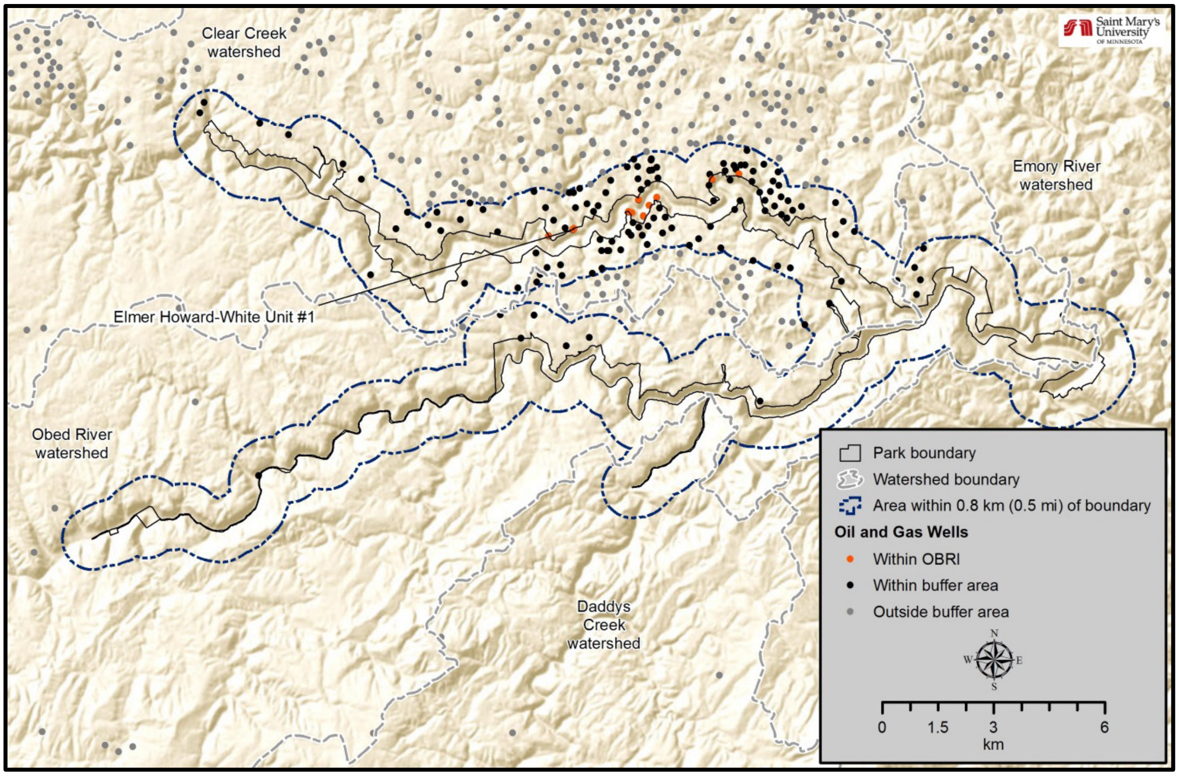


Figure 29. Locations of oil and gas wells within OBRI and in the immediate vicinity (NPS 2011, TDEC 2016a).

Overall, oil and gas exploration and production has decreased in the area as extraction processes in other areas have become more profitable (NPS 2015a, f). The installation of oil and gas wells is no longer permitted on park lands or within easements, but privately-owned mineral resources that are under federal surfaces may be extracted if they can be accessed from outside the boundary (NPS 2015f). Horizontal drilling is also coming to the region and potentially to those lands adjacent to the park (NPS 2015a, f). This drilling process poses a new threat to the park through the degradation of the park's viewshed and geologic formations (NPS 2015a, f).

Threats and Stressor Factors

A number of potential threats and stressors associated with landscape dynamics were identified by the project team. These included loss of connectivity with public or protected lands, increased development of residential, commercial, industrial, and agricultural lands, loss of natural habitat, population growth, and mineral resource extraction. Development, loss of natural habitat, and loss of habitat connectivity are related to population growth. Population growth invariably increases development of the landscape, increasing edge effects, habitat fragmentation, and the loss of habitat connectivity (Gross et al. 2009). Population growth has also been shown to be a contributing factor in declining biodiversity, usually due to the loss of habitat to land conversion (Hansen and Brown 2005, Hansen et al. 2005, Wilcove et al. 2009). Increases in population and the need for new housing developments can also drive up land prices in rural fringe areas, leading to the subdivision and conversion of agricultural and natural lands resulting in fragmentation and habitat loss (Daniels 1999).

Development (e.g., commercial, industrial, agricultural and residential) in the park's watershed can lead to a variety of additional impacts to the landscape. Increased residential, commercial, and industrial development results in an increase of impervious surfaces through the construction of roads, parking lots, and structures. This development impacts infiltration rates within the watershed, leading to shifts in the hydrologic regimes of rivers and streams (Gross et al. 2009). Development also poses a threat to the water quality and quantity found within OBRI (Emmott et al. 2005). Chemical pollutants carried by storm-water runoff, and chemical and biological pollutants from septic tanks and drain fields are among the water quality issues associated with increased development (Forester et al. 1998, Emmott et al. 2005). Development also contributes to the fragmentation of natural habitats, introduction of invasive species, alteration of wildlife migration patterns, and the expansion of the wildland-urban interface (i.e., edge effects) (Emmott and Murdock 2008). Furthermore, exurban and rural development is often located in proximity to public or protected lands (Theobald 2005). As developments in these areas increase, the protected areas can become more isolated, resulting in loss of habitat connectivity and wildlife corridors (Fahrig 2003, Worsham et al. 2013). This can also result in a decline of biodiversity and the overall environmental quality of habitat (Fahrig 2003).

Conversion of habitat types, particularly in context of human activity within the Cumberland Plateau, is known to cause shifts in the existing native biotic communities (Maestas et al. 2003). This poses a threat to OBRI as there are ecologically significant floral communities present within the park that support federally-listed plant species such as *Virginia spiraea* and Cumberland rosemary (Emmott et al. 2005, Wolfe et al. 2007). Loss of habitat also has a consistent negative effect on biodiversity (Fahrig 2003) and can result in changes to ecological functions and ecosystem services. Other effects associated with the loss of natural habitat include the fragmentation of sensitive habitat, the introduction of invasive/exotic species, and the degradation or loss of scenic vistas (Emmott and Murdock 2008).

Currently, there are no permitted coal mines operating within the Obed River watershed (Emmott et al. 2005). However, coal mining has occurred in the watershed in the past, with abandoned strip mines located in the headwaters of Daddy's Creek and the Emory River, and in proximity to several tributaries of Clear Creek (Emmott et al. 2005). Runoff from these abandoned mines poses a threat to the park's water quality from acid mine drainage and other water-borne pollutants associated with mining operations (Emmott et al. 2005). In addition to the large number of oil and gas wells already located within and in the vicinity of the park, there are also undeveloped lands within and adjacent to the park's boundaries that have their mineral rights held or leased by private entities (Forester et al. 1998, NPS 2012). Clearing and development of these lands for oil and gas production has the potential to impact water quality within the park through soil erosion, surface and groundwater pollution and the alteration of natural drainage patterns (Forester et al. 1998). Active wells pose a threat to the park's natural resources from the chemical and petroleum by-products associated with the production process (Forester et al. 1998). An additional threat is posed by the potential from spills or fires, such as what occurred in a well adjacent to the park in 2002 (Emmott et al. 2005) (Figure 29). This accident at the Elmer Howard-White Unit #1 Site impacted Clear Creek and Whites Creek. The aquatic resources appeared to have recovered by 2006, based on studies of the macroinvertebrate communities, however the forests affected by the spill and fire will require an estimated 170+ years before the age structure and standing biomass return to pre-spill conditions (Trustees 2008, NPS 2015f). Future resource extraction (e.g., coal, gas, and oil) and withdrawals of water upstream of OBRI may impact the Obed River water quality and its base flow (Emmott et al. 2005). Erosion and sedimentation associated with the clearing and disposal of the original surface cover can also have a negative impact on the water quality in the park.

Data Needs/Gaps

Impacts to the park's water quality and other natural resources continues from existing oil and gas wells within the area, despite a slowing in new exploration and development. Presently there is no monitoring program in place for oil and gas operations after the initial installation inspection (Forester et al. 1998). In addition, data in terms of the status of the existing oil and gas well are incomplete, so an accurate assessment of abandoned wells that have not been plugged could not be conducted. To the degree possible, active and abandoned wells should be included in future land use assessments. The assessment conducted in this analysis could provide baseline information.

A landscape change monitoring protocol is being developed by the APHN for implementation at OBRI (among other network parks) with the following objectives in mind: (1) determine the long-term changes in abundance, distribution and overall health of the dominant vegetation types in the park, (2) determine the status and trends in the areal extent and configuration of land use and land cover adjacent to the park, and (3) to analyze key landscape metrics similar to those included in this analysis (Emmott and Murdock 2008). This monitoring program would be conducted on a regular basis (every 5–10 years) in order to track change on lands directly adjacent to the park in order to manage for potential impacts to the park from these changes. This data could be supplemented by a similar scheduled update of the data in this condition assessment in order to track and manage for potential impacts to the park from regional changes as well.

Currently, there is a need for more research by the scientific community to better understand the pattern, rates, and ecological effects of urban and exurban sprawl (Theobald 2005). This is especially true in the case of exurban sprawl, due to the extensive and widespread changes to land cover and land use that are occurring (Theobald 2005). This exurban and rural development is often located nearby or adjacent to protected lands and is resulting in widespread changes in the biodiversity and natural resources that these areas are meant to conserve (Theobald 2005).

Overall Condition

Land Cover/Land Use

The project team assigned a *Significance Level* of 3 to this measure. In particular, changes in land cover/land use outside of the park boundary were of primary concern to resource managers. Land use in the watersheds above OBRI has the potential to influence many of the park's natural resources. Development in close proximity to the park can result in habitat fragmentation or the introduction of invasive species, among other potential impacts. Increases in impervious surfaces or resource extraction in the upper portions of the park's watersheds can have an impact on the water quality within the park. While loss of natural habitat has occurred since 2001, especially within forested habitats, the majority of this occurred between 2001 and 2006 (Table 13, Appendix B). The period between 2006 and 2011 exhibited lower levels of natural habitat loss, with gains in scrub/shrub, emergent wetlands, and evergreen forests. Due to this, a *Condition Level* of 1, indicating low concern, was assigned. However, as the area's population grows, continued conversion of natural areas to accommodate this growth is likely to occur. With natural cover, especially forested areas, making up a majority of the land cover in the AOA, protecting these resources on public lands, or through public-private partnerships will become extremely important.

Total Population

The total population measure was assigned a *Significance Level* of 2. Data analysis of human population characteristics can provide a direct indication of the level of anthropogenic impact on a landscape (Gross et al. 2009). Increases in population generally result in increases in developed land and higher natural resource demand (Davis and Hansen 2011). These increases in developed lands and resource demands lead to loss of natural habitat cover, habitat fragmentation, vegetation modification, creation of new disturbance regimes, and increases in point and non-point pollution sources (Gross et al. 2009). The total population within the AOA increased between the 1990 and 2010 census surveys. The population increases are concentrated around population centers within the AOA and none are in close proximity to the park. While the growth rates appear to have slowed somewhat since the 2000 census, population growth in the area surrounding the park is expected to increase in the coming years (NPS 2015f). Due to all these factors, a *Condition Level* of 2 or moderate concern was assigned.

Population Density

The population density measure was also assigned a *Significance Level* of 2 by the project team. As population density tends to mirror total population, many of the same effects on the natural habitat that are associated with total population can be magnified by concentrations of high population density. Growing population leads to increased density, more development, and conversion of natural habitat to provide housing and other infrastructure (Gross et al. 2009). Historic levels of population density have been low in the area surrounding the park (NPS 2015f). Projections are for increased population in the AOA, which would lead to increased population density. Based on the potential for increasing densities within the AOA, a *Condition Level* of 2, meaning moderate concern was assigned.

Housing Development

The housing development measure was assigned a *Significance Level* of 3 by the project team. Housing development and density has increased in the upper portions of Daddy's Creek, Clear Creek, and the Obed River watersheds. Housing densities in the areas in closer proximity to the park have increased, but at a much lower rate. Overall, within the AOA there has been a conversion of lands that were classified as rural density (specifically areas that were previously undeveloped or had < 1.5 units/km^2 [< 3.9 units/mi^2]) to exurban development densities Table 19). This conversion of rural lands into exurban categories is usually permanent (The H. John Heinz III Center for Science 2008, Gross et al. 2009). Studies have shown that increases in exurban development can have numerous impacts on biodiversity, such as changes to species richness, species distribution, species diversity, and increased invasive exotic ground cover (Hansen et al. 2002, Hansen et al. 2005). Also, increased growth in the low-density exurban category has been recognized as one of the primary drivers affecting how habitats perform ecological processes such as erosion control, natural flood regimes, nutrient cycling, and landscape connectivity (Hansen et al. 2005). Increased housing density within a watershed can also influence aquatic resources, as construction of infrastructure produces increased impervious surfaces and decreased infiltration rates (Monahan et al. 2012). The land cover conversion associated with housing development can lead to increased erosion and decreased soil stability, contributing to increased sedimentation in streams (Monahan et al. 2012). The fertilizers and pesticides used in landscaping and lawn maintenance can increase nutrient levels and contaminant pollution of streams (Monahan et al. 2012). Due to the increase in the exurban and suburban density classes in the upper reaches of the watersheds, and their potential to impact the biodiversity and aquatic resources of OBRI, a *Condition Level* of 2, meaning moderate concern, has been assigned.

Change in Edge Habitat Size

Changes to edge habitat were assigned a *Significance Level* of 3 by the project team. An increase in the amount of edge habitat can be an indicator of increased fragmentation (Monahan et al. 2012). Grassland edge habitat has increased during the period 2006–2011, while the forest edge habitat has remained relatively stable. A *Condition Level* of 2, meaning moderate concern, has been assigned primarily due to the increase in grassland edge habitat.

Change in Habitat Patch Size

Change in habitat patch size was also assigned a *Significance Level* of 3. The total size of forested core patches has remained relatively stable in terms of percent area, but there was a net loss of 1,276 ha (3,153.1 ac) within the AOA between 2006 and 2011. This is the result of an overall increase in number of core forest patches and a decrease in average patch size. The NPScape outputs for forested cover within the AOA all point towards an increase in fragmentation of forested landscapes. Due to this increased fragmentation, a *Condition Level* of 2, meaning moderate concern, has been assigned to this measure.

Land Ownership

Land ownership within the park's administrative boundary was assigned a *Significance Level* of 3 by the project team. Privately owned inholdings are a concern, as the park has no control over their land use or land management. With private inholdings comprising 21% of the total area of the park, they are considered a significant potential threat to the park's natural resources. Due to this factor, a *Condition Level* of 3, meaning significant concern, was assigned. It should be noted that the NPS is working on bringing these lands under NPS control through land swap and land purchase agreements.

Number of Oil and Gas Wells

The number of oil and gas wells within 0.8 km (0.5 mi) of the park was assigned a *Significance Level* of 3 by the project team. There are a large number of wells near the park boundary (140), and within the Emory and Obed River watersheds (1,374). While the exact distribution in terms of active, inactive, or abandoned wells is not known, the presence of these wells poses a threat to the natural resources within the park. The development of lands where these wells are installed has resulted in increased sedimentation and erosion. The chemicals used in the extraction process and petroleum by-products pose a potentially significant threat to the park's natural resources. This can be evidenced by the long recovery period for forested areas affected by 2002 Elmer Howard-White Unit #1 fire and spill. While new mineral extraction is not allowed within the park or park easements, directional drilling from adjacent lands is a concern (NPS 2015f). Due to these factors, a *Condition Level* of 3, or of high concern, was assigned to this measure.

Weighted Condition Score

The *Weighted Condition Score* for OBRI's landscape dynamics measure is 0.71, indicating significant concern. However, this result is near the lower limit of this category. A major concern is the number of oil and gas wells in the immediate vicinity of the park and the potential for serious impacts to the park's natural resources. Currently, the establishment of new wells in the region has slowed due to economic conditions; however, directional drilling could lead to a new surge in drilling in the region (NPS 2015a, f). Increases in grassland edge and decreased forest patch size could indicate a more fragmented landscape. Also, population is expected to increase in Crossville and other urban areas in the upper reaches of the Obed River and Daddy's Creek watersheds. With the exception of the number of oil and gas wells, the other measures will all be negatively impacted by the projected increase in population. This factor, coupled with the potential for increased oil and gas exploration due to horizontal drilling, resulted in the assignment of a declining trend.

Landscape Dynamics			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.71**
Land Cover/Land Use	3	1	
Total Population	2	2	
Population Density	2	2	
Housing Development	3	2	
Change in Habitat Patch Size	3	2	
Change in Edge Habitat Size	3	2	
Land Ownership	3	3	
Number of Oil and Gas Wells	3	3	

4.1.6. Sources of Expertise

- Michelle Kinseth, National Inventory & MonitoringGIS Specialist
- Etta Spradlin, NPS Environmental Protection Specialist

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4.2. Native Forests/Other Plant Communities

4.2.1. Description

Parks within the APHN are known to be rich and diverse in endemic (i.e., unique to the area) vascular and non-vascular plant species. One reason for the establishment of OBRI was to preserve these diverse communities (Photo 5) (NPS 2007). Several long-lived tree species like the eastern red cedar (*Juniperus virginiana*), as well as glacial relict plant populations, have been discovered along cliff sides inside the park, (Walker et al. 2003). Braun (1950) identified the Cumberland Plateau area as a mixed mesophytic forest region; this forest type is among the oldest and most complex of deciduous forests in the eastern U.S. Schmalzer (1989) classified the area's forest vegetation into ten types: river birch (*Betula nigra*), beech-tulip poplar (*Liriodendron tulipifera*, also known as tuliptree), white oak (*Quercus alba*), eastern hemlock (*Tsuga canadensis*), sweet birch (*Betula lenta*), hemlock-chestnut oak (*Quercus michauxii)*, chestnut oak-white oak, white pine (*Pinus strobus*)-white oak-chestnut oak, white oak-scarlet oak (*Quercus coccinea*), and Virginia pine (*Pinus virginiana*).

Photo 5. One of the reasons OBRI was protected as a wild and scenic river was to preserve the diverse and rich plant communities of the area (Photo by Kevin Benck, SMUMN GSS).

4.2.2. Measures

- Number of plant species
- Percent nativity of plant species

- Total area of non-native plant species
- Trends in Element Occurrences
- Hemlock mortality
- Distribution of emerald ash borer

4.2.3. Reference Conditions/Values

The reference condition for native forests and other plant communities in the park was defined as the condition described by Dr. Lucy Braun in her 1950 book titled "Deciduous Forests of Eastern North America." Braun was a professor of Plant Ecology at the University of Cincinnati, Ohio. In her book, she describes the area that is now OBRI as part of the mixed mesophytic forest region:

> *This region is characterized by the prevalence of mixed mesophytic climax communities. It is the stronghold of the Mixed Mesophytic association – the climax association in which dominance is shared by a number of species, particularly beech, tuliptree, several species of basswood (but not T. americana), sugar maple [Acer saccharum], yellow buckeye [Aesculus flava], chestnut [Castanea dentata], red oak [Quercus rubra], white oak, and eastern hemlock. This association develops only on moist but well-drained sites. Deeply melanized soil and a mull humus layer are characteristic features* (Braun 1950, p. 35).

According to Hinkle (1989), Braun (1950) remains the most cited reference on the vegetation of the Cumberland Plateau in Tennessee.

4.2.4. Data and Methods

The certified plant species list for OBRI (NPS 2015) includes all vascular plant species documented or believed to occur in OBRI. Occurrence in the park is identified as present, probably present, or unconfirmed. Other characteristics identified in this list include nativity and relative abundance. Non-vascular plants are also a part of the NPS certified species list, but at this time, no data are available for occurrence, nativity, or relative abundance of these species (NPS 2015).

The vegetation mapping inventory is a NPS initiative with the goal of classifying, describing, and mapping vegetation communities within more than 270 national park units (NPS 2012), including OBRI. This inventory uses procedures from the National Vegetation Classification Standard (NVCS) and produces "high-quality, standardized maps and associated data sets of vegetation and other land-cover occurring within parks" (NPS 2012, p. 1). As part of this effort, thirty permanent study plots were established at OBRI to be used by researchers for population counts and species monitoring (Figure 30). These plots are 1 ha (2.5 ac) in size and were chosen due to their safe locations in an otherwise rugged and difficult environment (Nordman 2010).

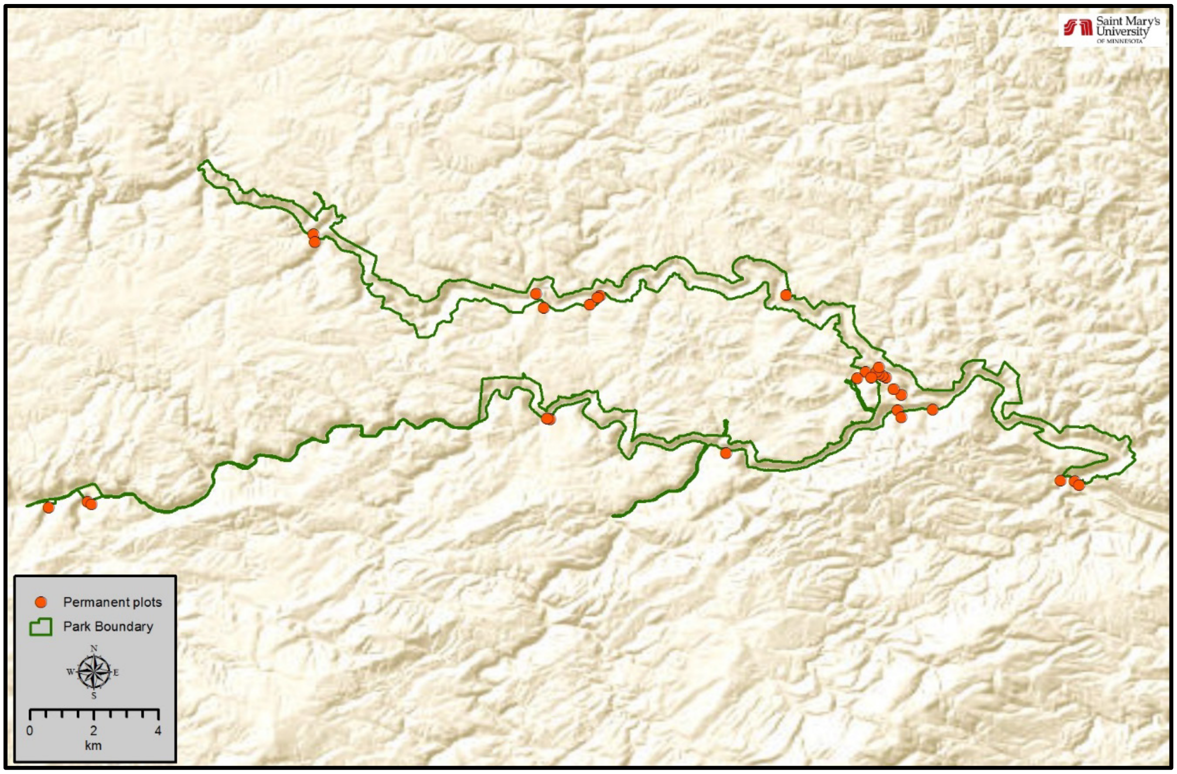

Figure 30. Locations of the 30 permanent plots used for population counts and monitoring inside OBRI; research uses these plots for vegetation monitoring (NPS 2011b).

Element occurrences (EOs) are one way of surveying, mapping, and assessing populations of high-priority species (NatureServe 2016). NatureServe (2016) developed the EO data standard, which provides standardized vocabulary, definitions, and guidelines for the collection and management of EO data. EO data provides information on where specific species exist on the ground, and their populations are ranked based on their overall viability or probability of persistence (NatureServe 2016).

Every EO is assigned a basic rank (Table 24); range ranks can be assigned when there is uncertainty or insufficient information that causes an EO to have relatively equal probability of falling into more than one category (Hammerson et al. 2008).

Table 24. Element of occurrence (EO) rankings and descriptions of each rank. Note that "range ranks" can be used to indicate a range of uncertainty (e.g., AB, CD) (Hammerson et al. 2008).

Rank	Explanation
A	**Excellent viability**: Occurrence exhibits optimal or exceptionally favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; if current conditions prevail, the occurrence is very likely to persist for the foreseeable future (i.e., at least 20–30 years) in its current condition or better.
B	**Good viability**: Occurrence exhibits favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; if current conditions prevail, the occurrence is very likely to persist for the foreseeable future in its current condition or better.
C	**Fair viability**: Occurrence characteristics (size, condition, and landscape context) are non-optimal such that persistence is uncertain under current conditions; or the occurrence is likely to persist but not necessarily maintain current or historical levels of population size or genetic variability.
D	**Poor viability**: Under current conditions, occurrence has a high risk of extirpation (due to small population size or area of occupancy, deteriorated habitat, poor reproductive conditions, ongoing inappropriate management that is unlikely to change, or other factors).
E	**Verified extant**: Occurrence has recently been verified as still existing, but sufficient information on the factors used to estimate viability has not yet been obtained.
H	**Historical**: Recent field information verifying the continued existence of the occurrence is lacking; generally recommended for occurrences that have not been reconfirmed for 20 or more years.

EO data for the state of Tennessee were originally maintained by the Natural Heritage Inventory Program (NHIP), but are now collected and maintained by the TWRA (in collaboration with TNC) (TN-WAPT 2015); park-specific data was provided to SMUMN GSS analysts by the TWRA.

4.2.5. Current Condition and Trend

Number of Plant Species

According to the NPSpecies list (2015), over 750 vascular plants have been identified as present or probably present inside the park. An OBRI park inventory conducted by APHN in 2007 added 112 of these plant species to the park species list (NPS 2007). In the Nordman (2010) report, it was determined that, among the 30 permanent plots sampled, the average species richness was 82.2 vascular plants per 1 ha (2.47 ac) plot. In one instance, 535 plant species were identified in a single plot (Nordman 2010).

Percent Nativity of Plant Species

According to Schmalzer (1989), the flora in OBRI is predominantly native. This is potentially due to the relative lack of anthropogenic disturbances (e.g., old fields, home sites) (Schmalzer 1989) and the isolated nature of the cliff-lined riparian area (Boggess 2013). As of 2016, 686 of the vascular plant species listed as present at OBRI are native to the area, representing approximately 90% of the total species (NPS 2015).

Total Area of Non-native Plant Species

Remaley and Johnson (1997) described OBRI as having a minimal presence of invasive plant species; only six were located in an area less than 1,000 m^2 (0.25 ac). There was no documentation in the report as to where this area was located within the park. At this time, there are no quantitative data available on the total area of non-native plant species in OBRI, just records of which non-native plants have been documented in the park (Appendix C). However, observations by NPS staff suggest that the total area covered by non-native species is much higher than 1,000 m^2 and has been increasing (Marie Tackett, BISO-OBRI Botanist, and Raskin, written communications, August 2016).

Trends in Element Occurrences

According to TWRA data obtained in early 2016, there are currently 17 EOs for plant species within OBRI (TWRA 2015), excluding cobble bar community species, which will be discussed in Chapter 4.6. The majority of these are for fetterbush (*Lyonia lucida*) (see Table 25). EO ranks for all species ranged from A (excellent viability) to E (verified extant) or H (historical) for older observations, which occurred before viability was ranked (NatureServe 2016). Two EOs were ranked as having excellent or good viability (A, B) and another two EOs were ranked as having fair viability (C) (TWRA 2015). The majority of EOs were ranked as verified extant (E) (TWRA 2015), meaning they are known to exist, but more information needs to be gathered in order to estimate viability (NatureServe 2016). All EOs for native forest species and other plant communities, with rankings and last observation years, are included in Table 25 (with the exception of cobble bars, which are discussed in Chapter 4.6).

Table 25. Element occurrence (EO) information for plant species known to occur in OBRI native forest and plant communities (TWRA 2015), excluding cobble bar community species, which will be discussed in Chapter 4.6.

Scientific Name (Common Name)	Most Recent Observation	EO Rank
Adlumia fungosa (Climbing fumitory)	2014	C
Helenium brevifolium (Shortleaf sneezeweed)	2014	E
Lyonia lucida (Fetterbush)	1969	H
	1977	H
	1977	H
	1979	H
	1980	E
	1981	E
	2000	C
	2000	E
	2000	E
	2000	E
	2000	E
	2000	E

* APHN staff visited this EO and observed this species in September 2014 but did not complete any formal monitoring/documentation (Raskin, written communication, 10 August 2016).

Hemlock Mortality

According to Protect TN Forests (2013), hemlock woolly adelgid (HWA) (*Adelges tsugae*) is the single greatest threat to hemlock populations in the eastern U.S. (Photo 6). HWA was discovered in Tennessee in 2002 and has been spreading ever since (Figure 31). It was first documented at OBRI in 2007, but based on the advanced decline and mortality of some trees at the park, it has likely been present since the early 2000s (Tackett, written communication, 18 August 2016).

Photo 6. Ovisacs of the hemlock woolly adelgid (HWA) are found from the late fall to early summer on the underside of hemlock branches. The white, wool-like wax filaments are created to protect the eggs and the insect from predation and drying out (USFS photo 2005).

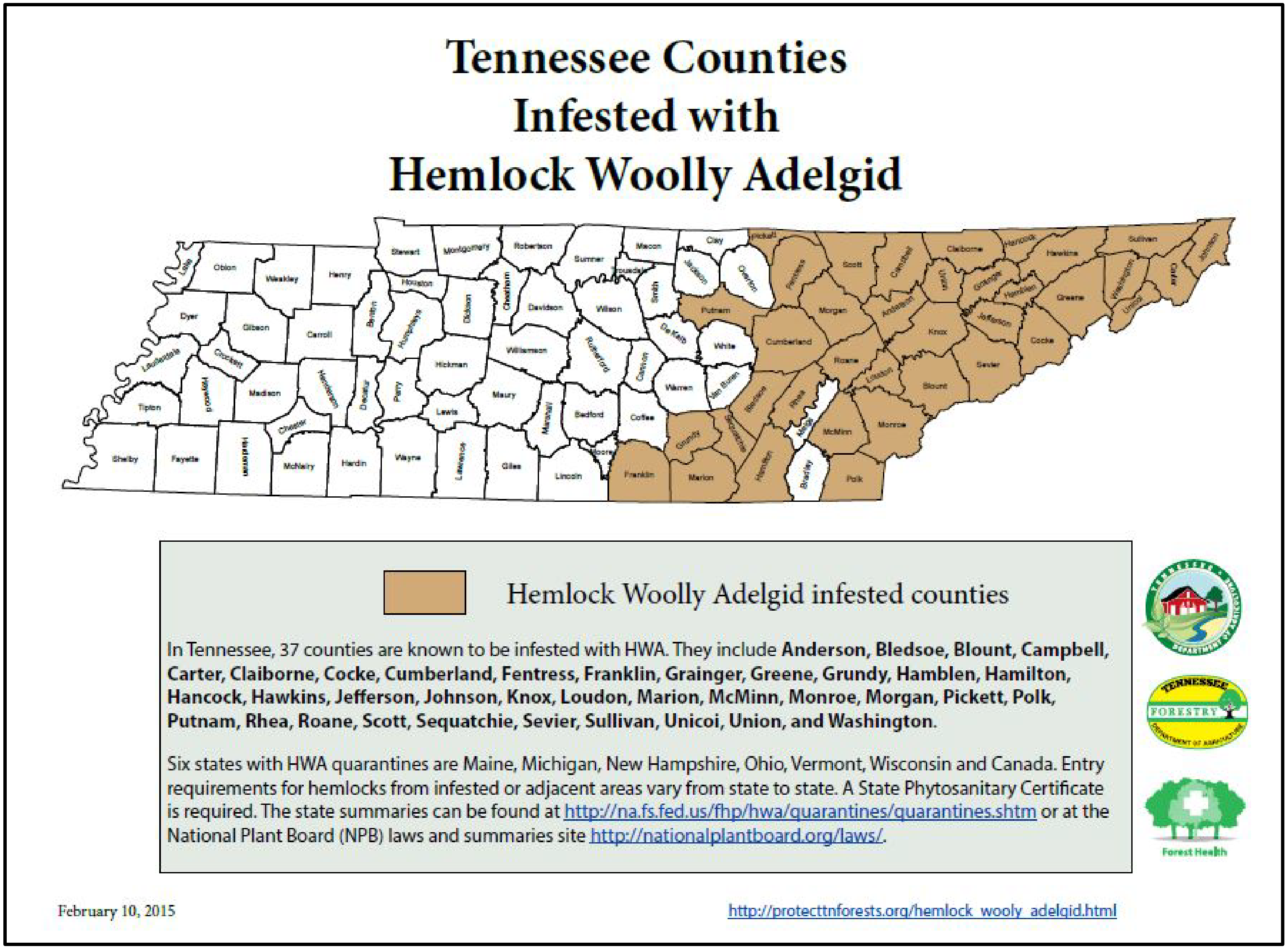

Figure 31. HWA was detected in Tennessee in 2002. By 2015 (when this figure was created), the insect had spread into central Tennessee, including Morgan and Cumberland counties, where OBRI is located (Protect TN Forests 2013).

It is very difficult to perform population surveys of HWA due to the small size of the insect (0.0625 in [1.5 mm]) (Protect TN Forests 2013). Currently, researchers are trying to determine the best possible management methods for controlling HWA outbreaks; the most common method is applying systemic insecticides, other methods include removing isolated infested hemlock trees from wooded areas, introducing natural predators, and applying insecticidal soaps and horticultural oils (Protect TN Forests 2013). Eastern hemlock is widespread in the park, covering 1,156 total ha (2,856.5 ac) (Figure 32). To date, the NPS has treated 13,449 trees on 188.6 ha (466 ac) where hemlock is dominant or co-dominant (Tackett, written communication, 18 August 2016). Staff regularly monitor these stands and other hemlocks in high-use areas (e.g., trailheads); no signs of hemlock decline or mortality have been noted in recent surveys (Tackett, written communication, 18 August 2016).

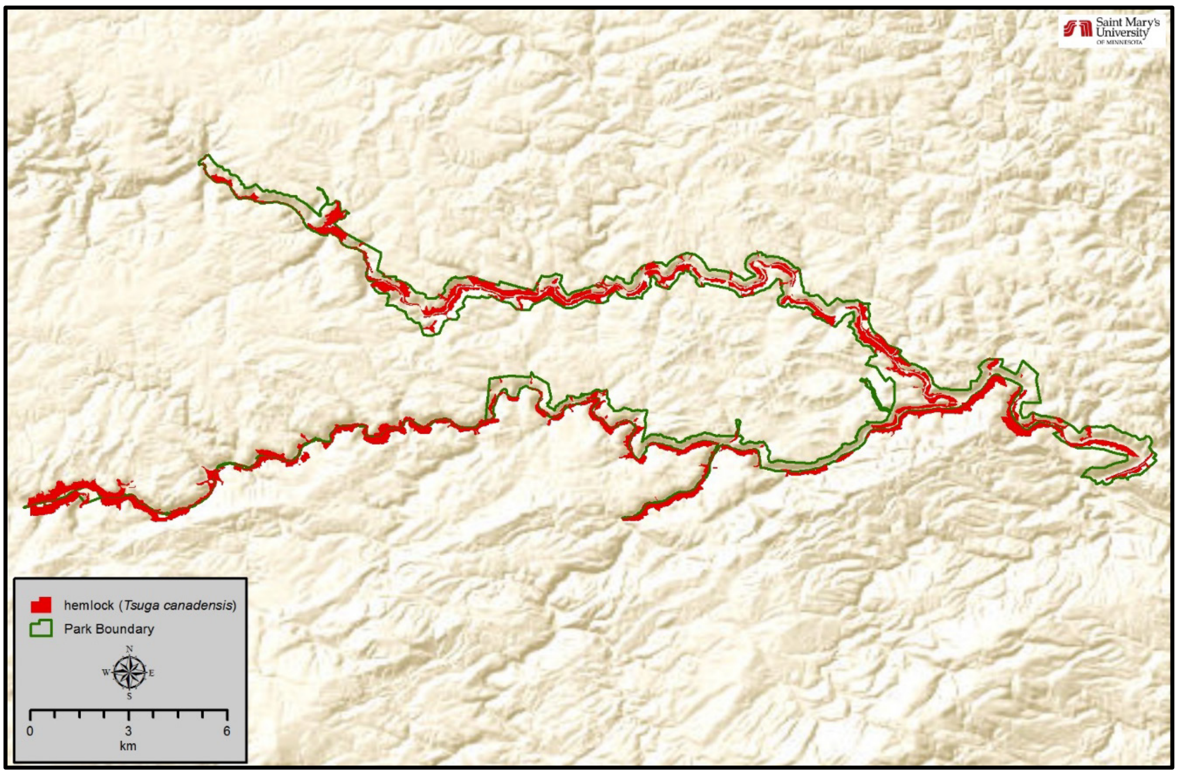

Figure 32. Locations of eastern hemlock trees inside OBRI (NPS 2011a).

Distribution of Emerald Ash Borer

The emerald ash borer (EAB) (*Agrilus planipennis*) was first discovered in the U.S. in Michigan in 2002 and has been spreading ever since (Protect TN Forests 2009). It was discovered in Morgan County, Tennessee in 2014 and Cumberland County, Tennessee in 2015 (Figure 33). EAB has been documented throughout OBRI and is considered to be present park-wide (Tackett, written communication, 18 August 2016).

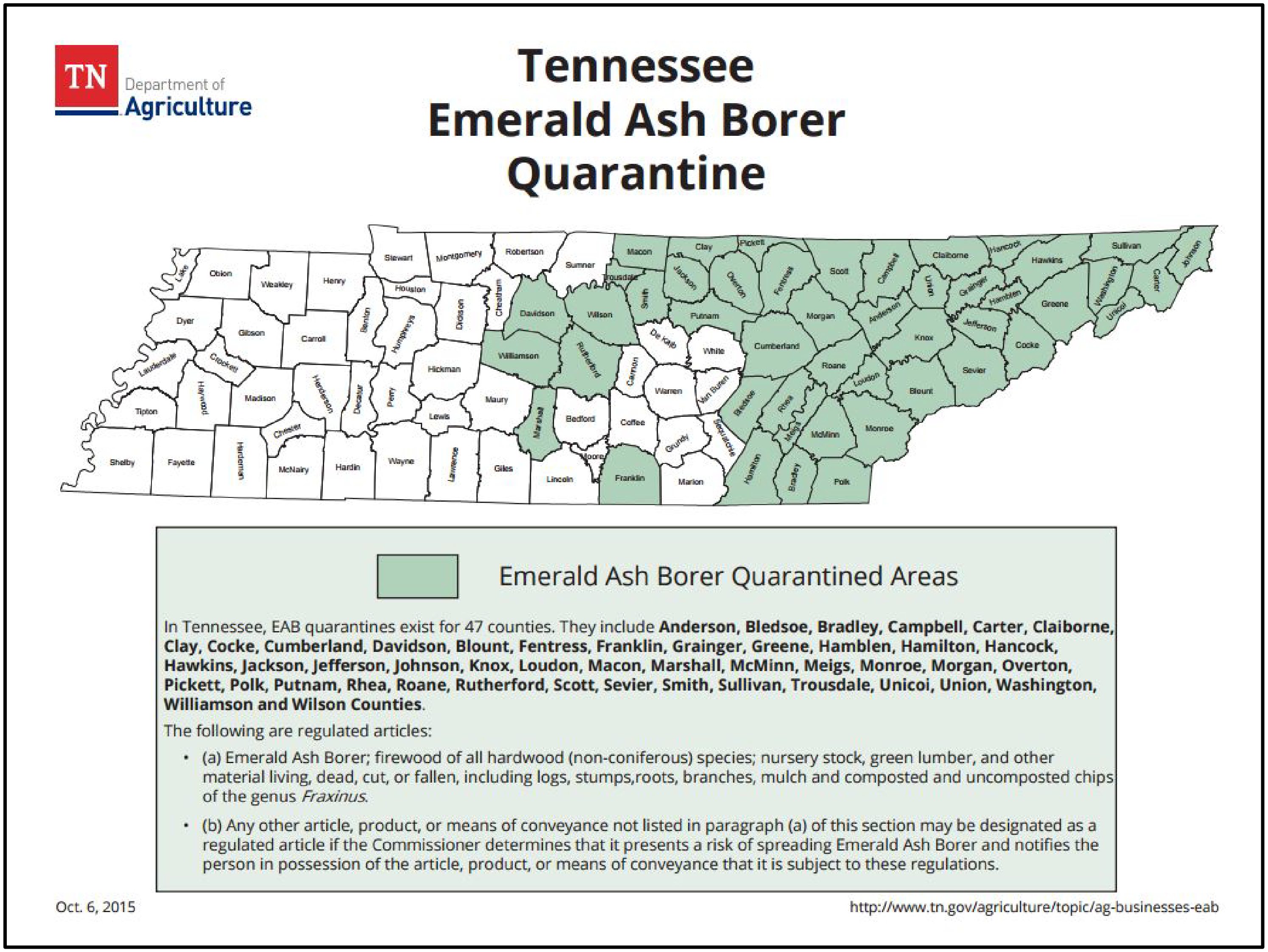

Figure 33. The emerald ash borer (EAB) is found all over eastern Tennessee, including Morgan and Cumberland counties, where OBRI is located (TDA 2016).

The EAB can be easily seen at any stage of life (Photo 7); whether it is the white larvae (2.5–3 cm [1–1.2 in]) forming S-shaped galleries under the bark or the adults with their bronze, golden, or reddish color and metallic green wings during the summer months (Protect TN Forests 2009).

Photo 7. The photo on the left shows the S-shaped galleries made by EAB larvae (TNC 2016), while the photo on the right is of an adult EAB (TNC photo 2016).

EAB is usually found on distressed ash trees, but has been detected on healthy ones as well (EAB IN 2016). EAB infestations are difficult to detect because impacted ash trees usually decline gradually, from the top down (Photo 8, left) (APHIS 2009). Infestations are always fatal, although it may take 1–3 years for trees to die (APHIS 2009).

Photo 8. Left: An ash tree in Tennessee infested with EAB. This infestation kills the upper and outer portions of the tree, then slowly progresses inward (Protect TN Forests 2009). Right: An emerald ash borer trap setup in Big South Fork National River and Recreation Area (BISO). As of 2014, 1,224 of these traps had been placed across the state of Tennessee (Protect TN Forests 2009) (NPS Photo).

EAB infestations are detected and monitored through a multi-state trapping program (Photo 8, right). Research is underway to determine the most effective ways to manage the species, but methods such as pesticide use and ash tree health practices (e.g., watering and pruning the trees), are already being implemented (Protect TN Forests 2009). Native ash trees do occur inside OBRI (NPS 2015), but no data are available at this time on the impact of EAB on OBRI tree populations.

Threats and Stressor Factors

OBRI staff have identified the following threats and stressors to native forests and other plant communities inside the park: climate change, extreme weather events, commercial poaching, visitor impact, fire suppression, non-native plants, and forest insects and disease.

In the mountainous region of the Southern Appalachians, the amount of snow, ice, wind, and rain, along with temperature, tends to change over relatively short distances. These small changes throughout the landscape have created "microclimates" that contribute greatly to the diversity of biotic communities across the Cumberland Plateau (Emmott et al. 2005). For example, precipitation can influence soil and fuel moisture (and, thereby, fire regimes), primary production, stream flow, and pollutant concentration in riverine systems (Emmott et al. 2005). Climate change has the potential to alter these natural processes and microclimates. Because extreme weather patterns are amplified at higher elevations, the OBRI plant communities are at an increased risk (Emmott et al. 2005). Periods of drought can have an especially detrimental effect on forest composition at thin-soiled sites that are prone to extreme drying events. The increased concentration of atmospheric carbon dioxide that is contributing to climate change can affect plant growth through potentially favoring non-natives over native plant species (Emmott et al. 2005).

As the impacts of climate change and related stressors compound over time, forests will experience more widespread changes in tree species composition, with cascading effects on other plants and wildlife (Fisichelli et al. 2014). In an effort to estimate the magnitude of potential change that forests on eastern national park lands may experience, Fisichelli et al. (2014) assessed the percentage of tree species expected to show large decreases or large increases in habitat suitability under climate change scenarios. Across 121 national park properties in the eastern U.S., estimated potential forest change (i.e., percent of tree species expected to experience large increases or decreases in habitat suitability) ranged from 22–77%. The estimate forest change for OBRI was 56% (Fisichelli et al. 2014). Habitat suitability projections for several of OBRI's key forest species are presented in Appendix E.

The atmospheric pollutant O_3 can cause foliar injury to sensitive plants when present at high levels (>80 ppb) (Kohut 2007). Considered phytotoxic, O_3 can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems. Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass; prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). Kohut (2007) states that the OBRI plant communities are at high risk from O_3 pollution (Appendix D).

Over-harvesting of natural resources in Tennessee has become an issue, particularly with medicinal plants like American ginseng (Photo 9) and goldenseal, and box turtles (*Terrapene* spp.) being collected as pets (TN-WAPT 2015). American ginseng is native to the eastern hardwood forests of the U.S. and has been a part of international trade since the beginning of the 18th century (USFWS 2016). The sale and distribution of ginseng has created a multi-million-dollar industry in Tennessee; this has led to the creation of licensing limits to help regulate commercial harvesting. These licensing limits monitor harvest levels to ensure the plant does not become endangered (TDEC 2016). Commercial poaching has been occurring in and around Tennessee's national parks (Emmott et al. 2005) and American ginseng is present at OBRI (NPS 2015), but there are no data available on the prevalence of poaching inside the park (Emmott et al. 2005).

Photo 9. The American ginseng plant is native to the eastern hardwood forests of the U.S. It has been used for medicinal purposes and sold commercially since the 18th century. Commercial poaching of this plant is occurring in and around Tennessee's national parks (Emmott et al. 2005) (USFWS Photo 2016).

Hiking and rock climbing are among the most popular visitor attractions inside OBRI (Begly et al. 2013). Without proper use and management, these activities can negatively affect the surrounding vegetation (Emmott et al. 2005). Cliff ecosystems tend to support rare and endemic plant species, as they often have experienced less historical anthropogenic impact than surrounding areas. Recent developments in rock climbing equipment have allowed climbers to access more remote cliff-side areas. While this has benefitted research efforts in these unique ecosystems, increased rock climbing can have negative effects on the cliff vegetation, through trampling of vegetation and the use of bolts, rope anchors, and other hardware (Walker et al. 2003, Boggess 2013). A dendroecological study completed by Walker et al. (2003) discovered that some of the ancient red cedars (*Thuja occidentalis*) found along the cliffs at OBRI had signs of anthropogenic impact, likely from the rock climbing community.

Although there are some fire-dependent communities within APHN parks (Emmott et al. 2005), water tends to be the driving force behind natural community maintenance at OBRI (NPS 2007). Fires are rare in cliff communities because of the lack of litter accumulation and the patchy nature of vegetation communities found there, which impedes the movement of fire (Walker et al. 2003). At this time, there is no information regarding the impacts of fire suppression inside OBRI, and due to the linear and vertical layout of the park, no prescribed fires have been conducted at OBRI (Emmott et al. 2005).

With the APHN region being known for its rare and endemic vegetation communities, any introductions of invasive species are a severe threat. Areas near APHN parks where invasive vegetation has been prominent are near population centers, ROW, adjacent private land, and along riparian corridors (Emmott et al. 2005). According to NPSpecies (2015), 68 non-native plant species have been documented as present or probably-present inside OBRI. According to Emmott et al. (2005), monitoring for invasive non-native plants is in place to minimize their impact.

Along with the HWA and EAB, there have been a number of tree pests and diseases discovered in both Morgan and Cumberland Counties that potentially pose a threat to OBRI's native plant communities (Table 26).

Table 26. Common invasive tree pests found in Morgan and Cumberland County, Tennessee (USFS 2016).

Scientific Name	Common Name	Morgan County	Cumberland County
Ceratocystis fagacearum	Oak wilt	–	X
Cronartium ribicola	White pine blister rust	X	–
Cryphonectria parasitica	Chestnut blight	X	X
Discula destructiva	Dogwood antharacnose	X	X
Popillia japonica	Japanese beetle	X	X
Sirococcus clavigignenti-juglandacearum	Butternut canker	X	X

Data Needs/Gaps

Both HWA and EAB have been detected in Morgan and Cumberland Counties, but there is no known monitoring program for these invasive pests inside the park at this time. Also, there is no data available regarding harvesting of plants, legal or illegal, inside OBRI. Harvesting of rare species inside the park could occur without park managers' knowledge or awareness (Emmott et al. 2005). Implementing monitoring programs for both of the aforementioned pests and for poaching practices could provide insight into the severity of these threats.

Even though non-native plant species do not seem to be a significant problem for the park (Remaley and Johnson 1997), having information on the distribution and total area covered by these plants could provide insight into how they could affect the surrounding environment through their spread and competition with native vegetation.

Overall Condition

Number of Plant Species

The project team assigned a *Significance Level* of 3 for number of plant species found in the park. The parks found in the APHN are known for their endemic flora diversity (NPS 2007). According to the NPSpecies list (NPS 2015), over 750 vascular plants have been identified as present or probably present at OBRI. As a result, species richness is currently of low concern (*Condition Level* = 1).

Percent Nativity of Plant Species

A *Significance Level* of 3 was assigned by the project team for the percent nativity component. Since the park is composed mainly of riverine and cliff environments, the land has seen relatively little development (Schmalzer 1989). This may have shielded OBRI somewhat from non-native plant invasions. With such a high percent (approximately 90%) of native plant species at OBRI, a *Condition Level* of 1 was assigned, or having low concern.

Total Area of Non-native Plant Species

The *Significance Level* assigned by the project team for the total area of non-native species was a 3. Although Remaley and Johnson (1997) felt that invasive species had minimal presence in the park, there is no current information to confirm that this is still the case. Due to the lack of recent data on non-native coverage inside the park, this measure is considered a data gap, therefore a *Condition Level* cannot be assigned at this time.

Trends in Element Occurrences

The *Significance Level* for trends of element occurrences was also assigned a 3 by the project team. According to recent data from the TWRA (2015), there are 17 EOs of plants known to occur in native forests and other plant communities within OBRI boundaries. Due to the majority of the EOs needing additional information in order to determine a proper EO rank, this measure is considered of moderate concern (*Condition Level = 2*).

Hemlock Mortality

The project team also assigned a *Significance Level* of 3 for hemlock mortality. HWA is found in both Cumberland and Morgan Counties and is considered the greatest threat to hemlock trees in the eastern U.S. (Protect TN Forests 2013). Many trees have been treated for HWA and no hemlock decline or mortality has been detected during recent monitoring. Currently, this measure is of low concern (*Condition Level* = 1), although continued monitoring is needed to quickly detect any potential infestations.

Distribution of Emerald Ash Borer

A *Significance Level* of 2 was assigned for distribution of the EAB by the project team. EAB is also found in both Cumberland and Morgan Counties and has been spreading fairly quickly throughout the eastern United States (Protect TN Forests 2009). EAB tends to infest sick ash trees, but has also been discovered on healthy ash trees ((EAB IN) 2016). With EAB detected in the counties around the park, but no monitoring set up at OBRI, the *Condition Level* for this component was assigned a 2, or of moderate concern.

Weighted Condition Score

The *Weighted Condition Score* for this component is 0.48, indicating moderate concern. The majority of concern is regarding pest infestation (e.g., HWA and EAB) and the lack of monitoring for the presence of these pests inside the park. Also, a more comprehensive analysis of plant EOs and non-native plant species would provide a more in-depth look at the health of the native forest and plant communities of OBRI. Due to the combination of lack of monitoring and data gaps, a trend cannot be assigned, and a medium confidence border is applied.

Native Forests/Other Plant Communities			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.48**
Number of Plant Species	3	1	
Percent Nativity	3	1	
Total Area of Non-native Species	3	N/A	
Trends in Element Occurrences	3	N/A	
Hemlock Mortality	3	2	
Distribution of Emerald Ash Borer	2	2	

4.2.6. Sources of Expertise

- Rebecca Schapansky, OBRI Resource Management Specialist
- Evan Raskin, APHN Assistant Data Manager/Biologist
- Marie Tackett, BISO-OBRI Botanist

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4.3. Mammals

4.3.1. Description

The Appalachian Mountain region of the U.S. supports a unique combination of ecosystems that has tremendous diversity in both habitat types and species. The Southern Appalachians are known to have the most diverse mammal populations in North America (Emmott et al. 2005). Within the boundaries of OBRI, a total of 57 mammal species have been identified; 31 species are listed as present, 19 as probably present, and seven are unconfirmed (NPS 2015a). The park is home to several common mammal species such as the white-tailed deer, Virginia opossum, the common raccoon, and the eastern gray squirrel (*Sciurus carolinensis*) (Photo 10). Additionally, OBRI may also support several rare mammal species, some of which are of conservation concern. Endangered mammal species that may be found at OBRI include three species of bat: the gray myotis (federally- and state-listed), Indiana bat (*Myotis sodalis*; federally- and state-listed), and northern long-eared bat (federally-listed as threatened and state-listed as endangered) (TWRC 2000a). Additional "In Need of Management" species in Tennessee, as defined by TWRC (2000b), that are present or probably present at OBRI include: woodland jumping mouse (*Napaeozapus insignis*), eastern small-footed bat (*Myotis leibii*), eastern big-eared bat (*Corynorhinus rafinesquii*), masked shrew (*Sorex cinereus*), smoky shrew (*S. fumeus*), and southeastern shrew (*S. longirostris*).

Photo 10. An eastern gray squirrel (*Sciurus carolinensis*) foraging at OBRI (NPS Photo).

Hunting and trapping of both big and small game mammal species is allowed during the legal Tennessee hunting seasons at OBRI (Emmott et al. 2005). The primary big game species at OBRI is the white-tailed deer (TWRA 2016a); black bear does occur in the area and can be legally harvested outside of the park (Emmott et al. 2005). There are an additional 15 small game species that can be harvested within OBRI throughout the various hunting/trapping seasons (TWRA 2016c).

4.3.2. Measures

- Species richness
- Annual harvest numbers
- Bear abundance

4.3.3. Reference Conditions/Values

The reference condition for this component was defined as Taylor et al. (1981). Taylor et al. (1981) conducted fieldwork at OBRI from 15 October 1979 to 10 December 1979. Through the use of snap traps, rat traps, and Hav-A-Hart traps, 31 mammal species were documented within park boundaries (Table 27).

Table 27. The mammal species found by the Taylor et al. (1981) study.

Scientific Name	Common Name
Blarina brevicauda	Northern short-tailed shrew
Castor canadensis	American beaver
Didelphis virginiana	Virginia opossum
Glaucomys volans	Southern flying squirrel
Lasiurus borealis	Eastern red bat
Lynx rufus	Bobcat
Marmota monax	Woodchuck
Mephitis mephitis	Striped skunk
Microtus pennsylvanicus	Meadow vole
Mustela frenata	Long-tailed weasel
Neotoma floridana	Eastern woodrat
*Neovison vison**	Mink
Ochrotomys nuttalli	Golden mouse
Odocoileus virginianus	White-tailed deer
Ondatra zibethicus	Muskrat
Oryzomys palustris	Marsh rice rat
Peromyscus gossypinus	Cotton mouse
Peromyscus leucopus	White-footed mouse
Peromyscus maniculatus	Deer mouse
Procyon lotor	Common raccoon

*Became valid in 2005, replacing the name *Mustela vison.*

Table 27 (continued). The mammal species found by the Taylor et al. (1981) study.

Scientific Name	Common Name
Scalopus aquaticus	Eastern mole
Sciurus carolinensis	Eastern gray squirrel
Sciurus niger	Eastern fox squirrel
Sorex cinereus	Masked shrew
Sorex longirostris	Southeastern shrew
Spilogale putorius	Eastern spotted skunk
Sus scrofa	Feral hog
Sylvilagus floridanus	Eastern cottontail rabbit
Tamias striatus	Eastern chipmunk
Urocyon cinereoargenteus	American gray fox
Vulpes vulpes	Red fox

*Became valid in 2005, replacing the name *Mustela vison.*

4.3.4. Data and Methods

NPS (2015a) represents the NPS Certified Mammal Species List for OBRI and contains a list of all mammal species in the park. Occurrence in the park is classified as present, probably present, or unconfirmed.

Taylor et al. (1981) conducted a mammal inventory from 15 October 1979 to 10 December 1979. 401 snap traps, 71 rat traps, and two Hav-A-Hart traps were set throughout the park. Along with setting traps, Taylor et al. (1981) contacted TWRA personnel and local trappers to gather information on sightings of mammals.

In 2000, the TWRA performed a GAP analysis for the state of Tennessee (TWRA 2006a). A vertebrate range distribution and habitat association's database was created which articulated the type of vegetation/habitat best suited particular vertebrate species. Extinct or extirpated species were excluded from the analysis. From there, a predicted species distribution map was assembled and compared to a vegetation map to determine suitable habitats. This produced as a 100 m (32.8 ft) raster (grid) spatial dataset. The vertebrate distribution grid was then broken down into the following species categories: bird, mammal, reptile, amphibian, and Neotropical migrant (TWRA 2006a). Seventy-five mammal species were initially included in this analysis; the 46 species with the highest richness were selected for a more detailed assessment.

The TWRA online hunter's toolbox (TWRA 2016b) provides yearly harvest statistics for white-tailed deer. For this assessment, annual harvest reports from the nearby CWMA were used. Although harvest is likely higher in the CWMA than in the park, numbers from this area provide the best available information, as harvest reports are not available specifically for OBRI. These annual reports summarize total harvest, antlered harvest, doe harvest, button harvest, and antlerless buck harvest from 2006–2015 (TWRA 2016b).

4.3.5. Current Condition and Trend

Species Richness

The NPS Certified Mammal Species List (NPS 2015a) for OBRI identifies 57 species. When excluding species that have not been confirmed in the park, the total number of mammal species at OBRI drops to 50 species (Appendix F). This list, however, does not allow for a specific analysis of species richness over time, as no data are collected yearly, and the list only documents the presence (or historic presence) of identified species.

Taylor et al. (1981) discovered 31 mammal species inside OBRI (Table 27). At the time of this study, mammal species were documented that had not been found in previous surveys of the area (Taylor et al. 1981). For example, evidence of American beaver (*Castor canadensis*) has been found inside the park boundary, likely due to re-introduction efforts in the CWMA during the mid-1950s (Taylor et al. 1981).

In the 2000 GAP analysis performed by the TWRA, it was predicted that 75 mammal species have suitable vegetation habitats somewhere within the state of Tennessee. Of the 46 species with the highest accounts of species richness in the state, 31 were predicted to occur inside OBRI. Although this data does not identify the type of mammal species, it demonstrates that OBRI potentially supports a fairly large number of mammal species within its boundaries. Figure 34 depicts how this predicted species richness is distributed throughout the park.

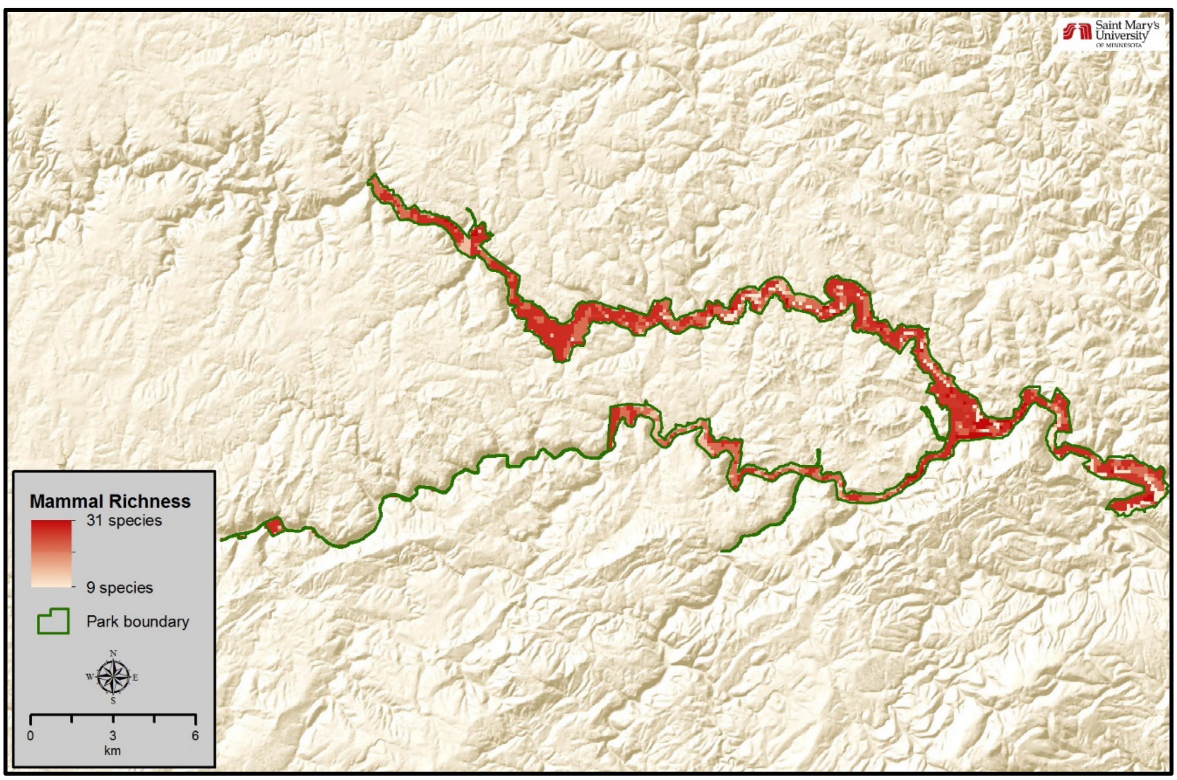

Figure 34. Mammal richness at OBRI according to the 2000 GAP analysis performed by the TWRA. Each value displayed represents the predicted total number of mammal species in that particular area considered for this detailed assessment were predicted to occur inside park boundaries (TWRA 2006a).

Annual Harvest Numbers

According to the TWRA (2000), small game mammals that can be hunted or trapped throughout the state of Tennessee include: the long-nosed armadillo (*Dasypus novemcinctus*), American beaver, bobcat (*Lynx rufus*), coyote (*Canis latrans*), eastern fox squirrel (*Sciurus niger*), eastern gray squirrel, gray fox (*Urocyon cinereoargenteus*), mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), Virginia opossum, raccoon, red fox (*Vulpes vulpes*), river otter (*Lontra canadensis*), eastern spotted skunk (*Spilogale putorius*), striped skunk (*Mephitis mephitis*), and long-tailed weasel (*Mustela frenata*). Hunting and trapping seasons vary between species Table 28; includes both the hunting and trapping season by species, along with the daily limit for small mammal species found at OBRI. Despite the rules and limitations on small game hunting in Tennessee, the TWRA does not maintain harvest statistics for small game mammals the same way they do for large game mammals (TWRA 2016b).

Table 28. Small-mammals that can legally be hunted and/or trapped in Tennessee. All of the mammals listed can be found inside OBRI. Dates are for the 2016/17 hunting/trapping season (TWRA 2016c).

Scientific Name	Common Name	Hunting Season	Daily Limit	Trapping Season	Daily Limit
Castor canadensis	American beaver	year-round	no limit	year-round	no limit
Dasypus novemcinctus	Long-nosed armadillo	year-round	no limit	–	–
Lynx rufus	Bobcat	18 Nov-28 Feb	1	–	–
Procyon lotor	Common raccoon	16 Sep-28 Feb	2	18 Nov-28 Feb	no limit
Canis latrans	Coyote	year-round	no limit	year-round	no limit
Sciurus niger	Eastern fox squirrel	27 Aug-28 Feb	10	–	–
Sciurus carolinensis	Eastern gray squirrel	27 Aug-28 Feb	10	–	–
Spilogale putorius	Eastern spotted skunk	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Urocyon cinereoargenteus	Gray fox	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Mustela frenata	Long-tailed weasel	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Neovison vison	Mink	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Ondatra zibethicus	Muskrat	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Vulpes vulpes	Red fox	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Lontra canadensis	River otter	18 Nov-28 Feb	no limit	18 Nov-28 Feb	no limit
Mephitis mephitis	Striped skunk	year-round	no limit	18 Nov-28 Feb	no limit
Didelphis virginiana	Virginia opossum	16 Sep-28 Feb	no limit	18 Nov-28 Feb	no limit

In terms of large game mammals, the TWRA (2016a) allows a bag limit of two per season for antlered bucks but no more than one antlered deer per day throughout the State of Tennessee. Designated days have been established for antlerless deer hunts (also known as "doe days"), and special permits are required (TWRA 2016a). See Table 29 for deer season types, season dates, and bag limits across the state.

Table 29. White-tailed deer hunting rules and regulations for the State of Tennessee vary depending on multiple factors. Dates are for the 2016/17 hunting season (TWRA 2016a).

County (State Unit)	Season type	Season date	Antlerless bag limit	Antlered bag limit
Cumberland (Unit A)	Archery (includes crossbows)	24 Sept 28 Oct 2016	4	2
	Archery (includes crossbows)	31 Oct-4 Nov 2016	4	2
	Muzzleloader and archery	5 Nov-18 Nov 2016	2	2
	Gun, muzzleloader, and archery	19 Nov 2016-8 Jan 2017	2	2
	Young sportsman	29–30 Oct 2016	2	2
	Young sportsman	14 Jan-15 Jan, 2017	2	2
Morgan (Unit B)	Archery (includes crossbows)	24 Sept-28 Oct, 2016	4	2
	Archery (includes crossbow	31 Oct-4 Nov 2016	4	2
Morgan (Unit B) (continued)	Muzzleloader and archery	5 Nov-18 Nov 2016	2	2
	Gun, muzzleloader, and archery	19 Nov 2016-8 Jan, 2017	2	2
	Young sportsman	29–30 Oct 2016	2	2
	Young sportsman	14 Jan-15 Jan, 2017	2	2

Rules for hunting deer inside the CWMA vary from the state rules and regulations (Table 30). The entire area of the CWMA is open to hunting, but bag limits are lower and the seasons are shorter.

Table 30. General rules and regulations for hunting white-tailed deer inside the CWMA. Hunting regulations inside Tennessee wildlife management areas vary from areas outside wildlife management areas. Dates are for the 2016/17 hunting season (TWRA 2016).

Season type	Season date	Antlered bag limit
Archery	8 Oct-16 Oct	1
Muzzleloader	17 Nov-20 Nov	1
Gun	10 Nov-13 Nov & 1 Dec-4 Dec	1
Young sportsman (gun)	29 Oct-30 Oct	1

Annual white-tailed deer harvest in the CWMA over the last 10 hunting seasons has averaged approximately 324 deer/year (Figure 35) (TWRA 2016b). Peak deer harvest occurred during the 2006/07 hunting season (469 deer) while the lowest reported harvest occurred during the 2014/15 hunting season (223 deer). When compared with other deer harvest numbers in the over 100 other wildlife management areas (WMAs) managed by the TWRA, the CWMA has produced consistently high deer harvests. The CWMA had the fourth- highest total harvest estimate (3,235 deer) and average yearly harvest (324 deer/year) in the state from 2006–2016 (TWRA 2016b).

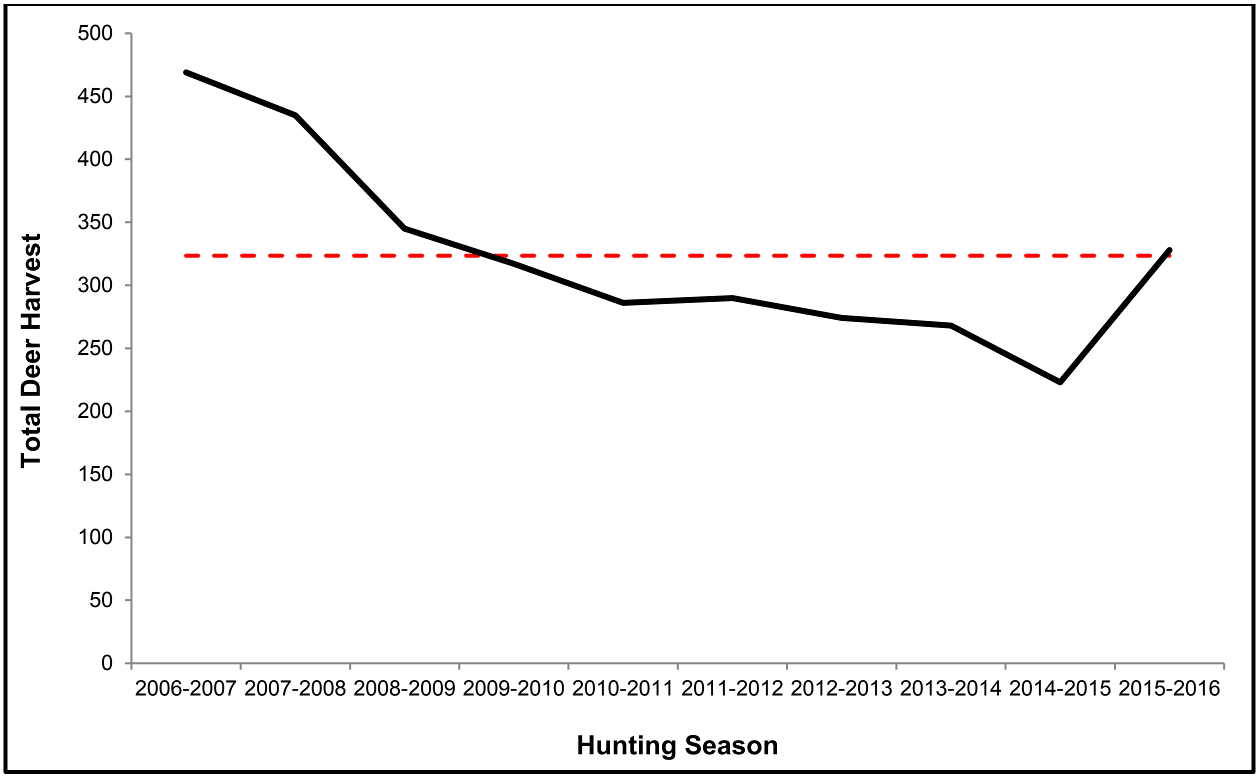

Figure 35. Annual white-tailed deer harvest in the CWMA from the 2006/07 hunting season through the 2015/16 hunting season (TWRA 2016b). The dashed line indicates the 10-season harvest average of 324 deer/year.

Bear Abundance

There are currently no data on the abundance of black bears at OBRI. According to the International Union for Conservation of Nature and Natural Resources (IUCN), the black bear is of least concern on a global scale; in fact, the species' population has been growing in 60% of U.S. states and Canadian provinces (IUCN 2008). Threats to black bear populations are rare but do occur in a few isolated places (i.e., poaching, human-bear conflicts, and increased land development) inlcuding on the Cumberland Plateau (Emmott et al. 2005, IUCN 2008). Black bears have been sighted recently within OBRI (Chris Simpson, TWRA Wildlife Diversity Coordinator, Region 3, phone conversation, 8 March 2016). Reintroduction programs are taking place in isolated pockets of low population, including Big South Fork National River and Recreation Area (BISO), which is located approximately 80 km (50 mi) north of OBRI. Currently, there is no monitoring of bear populations or plans for reintroduction at OBRI (Emmott et al. 2005).

Threats and Stressor Factors

OBRI staff have identified the following threats and stressors to mammal populations inside the park: loss of habitat, white-nose syndrome (WNS), poaching (i.e., illegal harvest), and invasive/exotic species.

For APHN parks, land use changes are the largest driving force behind habitat loss (Emmott et al. 2005). How habitats are arranged can have a major influence on the overall habitat quality for mammal species found at OBRI (Emmott and Murdock 2008). As habitat becomes more fragmented, migration patterns are altered, invasive species can become more prevalent, and the potential for edge effects (e.g., disturbances/threats more likely on habitat borders than in core areas) increases (Fahrig 2003, Emmott and Murdock 2008).

The TWRA determined priority habitat rankings for terrestrial animals at OBRI (Figure 36). Areas were assigned to one of nine ranking levels, ranging from none (for developed space or open water) to very high (Jeanette Jones, TWRA GIS Manager, written communication, 04 April, 2016). Even though this displays habitats for all terrestrial animals inside the park and not mammals specifically, it can provide insight for park management on which areas to prioritize. Table 31 shows the acreage associated with each rank with the majority of the land in the park falling into the high (2,231.1 ha [5,513.2 ac]) and moderately medium (2,175.1 ha [5,374.8 ac]) priority rank (TWRA 2006b).

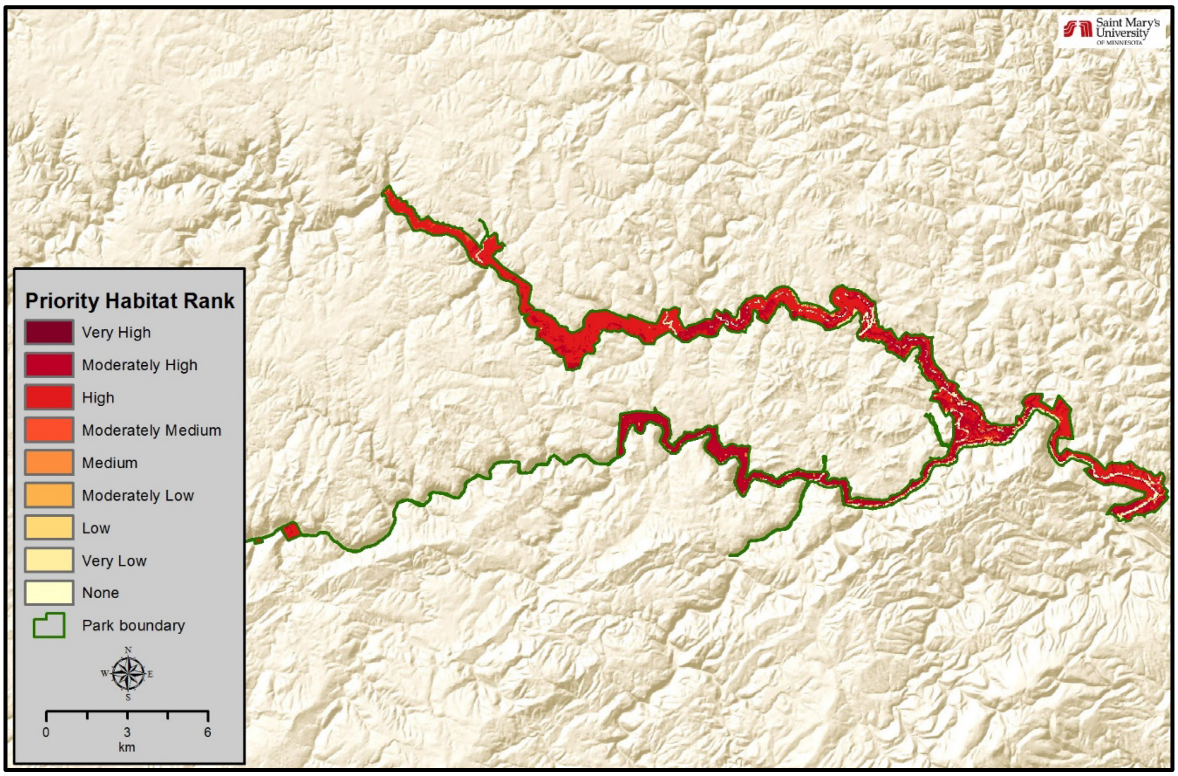

Figure 36. Priority habitats determined by the TWRA for terrestrial animals at OBRI; areas are divided into nine ranking levels (TWRA 2006b).

Table 31. Area coverage by priority habitat rankings for terrestrial animals at OBRI, according to the TWRA (2006b). The majority of land falls into the high and moderately medium priority ranks.

Priority habitat rank	Area in hectares (ac)
Very High	1,929.6 (4,768.1)
Moderately High	2,023.9 (5,001.2)
High	2,231.1 (5,513.2)
Moderately Medium	2,175.1 (5,374.8)

Table 31 (continued). Area coverage by priority habitat rankings for terrestrial animals at OBRI, according to the TWRA (2006b). The majority of land falls into the high and moderately medium priority ranks.

Priority habitat rank	Area in hectares (ac)
Medium	957.4 (2,365.8)
Moderately Low	1,442.8 (3,565.2)
Low	733.8 (1,813.2)
Very Low	1,895.3 (4,683.4)
None	2,157.2 (5,330.6)

The recent appearance (discovered in 2007 in upstate New York) and fast spread of WNS in North America poses a serious threat to the bats in the park (Castle and Cryan 2010). WNS is presumed to be caused by the fungus *Pseudogymnoascus destuctans*, resulting in a skin infection (Castle and Cryan 2010). The fungus was first detected in Tennessee in 2009 and has been spreading ever since (Worsham et al. 2013). WNS causes bats to arouse from hibernation more frequently or for longer periods than usual, depleting their body fat prematurely and causing them to starve (Foley et al. 2011). The disease was detected in Cumberland County in 2012 (USFWS 2016), but has not yet been documented in the park.

Poaching has become an issue in Tennessee, most notably with medicinal plants like ginseng and goldenseal, and box turtles being collected as pets (TN-WAPT 2015). Deer are also known to be targeted. This has been occurring in parks around OBRI, but there is no information available specific to poaching inside the park (Emmott et al. 2005).

Six mammal species on the OBRI certified species list are considered non-native; of these, five are probably present and one is unconfirmed (NPS 2015a). These non-native species are the feral hog (*Sus scrofa*), domestic dogs (*Canis familiaris*) and cats (*Felis catus*), fisher (*Martes pennanti*), house mouse (*Mus musculus*) and the unconfirmed species, the Norway rat (*Rattus norvegicus*) (NPS 2015a). Feral hogs, also known as wild pigs or wild hogs, are found inside the OBRI area (Simpson, phone communication, 8 March 2016) and are known to disrupt native communities through rooting for food and natural predation (TN-WAPT 2015). Currently, the TWRA has an eradication program in place to help control the hog population; this is done through trapping (TN-WAPT 2015). Within park boundaries, OBRI allows a designated hunting season for feral hogs to licensed hunters (NPS 2015b). As of 2005, OBRI does not have a plan in place for comprehensive monitoring of exotic mammals (Emmott et al. 2005).

<u>Data Needs/Gaps</u>

Hunting and trapping are allowed inside park boundaries (NPS 2015b), but there is currently no monitoring in place to keep track of legal harvesting of mammals. This may become an issue, given that poaching is a concern in the area. Harvesting of rare species could occur inside the park without the knowledge or awareness of park resource managers (Emmott et al. 2005). Implementing an up-to-date mammal inventory and a monitoring system inside park boundaries could bring awareness to this potential issue.

Black bears have been sighted inside the park (Simpson, phone conversation, 8 March, 2016), but there is no monitoring in place to determine the extent of the bear population. Even though bears are fairly prevalent throughout the nation (IUCN 2008), the Cumberland Plateau is an area where populations have shown a decrease (Emmott et al. 2005). Once a bear survey is completed, the park could determine whether or not a reintroduction program is needed.

Overall Condition

Species Richness

The project team assigned a *Significance Level* of 3 for species richness. Known mammal species richness, based on the NPSpecies List (NPS 2015a), has more than doubled since the time of the Taylor et al. (1981) study. Although it is not clear if this represents an actual increase in species richness or is simply the result of continued survey efforts, this measure is currently of low concern (*Condition Level* = 1).

Annual Harvest Numbers

A *Significance Level* of 2 was assigned for annual harvest numbers by the project team. Small and large game mammal hunting is legal throughout the State of Tennessee, including wildlife management areas such as the CWMA adjacent to OBRI. However, the TWRA does not maintain harvest statistics for small game mammals the same way they do for large game mammals. Harvest reports for large game mammals articulate that the CWMA has consistently reported one of the highest deer-harvest numbers of all wildlife management areas in the state (TWRA 2016b). Annual harvest reports from the nearby CWMA were used for this analysis since harvest reports were not available specifically for OBRI. With a lack of park-specific data on mammal harvest and no statistics on small mammal harvest in the region, a *Condition Level* cannot be assigned at this time.

Bear Abundance

The *Significance Level* for bear abundance was assigned a 2 by the project team. The black bear is a fairly prevalent species throughout the U.S. (IUCN 2008), except for a few pockets in the Cumberland Plateau where the species has been declining (Emmott et al. 2005). Black bears have been spotted in the park (Simpson, phone conversation, 8 March 2016), but again, due to the lack of monitoring inside park boundaries, a *Condition Level* cannot be assigned at this time.

Weighted Condition Score

Due to a lack of park-specific monitoring and recent data for two of the three measures, a *Weighted Condition Score* could not be calculated at this time. Due the majority of the components being data gaps, the current condition and any trends for mammals at OBRI are unknown at this time.

Mammals			
Measures	Significance Level	Condition Level	WCS = N/A
Species Richness	3	1	
Annual Harvest Numbers	2	N/A	
Bear Abundance	2	N/A	

4.3.6. Sources of Expertise

- Chris Simpson, TWRA Wildlife Diversity Coordinator, Region 3
- Jeanette Jones, TWRA GIS Manager
- Rebecca Schapansky, OBRI Resource Management Specialist

4.3.7. Literature Cited

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4.4. Birds

4.4.1. Description

Bird populations often act as excellent indicators of an ecosystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are typically highly visible components of ecosystems, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010; Photo 11). OBRI has a variety of critical habitat types, and was designated as an important bird area (IBA) in 2006 by the State of Tennessee and the North American Audubon Society (TOS 2006). Of particular importance to birds are the narrow, forested gorges and bluffs of the Obed River and Clear and Daddy's Creeks. These areas provide critical nesting habitat to a large number of Neotropical migrants, as well as rare and management priority species such as the cerulean warbler, Swainson's warbler, and the northern saw-whet owl (*Aegolius acadicus*).

Photo 11. Two barred owl (*Strix varia*) chicks in OBRI (NPS photo).

In total, OBRI has more than 150 species of birds that are either present in the park or are listed as probably present (NPS 2015). OBRI is located near an important migratory crossover location for the Atlantic flyway, as species cross over to the Atlantic coast from the Mississippi flyway (Figure 37).

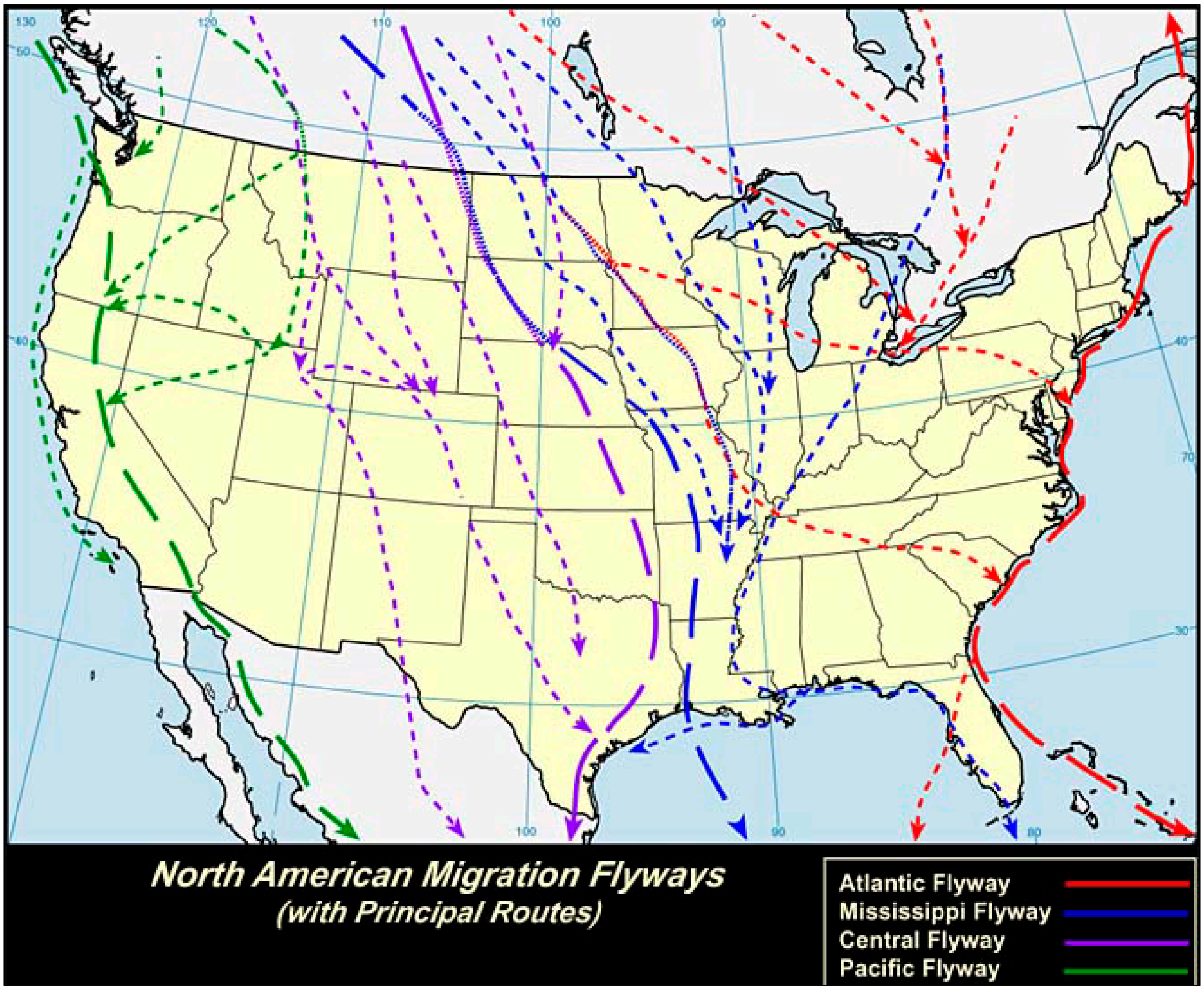

Figure 37. Major North American migratory flyways. OBRI is located near a crossover site for species utilizing the Atlantic Flyway as they transition from the Mississippi River corridor to the Atlantic coast (NPS 2016).

Long-distance migratory species are highly informative indicator species, as their overall health depends on several different ecosystems. Global Christmas Bird Count (CBC) data indicate significant declines in migratory bird numbers in recent years (Peterjohn and Sauer 1999, Vickery and Herkert 2001). Nearctic-Neotropic migrants, hereafter Neotropical migrants, are bird species that breed in the temperate latitudes of the U.S. and Canada, but migrate to the tropical latitudes of Central and South America in the winter months (Figure 38) (TPWD 2015). OBRI is home to a high diversity of Neotropical migrants, as the species heavily utilize the park's undisturbed forested and canyon habitats (Stedman and Stedman 2007b).

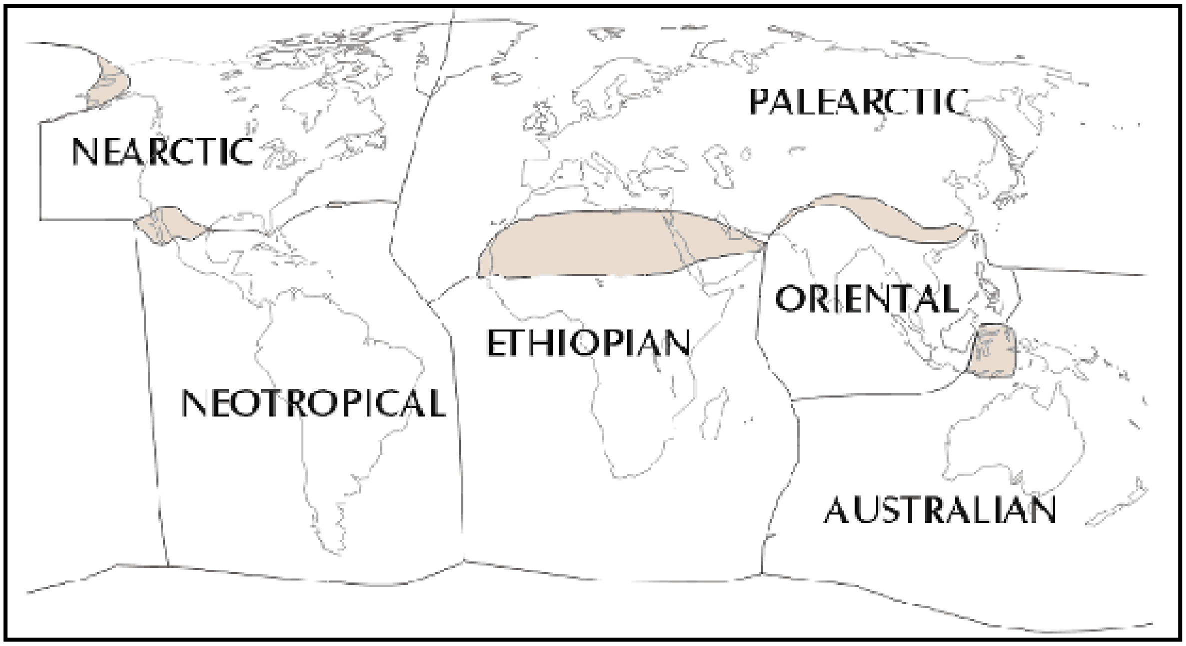

Figure 38. Zoogeographic regions of the world; shaded areas represent transition areas between regions (TPWD 2015).

OBRI represents an area of tremendous ornithological importance in the eastern U.S., particularly due to the unusually large assemblage of Neotropical migrants that are found in the park. Additionally, over 80% of the river miles in OBRI fall within the rhododendron/hemlock habitat (TOS 2006), a habitat type that is vitally important to many avian species of conservation concern; this habitat type in the park supports one of the largest concentrations of Swainson's warblers in Tennessee (TOS 2006). The forested river gorges and bluffs of OBRI represents a globally declining habitat type and contain important stop over and nesting habitat for several at-risk avian species, many of which are Neotropical migrants. Table 32 lists all of the bird species of conservation concern that have been documented in OBRI. A species was included on this table if it was identified as either endangered, threatened, or deemed in need of management by the State of Tennessee, if it was defined as a regional high priority species by Watson (2005), or if it received a Partners in Flight (PIF)-based conservation rank of 4 (Nuttle et al. 2003).

Table 32. Bird species of conservation concern that have been documented in OBRI. Conservation lists included: federal- and state-listed species, species identified by total PIF scores as regional high-priority breeders for the physiographic region (Watson 2005), and species receiving a PIF-based conservation rank of 4 (Nuttle et al. 2003). E = endangered; T = Threatened; MC = management concern; – = not applicable (Table modified from Table 51 of Worsham et al. 2013).

Priority Species	Federal- (State) Listing	Regional High Priority	PIF4
Acadian flycatcher	–	X	–
Bachman's sparrow	–	X	–
Bald eagle	MC (–)	–	–
Barn owl	MC (MC)	–	–
Bewick's wren	–	X	–
Black-throated blue warbler	–	X	–
Blue-winged warbler	–	–	X
Cerulean warbler	MC (MC)	X	–
Eastern wood-pewee	–	X	–
Golden-winged warbler	MC (–)	X	–
Henslow's sparrow	–	X	–
Hooded warbler	–	X	–
Kentucky warbler	–	X	–
Louisiana waterthrush	–	X	–
Northern bobwhite	–	–	X
Northern harrier	MC (MC)	–	–
Northern rough-winged swallow	–	–	X
Northern saw-whet owl	T (T)	–	–
Peregrine falcon	– (E)	–	–
Prairie warbler	–	X	–
Red-headed woodpecker	–	–	X
Ruffed grouse	–	–	X
Sharp-shinned hawk	MC (MC)	–	–
Summer tanager	–	X	–
Swainson's warbler	MC (–)	X	–
Wood thrush	–	X	–
Worm-eating warbler	–	X	–
Yellow-bellied sapsucker	MC (–)	–	–
Yellow-throated vireo	X	–	–

4.4.2. Measures

- Species richness
- Trends in Neotropical migrants

- Annual turkey harvest statistics

4.4.3. Reference Conditions/Values

Despite several sources of data existing for this component, a reference condition was not assigned. Comparisons between the many data sources summarized in this document are problematic for a variety of reasons. The data that were collected as part as the long-running CBC were collected exclusively by volunteers of differing identification skills, the exact locations were not recorded, and Neotropical migrants (which are of high importance to OBRI managers) are not sampled due to timing of the count. The surveys of (Stedman and Stedman 2005, 2007b) are excellent point counts with regimented methodologies. However, the authors do not advise comparison between point count efforts due to differing sample locations between studies, and due to the fact that the total number of point counts were not consistent between efforts.

For this assessment, the best professional judgment of identified experts and NPS staff was used to assess condition. Future assessments of condition may be able to utilize this summary as a baseline for comparison.

4.4.4. Data and Methods

The NPS Certified Bird Species List (NPS 2015) for OBRI was used for this assessment; this list represents all of the confirmed bird species present in the park. For this assessment, birds were considered to be a Neotropical migrant if they were defined as such under the Neotropical Migratory Bird Conservation Act. The full list of these species is available from: http://www.fws.gov/birdhabitat/Grants/NMBCA/BirdList.shtm.

Much of the avifaunal research in the OBRI region has been the product of Dr. Stephen Stedman and his wife Barbara. Much of these data are available from Dr. Stedman's website (UCO 2015) or from their many avian publications in the area (e.g., Stedman and Stedman 2005). From 1998–2003, the Stedmans established and surveyed 50 point count locations in OBRI. Each point count location was surveyed during the breeding season for 5 minutes, and all species observed or heard were recorded (Stedman and Stedman 2005). The timing of these breeding surveys coincided with the southern pine beetle (*Dendroctonus frontalis*) outbreak in the area, and helped to provide some insight into potential effects that this infestation may have had on the avifauna of the area.

In an effort to inventory the avifauna of OBRI, Stedman and Stedman (2007b) surveyed the park from 2003–2005, and utilized five different survey methodologies in an effort to identify as many bird species as possible within the park. The most regimented survey methodology utilized during Stedman and Stedman (2007b) was the point count technique. Thirty point counts (Figure 39) were established in the park and were surveyed once a year in June of 2004 and 2005. About half of the point counts selected in 2004 and 2005 overlapped with sites surveyed during previous point counts conducted by the Stedmans. Observers stood at the point for 10 minutes and identified all birds heard and seen within a 100 m (328 ft) diameter area; flyover species were also included in observation records. Observers recorded the species observed, the distance interval of each observation (<25 m [82 ft], 50–100 m [164–328 ft], and >100 m [328 ft]), and the temporal interval that the bird(s) were observed (0–3 min, 3–5 min, 5–10 min).

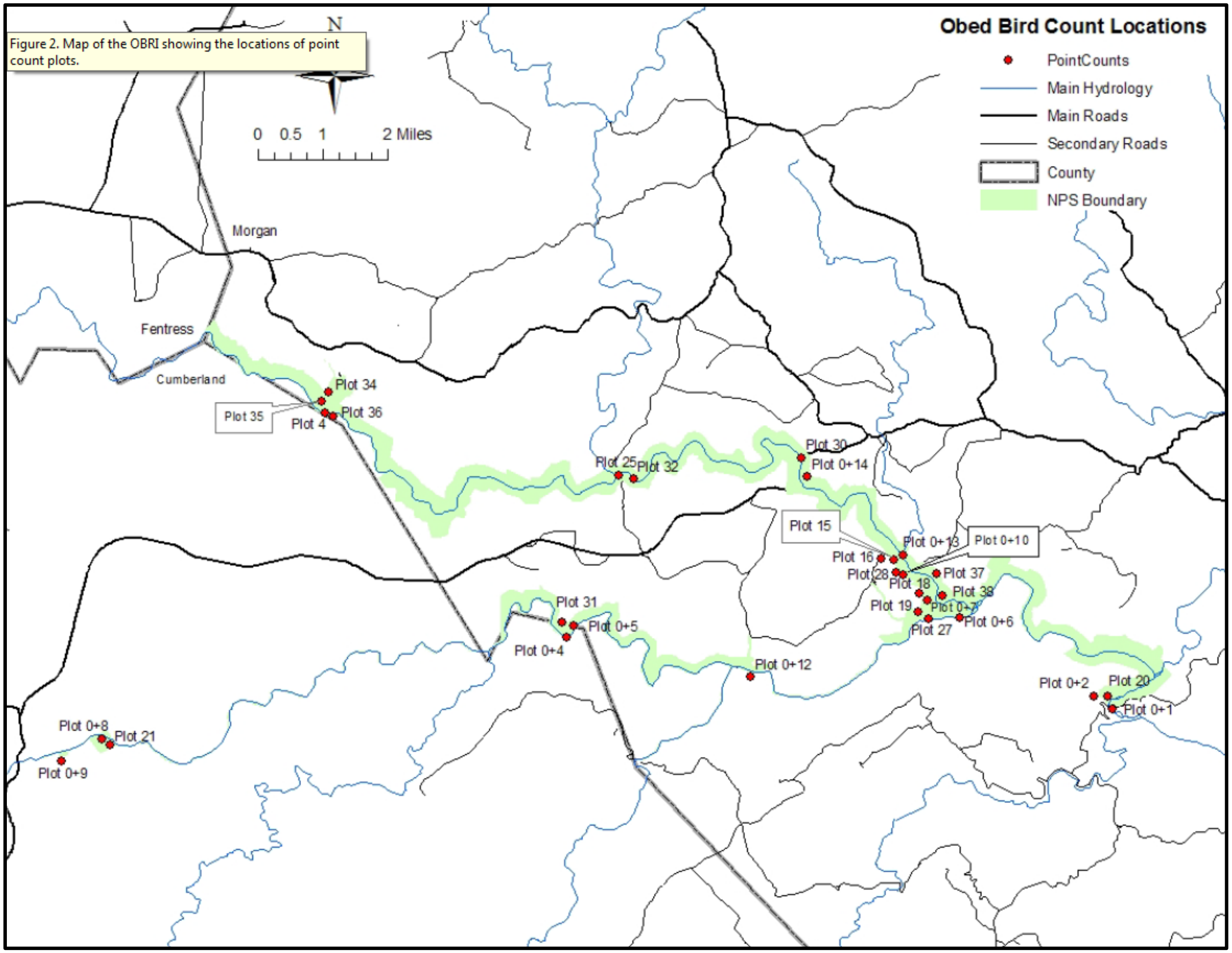

Figure 39. Map of OBRI showing the point count plot locations surveyed by Stedman and Stedman (2007b) from 2004–2005 (Reproduced from Stedman and Stedman 2007b). It should be noted that the NPS boundary depicted in this figure is no longer accurate, as it depicts the boundary in 2004–2005.

The second survey methodology used by Stedman and Stedman (2007b) was a migration walk. Observers took three or four walks in both the spring and fall seasons of 2003–2005. These walks lasted between 1 and 2 hours and generally went for 1.5 km (1 mi). The purpose of the migration walk was to traverse habitats that may be suitable for migrant bird species; all species seen or heard during these walks were recorded.

Stedman and Stedman (2007b) also conducted raptor-specific surveys in OBRI. These surveys generally lasted 2–4 hours, and were completed during the late mornings in the fall and early winter. Raptor surveys were conducted by a stationary observer at Lilly Bluff, rather than via an automobile, due to the lack of many roads in the park. Lilly Bluff offered good visibility for a large area, and provided a good vantage point when raptor flight was expected. All raptor species that were seen or heard were documented by observers.

The fourth survey type utilized by Stedman and Stedman (2007b) was a nighttime survey. These surveys were mostly informal, and were useful in identifying owl and nightjar species. Tape-recorded owl calls were used in an attempt to elicit a response from owls at each site. All species that were heard or seen were recorded.

The final survey type used by Stedman and Stedman (2007b) was a general inventory of the park. This inventory involved relatively informal visits to habitat sites in the park that were suspected to support bird species. These searches also documented all suspected breeding species, and documented species that were confirmed as breeding, probable as breeding, or possible as breeding. Additional searches using canoe surveys were made on all rivers and large creeks in the park. Stedman and Stedman (2007b) also waded and swam in areas of Clear Creek above Barnett Bridge during low flow periods in July in order to observe additional bird species.

Watson (2005) prepared an avian conservation implementation plan for OBRI, which documented and discussed avian-related management options in the park. In addition to a detailed discussion regarding management options and directions, Watson (2005) also identified species of conservation concern for the park using PIF conservation scores. PIF is a multi-agency bird conservation program that assigns bird species scores based on the severity of threats each species faces throughout its life history and geographic range. Watson (2005) provided additional lists that documented high priority species assemblages that could be expected to occur in the OBRI region and the greater Cumberland Plateau area.

Breeding bird survey routes are part of the large-scale North American Breeding Bird Survey (BBS), which began in 1966 and is coordinated by the USGS and the Canadian Wildlife Service (Robbins et al. 1989). The standard BBS route is approximately 40 km (25 mi) long with survey points every 0.8 km (0.5 mi). The survey begins ½ hour before sunrise, and at each survey point the number of birds seen and heard within a 0.4 km (0.25 mi) radius during a three-minute interval is recorded. While not part of the global BBS effort, Stedman (2010) completed yearly BBS efforts in BISO. These efforts were modelled after the international BBS initiative and sampled the BISO area in May or June from 1997–2006. Observers drove along four established routes (Figure 40) and stopped at one of 100 specific intervals to count all birds seen and heard within an unlimited radius of the point count location; counts lasted for five minutes.

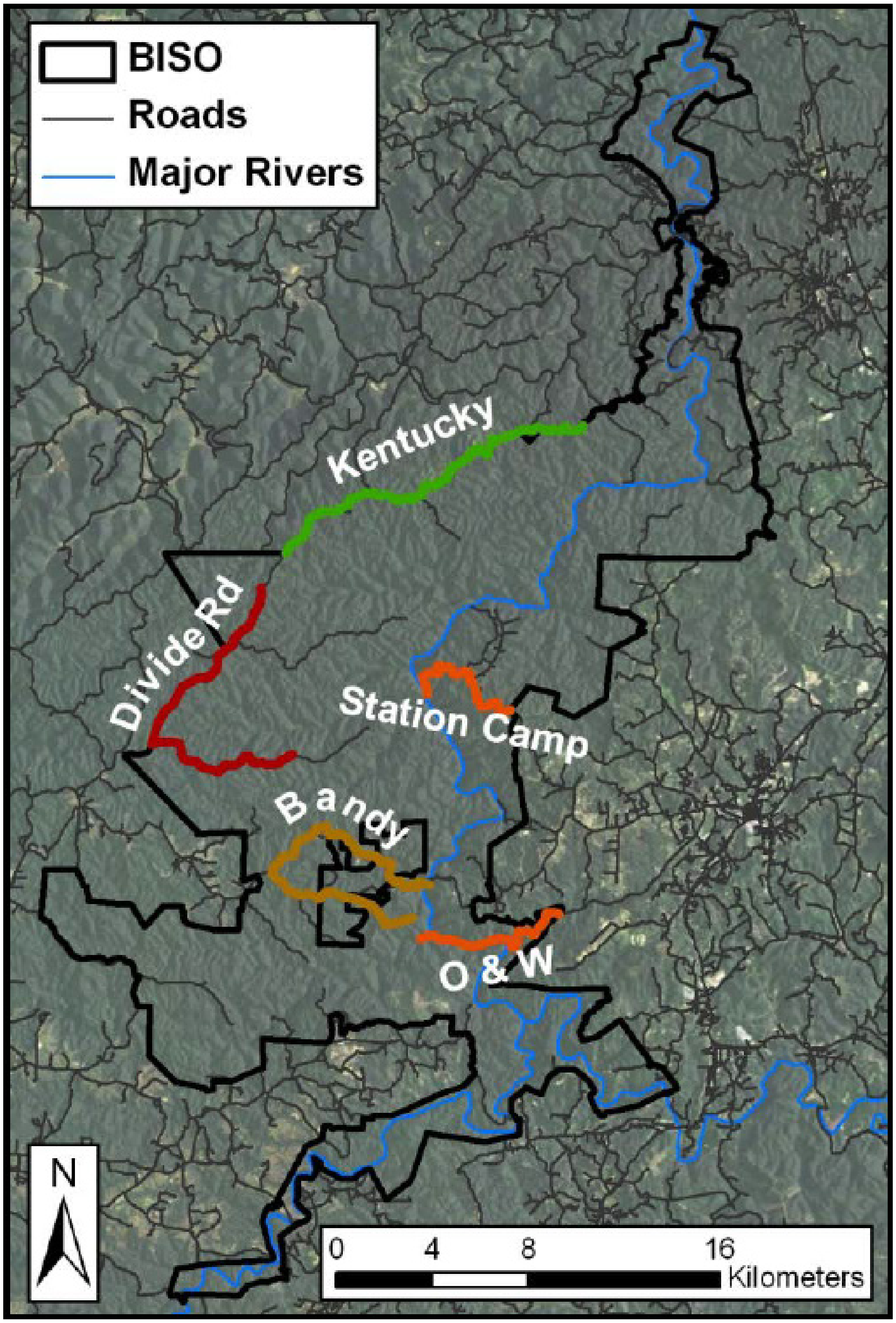

Figure 40. Breeding bird survey routes completed by Stedman (2010) in BISO from 1997–2006. The Station Camp route and the O & W routes were treated as a single route and were sampled the same day each year (Figure reproduced from Worsham et al. 2013).

An annual CBC is centered southwest of OBRI boundaries near the town of Crossville, TN and has been completed annually since 2006. The Crossville CBC is part of the International CBC, which started in 1900 and is coordinated by the Audubon Society. Multiple volunteers surveyed a 24 km (15 mi) diameter area on one day, typically between 14 December and 5 January, by foot, boat, or car. The center point of the 24 km (15 mi) diameter was 35.862089 ºN, 85.016889 ºW (Figure 41). Unlike surveys that occur during the breeding season (such as the BBS), the CBC surveys overwintering and resident birds that are not territorial and singing. The total number of species and individuals were recorded each year.

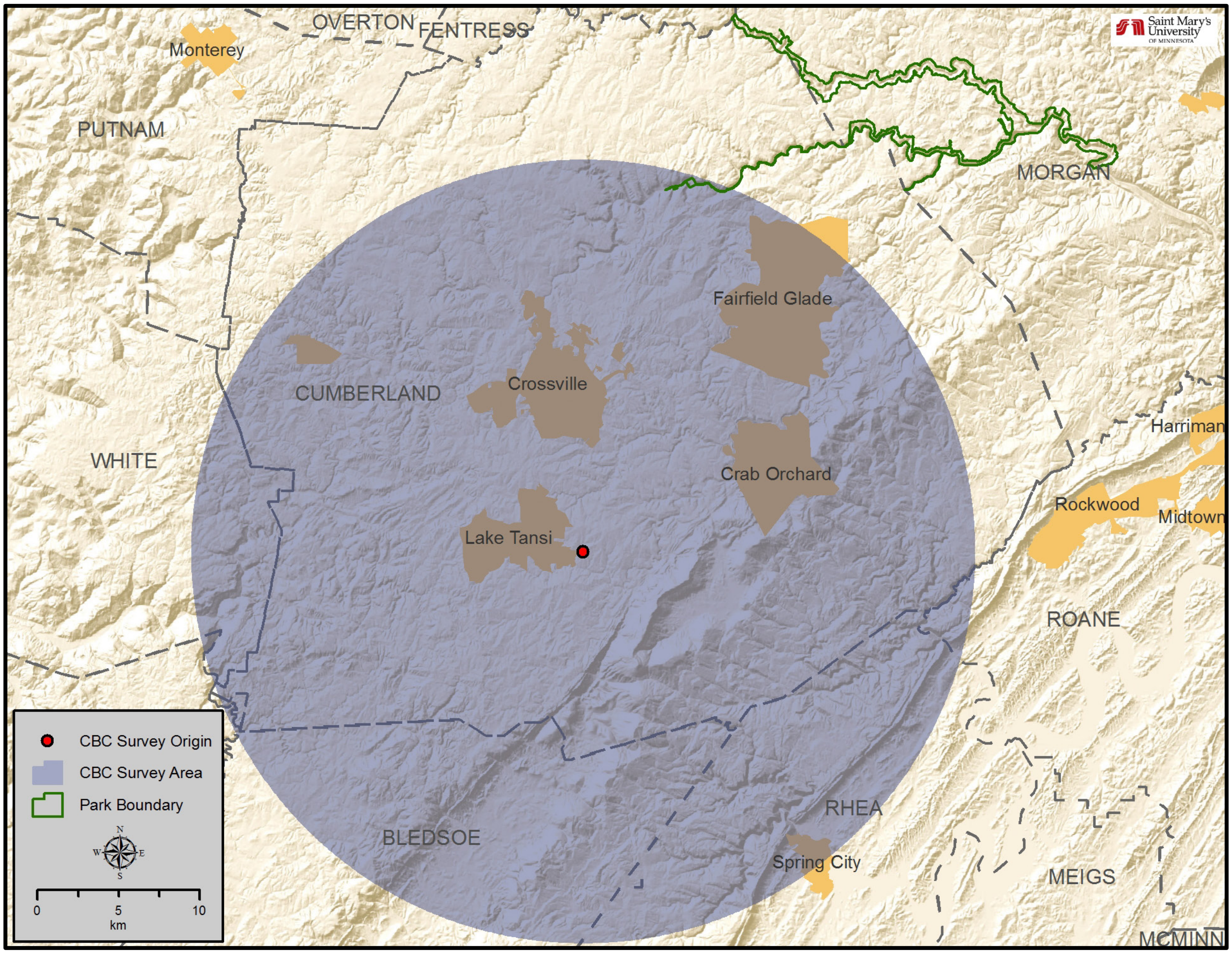

Figure 41. The location of the Crossville CBC in relation to OBRI. The count circle has a diameter of 24 km (15 mi).

The trends in Neotropical migrant's measure used Sauer et al. (2014) for trend analysis among Neotropical species. Sauer et al. (2014) presented population change information for over 400 bird species, and used BBS route data to estimate trends for a variety of regions; statistical significance of reported trends was also provided. Trend estimates obtained from Sauer et al. (2014) utilized a hierarchical model trend estimate protocol which is explained in detail in Link and Sauer (2002).

USGS (2016) provides population trend maps for over 400 avian species. These maps are the result of BBS efforts across the U.S., and provide an estimate for a species' population change across its range. The maps produced by USGS (2016) represent general views of population trends, and unlike Sauer et al. (2014), do not represent any degree of statistical significance. They are provided in this document in order to visually display the approximate population changes from 1966–2010 for several of the commonly observed species in OBRI. These maps do not provide much insight for recent changes, but are more useful to observe potential long-term population shifts USGS (2016). For a detailed discussion of the methodology used to create these maps, see also: Droege and Sauer (1990) and Link and Sauer (1994).

The TWRA online hunter's toolbox (TWRA 2016) was used to obtain yearly harvest statistics for wild turkey (*Meleagris gallopavo*). For this assessment, annual harvest reports from the nearby CWMA were used. This site will be used as a representation of harvest for the park, as harvest reports are not available specifically for OBRI. These annual reports summarize total harvest (number of males and females harvested), male harvest, female harvest, and juvenile harvest from 2006–2015.

Turkey hunting seasons typically occur in the spring and fall. For example, the 2015/16 turkey hunting seasons are:

- Spring Turkey Hunting:
    - Statewide Spring Season: 2 April-15 May 2016 with 1 bearded turkey per day, not to exceed 4 per season.
    - Statewide Young Sportsman Hunt: 26–27 March 2016 with 1 bearded turkey, which counts towards statewide bag, unless designated as a bonus bird.
- Fall Turkey Hunting:
    - 17–30 October (Gun, Archery). All counties with a turkey gun hunt are open for archery-only turkey hunting during archery-only deer seasons (26 September-30 October, 2–6 November). Turkeys harvested during the deer/archery-only season count toward the county bag limit (TWRA 2015a).

Turkeys may only be harvested with shotguns (including muzzle-loading shotguns) that use ammunition that is No. 4 shot or smaller, or archery equipment (TWRA 2015b). Legal hunting hours are a half hour before legal sunrise to the legal sunset (TWRA 2015b).

4.4.5. Current Condition and Trend

<u>Species Richness</u>

The species richness measure can indicate overall habitat suitability for birds, and is vital to understanding the effects of changing landscapes on native biodiversity.

NPS Certified Species List

As of 2016, the NPS Certified Bird Species List for OBRI contains 159 species that are "present in park" (NPS 2015). This list, however, does not allow for a specific analysis of annual species richness, as no data are collected yearly, and the list only documents the presence (or historic presence) of the identified species. The NPS Certified Bird Species List was largely assembled based on the work of Stedman and Stedman (2007b), as there was not an OBRI checklist for bird species prior to Stedman and Stedman (2007b).

Stedman and Stedman (2005)

During surveys at 50 point count locations in OBRI from 1998–2003, Stedman and Stedman (2005) identified 82 avian species. Annual species richness values ranged from 63 species (2000, 2001) to 77 species (1998), and the average annual species richness value was 67 species per year (Figure 42). Species richness values dropped after 1998 survey efforts (Figure 42). The timing of this decline coincided with the southern pine beetle outbreak that occurred in the area from 1999–2002. This outbreak changed the park's forest structure in several places, and likely caused changes in the avifauna of the park as well, especially among shrub-scrub obligate species (Stedman and Stedman 2005, 2007b).

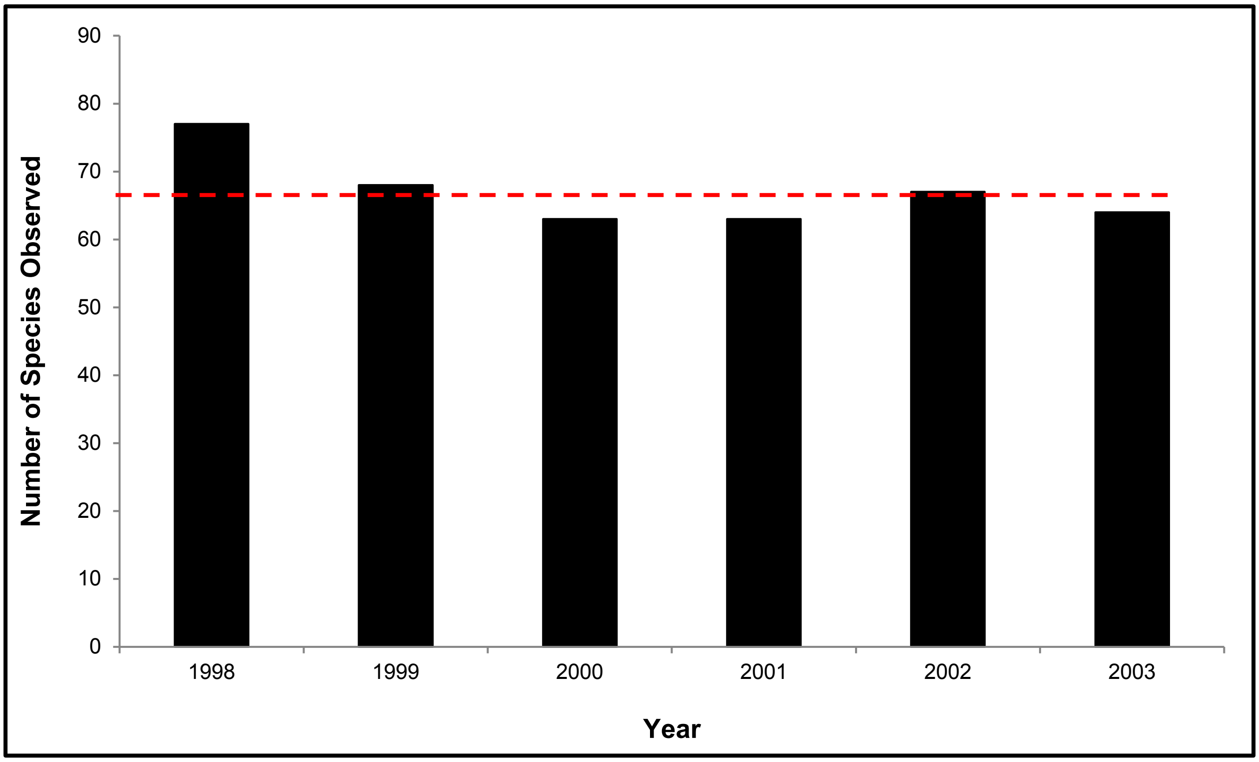

Figure 42. Species richness values observed in OBRI from 1998–2003 during Stedman and Stedman (2005) point count surveys. The dashed red line represents the 6-year average of 67 species per year.

Stedman and Stedman (2007b)

The 2003–2005 inventory completed by Stedman and Stedman (2007b) identified 146 avian species in OBRI, of which 133 were confirmed as present (the remaining 13 species were identified as probably present based on regional records and lists). The point counts that were completed in 2004 and 2005 surveys yielded 64 and 71 species, respectively.

According to UCO (2015), comparisons between the 1998–2003 and 2004–2005 point counts is not advised due to the more recent dataset not being robust enough to support potential comparisons or trends. Differences in survey locations and the number of point count locations likely compound the difficulty in comparisons between the two datasets.

Stedman (2010) Breeding Bird Survey Results (Big South Fork National River and Recreation Area)

Four BBS routes were monitored in BISO from 1997–2006 by Stedman (2010). While not sampled within OBRI, the BISO results are likely comparable to OBRI as they sample similar habitat types and are somewhat close, spatially. The BBS efforts of Stedman (2010) utilized a road-based survey design, and with few roads in OBRI, it is unlikely that a BBS would ever be able to sample extensively within the park's boundaries. The results of the BISO BBS are presented below only as an approximation of what may be found in OBRI, and results should be interpreted with caution as habitat types sampled may include areas/types not found within OBRI.

A total of 79 species were documented during the 10-year BBS effort (Stedman 2010). Annual species richness values ranged from 58 (2003) to 66 (2001) species, and the average annual species richness value was 61.5 species per year (Figure 43).

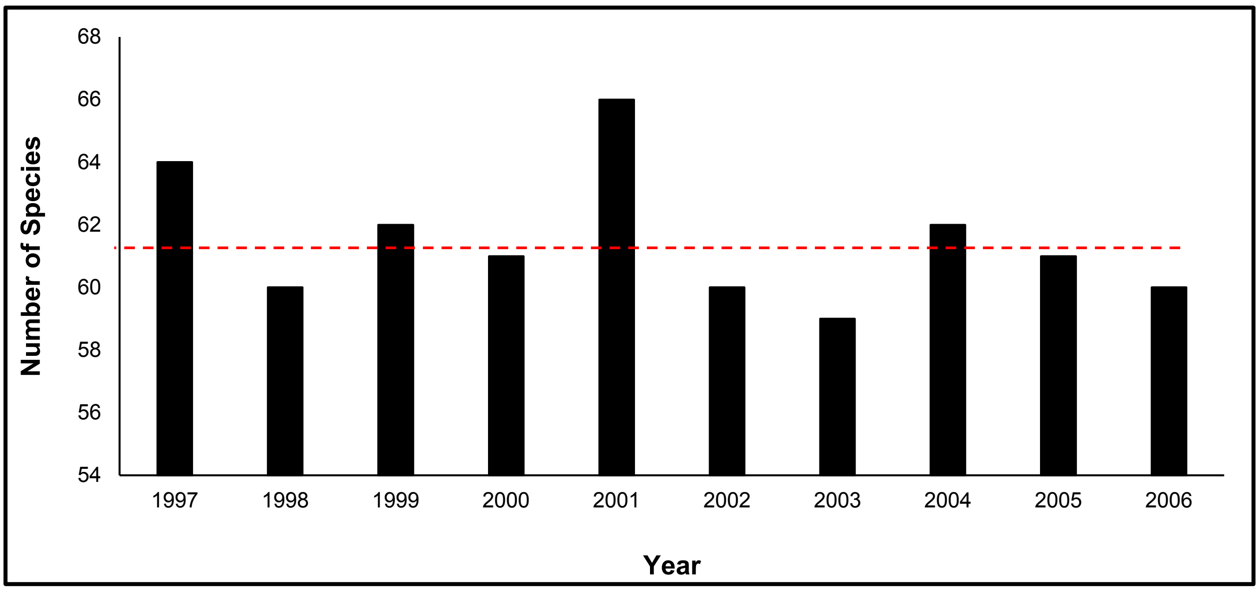

Figure 43. Species richness values observed during the BISO CBC from 1997–2006. The red dashed line represents the 10-year average species richness value for the routes (61.5 species/year) (data from Stedman 2010).

Crossville Christmas Bird Count

The Crossville CBC has identified 116 unique avian species during the 9 years of count data (NAS 2016). The number of species observed in a year has ranged from 78 (2006) to 92 (2007) species, with an average of 86.4 species being observed in a given year (Figure 44). Species richness values were relatively stable and consistent from 2009–2013, with values fluctuating between 90 species (2009, 2010) and 88 species (2011, 2012, 2013). Species richness estimates in 2014 were below average for the first time since 2008 (Figure 44).

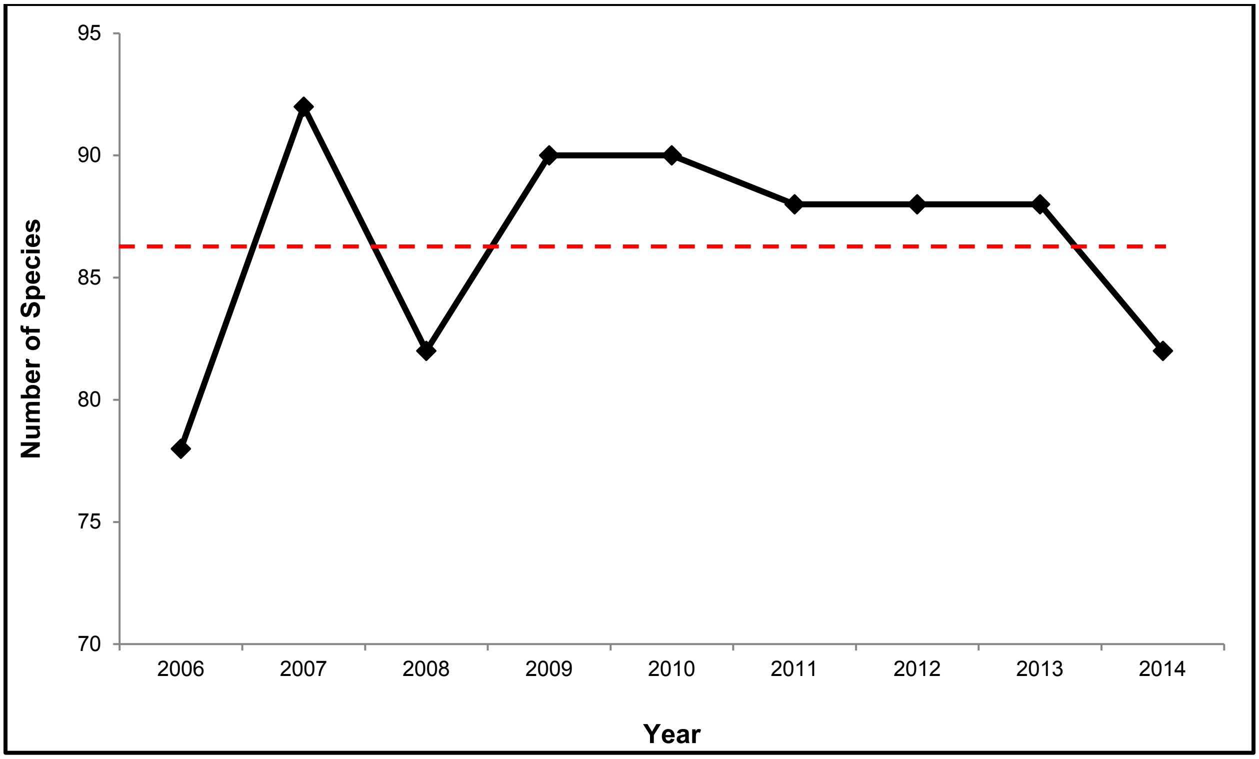

Figure 44. Species richness values observed during the Crossville CBC from 2006–2014. The red dashed line represents the 9-year average species richness value for the route (86.4 species/year) (data from NAS 2016).

Species Richness in Priority Early Successional and Forest Species

In an effort to display the seasonal variation among habitat specialist species in BISO, Worsham et al. (2013) modified the categories of high priority habitat-associated species from Watson et al. (2005). Modifications included combining the priority "grasslands" and "shrub-scrub" birds to create an "early successional" category and combining the "northern hardwood", "mixed hardwood pine", and "hemlock/white pine" birds to create a "forest birds" category; Chuck-will's-widow (*Caprimulgus carolinensis*) and whip-poor-will (*Caprimulgus vociferus*) observations were excluded from these lists are most data sources observed them outside of usual sampling times (i.e., at night). Discussions that follow below for species richness in priority early successional and forest species used the same habitat guild modifications that were described in Worsham et al. (2013). Table 33 provides a list of which priority species fell within each of the habitat related categories and when those species have been observed in the park.

Table 33. Population trend data for high priority Neotropical migrant species in four regions between 1966 and 2013. Bolded numbers indicate statistically significant (p<0.05) population trend. CI = confidence interval. Red text indicates a population decline. Trend data and statistical significance determined from Sauer et al. (2014).

Species	Tennessee		BCR 28 (Appalachian Mountains)		Eastern BBS Region		Survey-wide	
	Per year (%)	CI (2.5%, 97.5%)	Per year (%)	CI (2.5%, 97.5%)	Per year (%)	CI (2.5%, 97.5%)	Per year (%)	CI (2.5%, 97.5%)
Acadian flycatcher	**0.7**	**(0.0, 1.5)**	**-0.9**	**(-1.5, -0.4)**	**-0.4**	**(-0.7, -0.1)**	**-0.4**	**(-0.6, -0.1)**
Black-throated blue warbler	–	–	0.4	(-0.8, 1.4)	**2.2**	**(1.5, 3.1)**	**2.2**	**(1.5, 3.1)**
Blue-winged warbler	-0.7	(-2.2, 0.9)	-0.1	(-1.2, 1.2)	-0.6	(-1.3, 0.2)	-0.6	(-1.2, 0.2)
Cerulean warbler	**-3.0**	**(-4.6, -1.5)**	**-2.8**	**(-3.9, -1.8)**	**-2.9**	**(-3.0, -2.0)**	**-2.8**	**(-3.8, -2.0)**
Eastern wood-pewee	**-0.7**	**(-1.2, -0.3)**	**-2.9**	**(-3.2, -2.6)**	**-1.6**	**(-1.8, -1.5)**	**-1.5**	**(-1.6, -1.4)**
Golden-winged warbler	–	–	**-8.3**	**(-9.7, -7.2)**	**-2.3**	**(-3.1, -1.5)**	**-2.2**	**(-3.1, -1.5)**
Hooded warbler	0.8	(-0.2, 2.0)	**2.1**	**(1.4, 3.0)**	**1.5**	**(1.1, 2.0)**	**1.4**	**(1.0, 1.9)**
Kentucky warbler	-0.4	(-1.2, 0.4)	**-1.7**	**(-2.8, -0.6)**	**-0.9**	**(-1.4, -0.4)**	**-1.0**	**(-1.4, -0.6)**
Louisiana waterthrush	0.2	(-1.0, 1.3)	-0.1	(-0.8, 0.6)	0.4	(-0.1, 0.9)	0.5	(0.1, 1.0)
Northern harrier	–	–	0.4	(-2.1, 2.9)	**-2.0**	**(-3.3, -0.9)**	**-1.2**	**(-1.7, -0.8)**
Northern rough-winged swallow	**2.0**	**(0.8, 3.2)**	0.3	(-0.6, 1.2)	0.3	(-0.5, 0.8)	**-0.5**	**(-1.1, -0.2)**
Peregrine falcon	–	–	–	–	–	–	1.4	(-2.6, 5.9)
Prairie warbler	**-1.9**	**(-2.8, -1.1)**	**-3.6**	**(-4.2, -2.8)**	**-1.9**	**(-2.3, -1.6)**	**-2.0**	**(-2.3, -1.6)**
Sharp-shinned hawk	2.7	(-0.4, 6.2)	**1.7**	**(0.4, 2.8)**	1.3	(-0.6, 2.6)	0.8	(-1.4, 1.8)
Summer tanager	-0.4	(-1.0, 0.3)	**-2.4**	**(-3.2, -1.6)**	-0.2	(-0.5, 0.0)	0.1	(-0.1, 0.3)
Wood thrush	**-2.0**	**(-2.6, -1.5)**	**-1.6**	**(-1.9, -1.4)**	**-2.1**	**(-2.3, -2.0)**	**-2.1**	**(-2.3, -2.0)**
Worm-eating warbler	**-1.5**	**(-3.1, -0.1)**	0.1	(-0.9, 1.4)	0.6	(-0.2, 1.5)	0.4	(-0.2, 1.3)
Yellow-bellied sapsucker	–	–	**6.7**	**(5.2, 8.4)**	0.8	(-0.6, 1.6)	0.6	(-2.1, 1.5)
Yellow-throated vireo	**1.2**	**(0.3, 2.0)**	-0.1	(-0.7, 0.6)	**0.8**	**(0.6, 1.1)**	**1.1**	(0.8, 1.3)

In total, 31 regional high priority species were identified by Watson (2005) as potentially occurring in the area, with 12 "early successional" species and 19 "forest species". Of these species, 26 have been documented in OBRI (eight early successional species, 18 forest species; Table 34). The percentage of high priority early successional species was lower across all data sources (Figure 45), which is not unusual, as most of OBRI is forested and the point count and BBS count locations occurred in areas that were more densely forested and mature. The Stedman (2010) BBS effort in BISO had the highest percentage of early successional species (7.7%), although all data sources were comparably low (ranging from 5.0–7.7%) (Figure 45). High priority forest species accounted for between 11.4 and 15.4% of all observations, with the Stedman and Stedman (2005) point counts having the highest percentage of high priority forest species.

Table 34. Conservation priority species grouped by habitat type that were documented in OBRI between 1999 and 2005.

Habitat Assemblage	Species Name
Grassland Species	Bewick's wren
	Chestnut-sided warbler
	Eastern towhee
	Field sparrow
	Golden-winged warbler
	Grasshopper sparrow
	Gray catbird
	Henslow's sparrow
	Northern bobwhite
	Northern harrier
	Prairie warbler
	Yellow-breasted chat
Forest Species	Acadian flycatcher
	American redstart
	Black-and-white warbler
	Blackburnian warbler
	Black-throated blue warbler
	Blue-headed vireo
	Cerulean warbler
	Chuck-will's-widow*
	Common raven
	Eastern wood pewee
	Hooded warbler
	Kentucky warbler

* Indicates a species that was observed during nighttime surveys and were excluded from many analyses due to sampling differences.

Table 34 (continued). Conservation priority species grouped by habitat type that were documented in OBRI between 1999 and 2005.

Habitat Assemblage	Species Name
Forest Species (continued)	Louisiana waterthrush
	Red-headed woodpecker
	Ruby-throated hummingbird
	Summer tanager
	Whip-poor-will*
	Wood thrush
	Worm-eating warbler
	Yellow-throated vireo
	Yellow-throated warbler

* Indicates a species that was observed during nighttime surveys and were excluded from many analyses due to sampling differences.

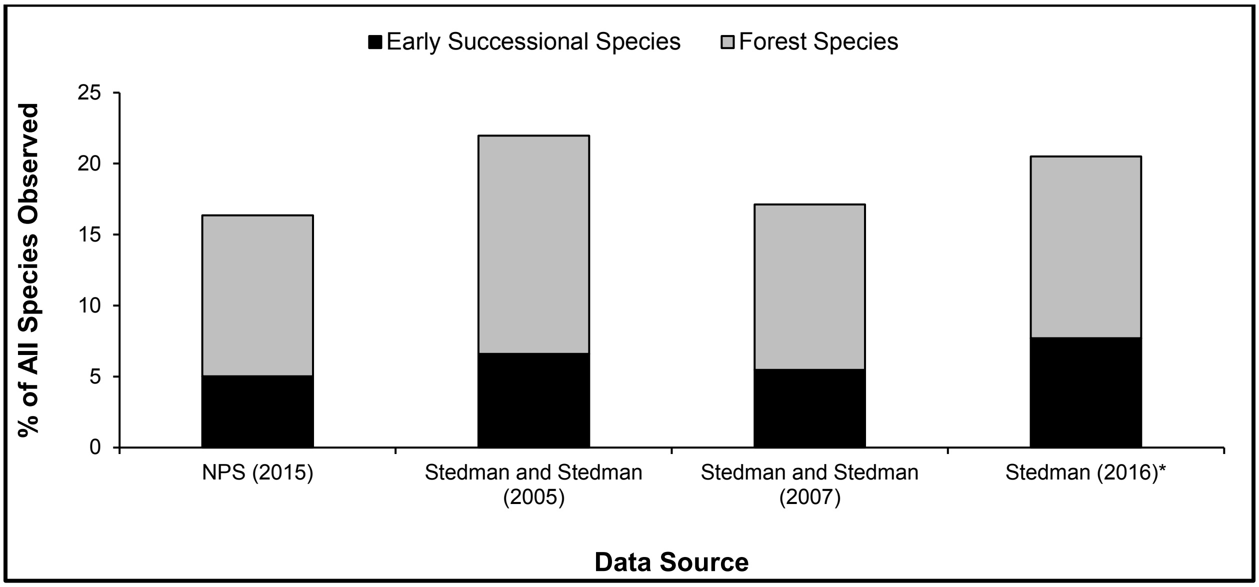

Figure 45. Percentage of priority early successional and forest specialist species observed during the different bird sampling efforts in OBRI (1999–2006). * denotes that the BBS data comes from BISO, and not OBRI.

Trends in Neotropical Migrants

OBRI has a highly diverse Neotropical migrant community which stems largely from the park's undisturbed forests (Stedman and Stedman 2007b). Of the 146 species documented in OBRI by Stedman and Stedman (2007b) 108 (74%) were considered Neotropical migrants; this estimate is comparable with results found at nearby BISO during a similar inventory effort (Stedman and Stedman 2007a). Point count efforts from 1998–2005 documented 93 species across all point count locations, 66 of the documented species were Neotropical migrants (71%). The five most abundant Neotropical species of conservation priority that were observed during the Stedman and Stedman (2005, 2007b) point counts in OBRI were the hooded warbler (*Setophaga citrina*), Acadian flycatcher, wood thrush, worm-eating warbler (*Helmitheros vermivorum*), and the Louisiana waterthrush (*Parkesia motacilla*) (Figure 46).

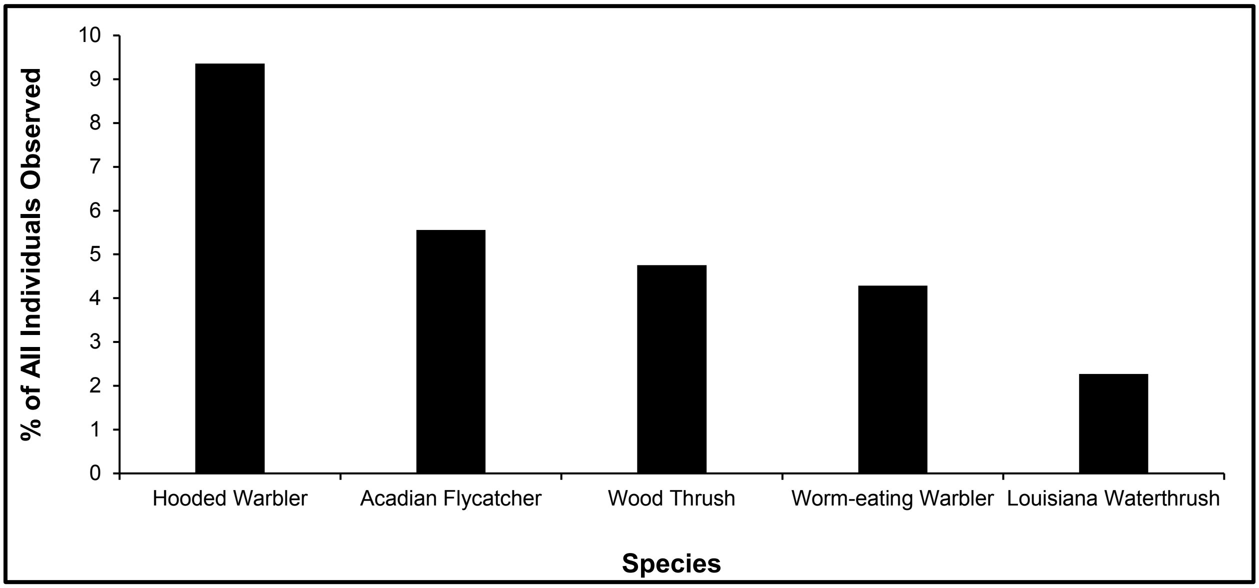

Figure 46. The five most abundant Neotropical species of conservation concern during the Stedman and Stedman (2005, 2007b) point count efforts in OBRI.

Sauer et al. (2014) is an online tool that estimates population trends for avian species. This assessment will discuss the estimates of current trends (reported as percent change per year from 1966–2013) for high priority species in OBRI. High priority species in OBRI are displayed in Table 32 and were species that were identified as either endangered, threatened, or deemed in need of management by the State of Tennessee, defined as a regional high priority species by Watson (2005), or if it received a PIF-based conservation rank of 4 (Nuttle et al. 2003). Trends are reported for the State of Tennessee, Bird Conservation Region (BCR) 28 (Appalachian Mountains; Figure 47), the Eastern BBS Region, and for BBS survey-wide results (Table 33).

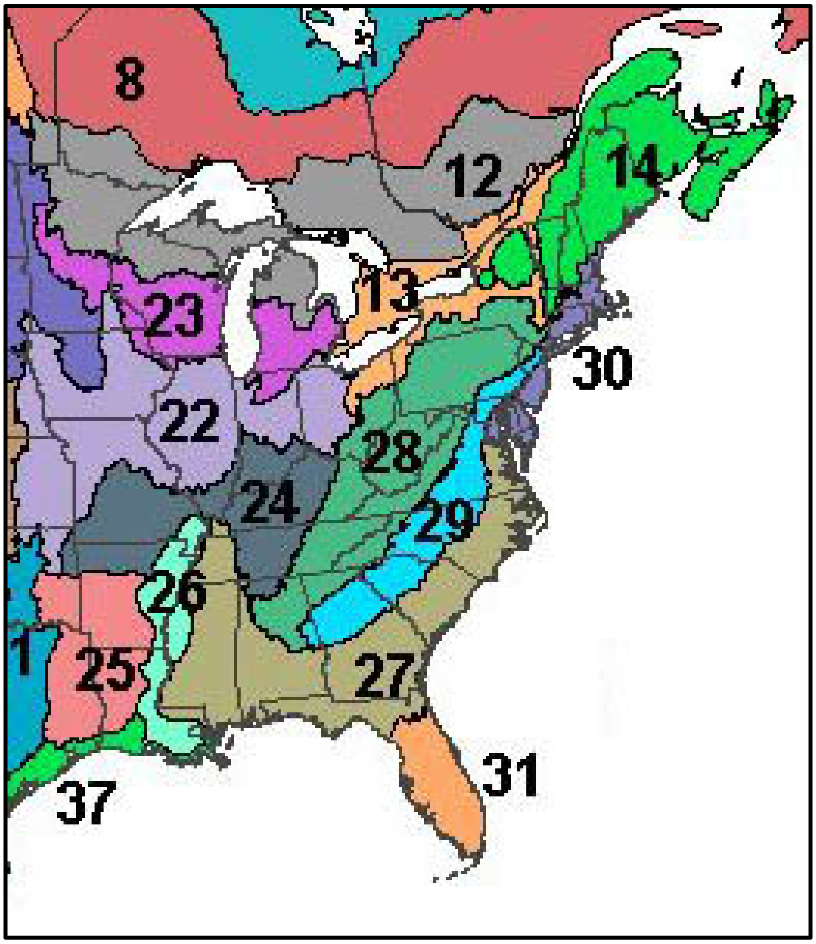

Figure 47. BCRs of the Eastern United States. OBRI falls within BCR 28 (Appalachian Mountains).

While Table 33 displays predominantly declining trends for priority species across most of the summarized ranges, a few species did exhibit increases in abundance. The hooded warbler exhibited statistically significant population increases across BCR 28 (2.1%/year), the Eastern BBS Region (1.5%/year), and the entire BBS survey region (1.4%/year) (Figure 48); there was an apparent increase in the Tennessee region, however this increase was not statistically significant (Table 33). This species has similarly been observed in high numbers in OBRI, with annual abundance estimates during Stedman and Stedman (2005, 2007b) averaging 66 individuals/year. The hooded warbler accounted for approximately nine percent of all bird observations during Stedman and Stedman (2005, 2007b) point counts (Figure 48).

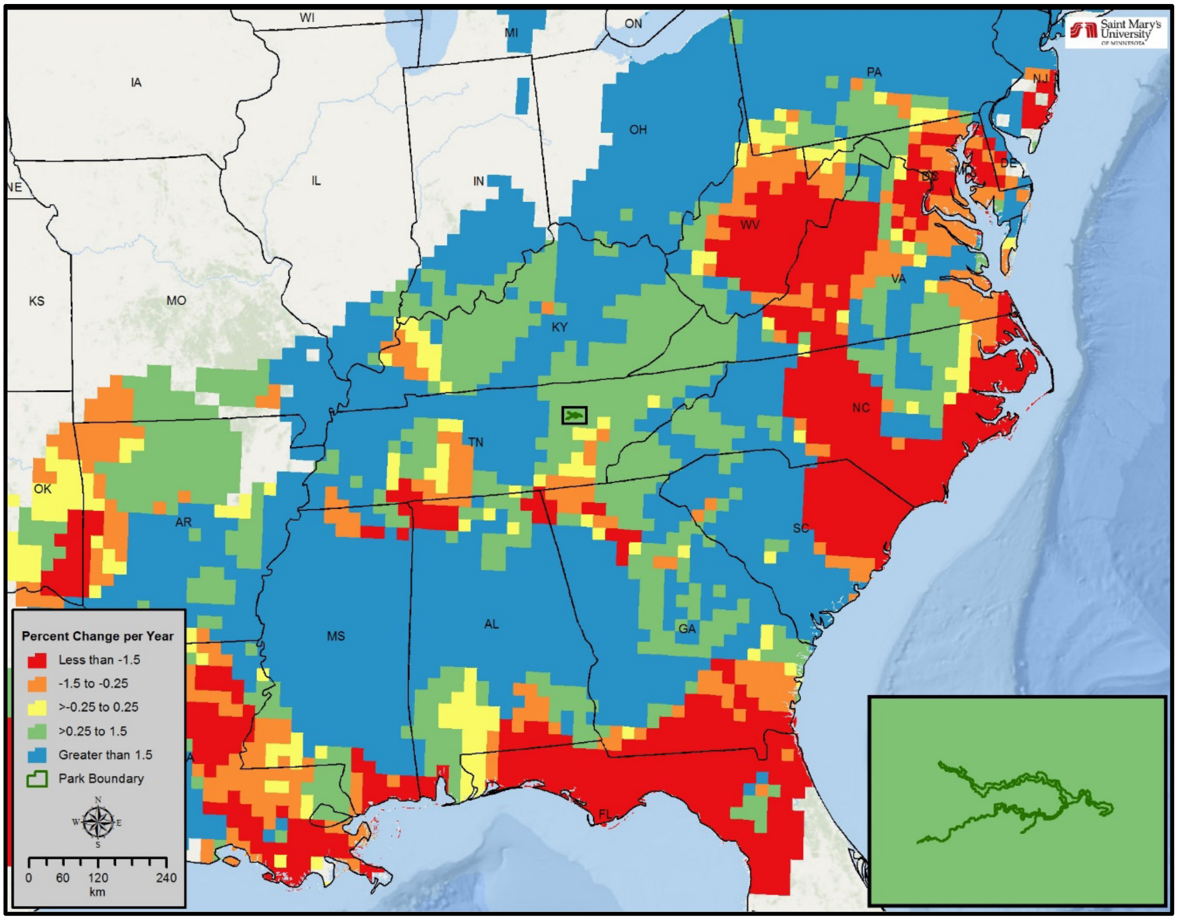

Figure 48. Annual population trends for the hooded warbler. Trends were calculated from the 1966–2013 period, and were estimated by Sauer et al. (2014). Population growth estimates shown in this figure are statistically significant (p<0.05) (Sauer et al. 2014).

The yellow-throated vireo (*Vireo flavifrons*) exhibited statistically significant increases in population sizes in all regions except for BCR 28, where it displayed only a 0.1% decline that was not statistically significant (Table 33). This species was observed in OBRI during all 8 years of point count efforts, with an average annual abundance of 4.6 individuals/year. The yellow-throated vireo made up a small proportion of total observations, accounting for only 0.8% of all individuals observed during the point counts.

Many of Neotropical species of conservation concern in Table 33 exhibited significant declining trends from 1966–2013. In Tennessee, five species in Table 33 exhibited statistically significant declines, with the cerulean warbler having the highest rate of decline of any species reported in Table 33. The cerulean warbler has declined by 3.0% per year since 1966 in Tennessee, and similar rates of decline have been observed range-wide (Table 33). This species was not observed in high frequency during (Stedman and Stedman 2005, 2007b), and was not observed during the final two years of point count efforts (2004, 2005).

The golden-winged warbler (*Vermivora chrysoptera*) was not observed during Stedman and Stedman's (2005, 2007b) point counts but was detected during the general park inventory. This species has declined at a very steep rate during the past half century, which extremely steep declines in the Appalachian Mountains BCR. Average population declines of 8.3% per year have been reported in this area between 1966 and 2013 (Table 33), and smaller, but still significant, declines have been observed throughout the species range. This is a species that moves into mature forests shortly after leaving the nest, and the dense and continuous forests of OBRI may provide suitable habitat for this at-risk species.

Another species that has exhibited statistically significant, range-wide declines over the past half century is the prairie warbler (*Setophaga discolor*). The prairie warbler was observed relatively frequently during point count efforts in the park, with an average annual abundance of 11.6 individuals observed per year. This species accounted for approximately 1.5% of all individuals observed during Stedman and Stedman (2005, 2007b). In Tennessee, the prairie warbler has declined at an average rate of 1.9% per year, while the Appalachian Mountains region has seen declines averaging 3.6% per year between 1966 and 2013 (Table 33).

Much like the prairie warbler, the eastern wood pewee (*Contopus virens*) exhibited range-wide declines from 1966–2013. Approximately five eastern wood pewees were observed each year during the Stedman and Stedman (2007b) point count efforts, and the species accounted for about one percent of all bird observations. Rates of population decline for this species closely resemble the rates exhibited by the prairie warbler, as statistically significant declines ranging from 0.7 to 2.9%/year were observed across all summarized regions.

<u>Annual Turkey Harvest Statistics</u>

The wild turkey exists in a wide variety of habitats across its native range (historically in 39 states in the U.S.), and was almost driven to extinction shortly after North America was colonized by Europeans (Dickson 1992). By 1920, wild turkey populations had been extirpated in 18 of the 39 states within the species' native range (Dickson 1992). Population numbers nationwide have returned to high levels, and hunting seasons exist for the species in nearly every state it is found. Turkey hunts resumed in Morgan County during the 2005–2006 season, while hunts in Cumberland County and CWMA resumed during the 2006–2007 season. For this measure, the CWMA harvest statistics will be summarized, as this site is in close proximity to the park and shares several borders with OBRI.

Annual harvest in the CWMA over the 10-year period since hunting has resumed in the state has averaged approximately 83 turkeys/year (Figure 49). Peak turkey harvest occurred during the 2006–2007 season (114 turkeys), while the lowest harvest reported for this area was during the 2014–2015 season (57 turkeys).

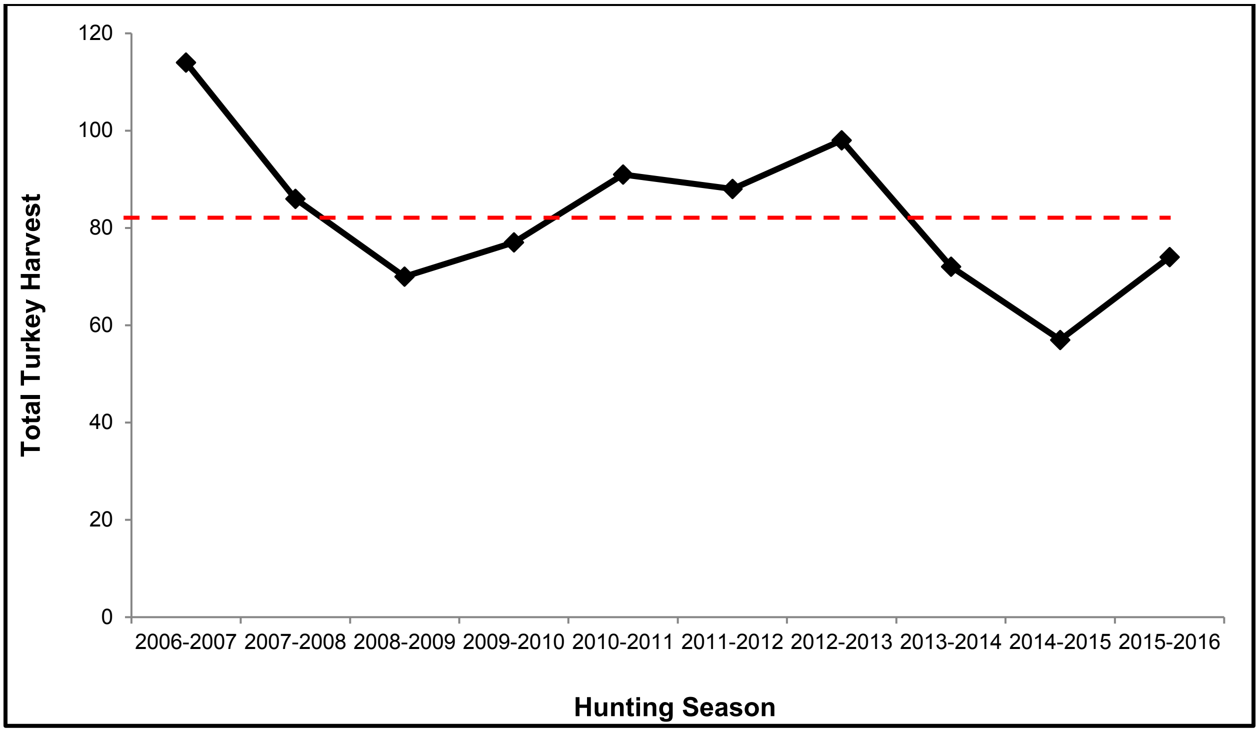

Figure 49. Annual wild turkey harvest in CWMA from the 2006/07 hunting season through 2015/16 (TWRA 2016). The dashed red line indicates the 10 season harvest average of 83 turkeys/season.

Threats and Stressor Factors

One of the major threats facing land bird populations across all habitat types is land cover change (Morrison 1986). Land cover change is not restricted to the breeding habitat; many species depend on specific migratory and wintering habitat types that are also changing. The encroachment of non-native plant species may be a contributor to land cover change in all habitats. Altered habitats can also compromise the reproductive success or wintering survival rates of species adapted to that habitat. They can also allow generalist, non-native species, such as the European starling (*Sturnus vulgaris*) or house sparrow (*Passer domesticus*), to move in and outcompete native bird species. Grassland and shrub-scrub dependent species in OBRI, such as the eastern meadowlark (*Sturnella magna*) and field sparrow (*Spizella pusilla*), require specific vegetative communities for successful nesting to occur. A loss or alteration of these vegetative structures, or competition for resources from non-native species could compromise the nesting success of these native species in OBRI.

As urban areas continue to develop and grow, modern alterations to the landscape often foster competition between native and non-native bird species. Human-made structures may fragment and reduce the continuity of a landscape, and often as these changes occur, non-native bird species are able to inhabit the areas. Marzluff (2001), pp. 26–28 states that, "The most consistent effects of increasing settlement were increases in non-native species of birds, increases in birds that use buildings as nest sites (e.g., swallows and swifts), increases in nest predators and nest parasites (brown-headed cowbirds [*Molothrus ater*]), and decreases in interior- and ground-nesting species." Non-native bird species can often be observed at OBRI, and include species such as rock dove

(*Columba livia*), Eurasian collared-dove (*Streptopelia decaocto*), European starling, and house sparrow.

Migratory bird species also face deteriorating habitat conditions along their migratory routes and wintering grounds. Most of the birds that breed in the U.S. winter in the Neotropics (MacArthur 1959); deforestation rates in these wintering grounds have occurred at an annual rate up to 3.5% (Lanly 1982). While forest and habitat degradation does occur in the U.S., it does not approach the level of degradation seen in the tropics (WRI 1989). Furthermore, Robbins et al. (1989) supported the suggestion that deforestation in the tropics has a more direct impact on Neotropical migrant populations than deforestation and habitat loss in the U.S.

While the threat of predation is a natural occurrence for avian species, there are several instances of predation from non-native predators that represent a more substantial threat. Domestic and feral cats are one of the largest causes of bird mortality in the U.S. According to Loss et al. (2012), annual bird mortality caused by outdoor cats is estimated to be between 1.4 and 3.7 billion individuals. The median number of birds killed by cats was estimated at 2.4 billion individuals, and almost 69% of bird mortality due to cat predation was caused by un-owned cats (i.e., strays, barn cats, and completely feral cats) Loss et al. (2012).

Avian brood parasite species (e.g., brown-headed cowbird) represent a threat to several avian species in OBRI. Brood parasites are species that lay their eggs in the nests of other breeding species, which then in turn incubate and care for the young (Photo 12) (Payne 1977). Brood parasitism generally reduces the reproductive success of the host species, as host species typically fledge fewer young compared to non-parasitized parents of the same species (Payne 1977).

Photo 12. Brown-headed cowbird egg (mottled color), that has been laid in a chipping sparrow (*Spizella passerina*) nest (NPS Photo).

Brown-headed cowbirds are a native species in OBRI, and can directly contribute to the reduced nesting success of host species, as they will often puncture or remove host species eggs (Freidmann 1963). Brown-headed cowbirds often hatch earlier than host species eggs, and grow larger and faster than the host species, which often results in the death of the host chicks due to starvation, neglect, overcrowding, or direct mortality by trampling or removal from the nest (Freidmann 1963, Payne 1977). Many breeding species are targeted by brood parasites, although warblers, blackbirds, and vireos are among the most commonly parasitized species. While a natural phenomenon, brood parasitism can be actively managed against; instances of cowbird egg removal from host nests has resulted in increases in reproductive success in various parts of the species' home range (Mayfield 1960, Walkinshaw 1972, Payne 1977).

Data Needs/Gaps

Annual monitoring of the park's avifauna is needed. The most recent park-specific monitoring effort was completed in 2005. An expansion of Stedman and Stedman's (2005, 2007b) point count efforts would allow for more accurate comparisons between time periods. Similarly, the park's Certified Species List has not been updated since the completion of Stedman and Stedman (2007b), and is in need of an update. It is reasonable to assume that additional species occur in OBRI during the various seasons that were not documented during the Stedman and Stedman (2007b) inventory effort. Eight species identified on the current Certified Species List are listed as unconfirmed, and additional research would provide further insights into the actual occurrence of these species in the park.

Overall Condition

Species Richness

The species richness measure was assigned a *Significance Level* of 3 during project scoping. Species richness values have remained fairly constant in the OBRI area during the periods that have been sampled. Stedman and Stedman (2005) observed slight variations from 1998–2003, and Stedman and Stedman (2007b) also observed similar richness variation from 2004–2005. Richness values obtained from both the CBC and BBS efforts make it difficult to observe trends, as the results are likely strongly influenced by the number of observers and the locations sampled each year. OBRI is in need of an updated park-wide inventory, and additional monitoring is needed to determine any current trends. Stedman and Stedman (2007b) noted that the park's avifauna is moderately diverse, which was consistent with expectations based on the moderate size of the park. Of particular importance to park managers is the current condition of forest dependent species, as this habitat type is a declining resource in the eastern U.S. Additional monitoring is needed that focuses on the avifauna of this relatively unique habitat, and the current status lends a degree of concern at this time. A *Condition Level* of 1 was assigned to the species richness measure, indicating low current concern.

Trends in Neotropical Migrants

During project scoping, the OBRI project team assigned a *Significance Level* of 3 to the trends in Neotropical migrant's measure. As noted in Stedman and Stedman (2007b), OBRI has a highly diverse Neotropical migrant community which stems largely from the park's undisturbed forests. State, regional, and national trends in Neotropical migrant species are variable, although many of the Neotropical species of conservation concern in the park have exhibited statistically significant declines in Tennessee and the broader region based on BBS results (Table 33). This is not just true for species of conservation concern, however, as the ovenbird (*Seiurus aurocapilla*), a common species observed in high numbers during both Stedman and Stedman (2005) and (2007b), has exhibited an annual decline of 3.1% per year in the Tennessee area (Sauer et al. 2014). Trends in Neotropical migrant species are often problematic to managers, as these trends are often influenced by factors outside of the park along the species' migratory and wintering habitats. Because of the high number of declining population trends observed in Tennessee and the region, and because OBRI is home to a high diversity of Neotropical species, this measure was assigned a *Condition Level* of 2, indicating moderate concern.

Annual Turkey Harvest Statistics

The annual turkey harvest statistics measure was assigned a *Significance Level* of 2 during project scoping. Turkey hunting seasons were re-instituted in the CWMA during the 2006/2007 hunting season, and average season harvest has been 82.7 turkeys/year in the seasons since. The three most recent hunting seasons have seen harvests below average (Figure 49). Recent harvest statistics, combined with the fact that turkeys were once extirpated from the area and are now at huntable and sustainable populations, indicates that this component is currently of low to no concern for OBRI managers. A *Condition Level* of 0 was assigned to this measure.

Weighted Condition Score

The birds component was assigned a *Weighted Condition Score* of 0.38, indicating a current condition of moderate concern. A trend arrow was not determined due to a lack of recent, park-specific data.

Because of the lack of park-specific data within the last 10 years, and because many of the existing long-term counts (i.e., CBC and BBS) occurred on lands and habitats outside of OBRI, the overall confidence in this assessment is low. Additional monitoring within the park, particularly in the migratory periods, is needed in order to assess this condition with a higher degree of confidence.

Birds			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.38**
Species Richness	3	1	
Trends in Neotropical Migrants	3	2	
Annual Turkey Harvest Statistics	2	0	

4.4.6. Sources of Expertise

- Robert Emmott, APHN Biologist
- Rebecca Schapansky, OBRI Resource Management Specialist

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4.5. Fish Communities

4.5.1. Description

The Obed River and its tributaries within OBRI provide valuable habitat for a diverse aquatic community, including over 50 species of fish (Scott 2010a, NPS 2015b). Preserving these healthy aquatic communities in a free-flowing state was one of the primary reasons for the Wild and Scenic Rivers Act, under which OBRI is protected (Emmott et al. 2005). Fishing is allowed in the park and is a popular recreational activity (Emmott et al. 2005, NPS 2015b). The park supports a small population of the rare Cumberland Plateau strain of the muskellunge (*Esox masquinongy ohioensis*), maintained through annual stocking by the TWRA (Scott 2010a, NPS 2015b).

The Obed River system also supports a federally-threatened fish species, the spotfin chub (Photo 13). This small fish is endemic to the clear upland waters of the Tennessee River drainage (Candlish 2010, Emmott and Hughes 2013). Only four known spotfin chub populations remain, and the Obed-Emory River population is the only one within a protected area (Emmott and Hughes 2013). Clear Creek within OBRI has been federally designated as critical habitat for the species (Trustees 2008).

Photo 13. Spotfin chub (NPS photo by E.M. Scott).

4.5.2. Measures

- Species diversity
- Abundance
- Density
- Age class distribution/recruitment
- Index of biotic integrity
- Trends in rare fish spatial distribution

4.5.3. Reference Conditions/Values

The information in Russ (2006) and Scott (2010a, 2010b) will serve as reference conditions for the species diversity, abundance, and IBI measures. The work of Jenkins and Burkhead (1984), as described in Russ (2006), provides a reference condition for spotfin chub distribution within OBRI. Reference conditions have not been defined for density or age class distribution.

4.5.4. Data and Methods

Russ (2006) conducted a study of spotfin chub distribution and seasonal habitat use in the Emory River watershed. An additional objective of this study was to characterize fish communities within the watershed, particularly in segments where data were lacking. Fifty-seven 200 m (656 ft) segments were surveyed within four sub-watersheds: Daddy's Creek, Clear Creek, Obed River, and Emory River (the NRCA project team requested that fish communities be assessed by these watersheds, when possible). Of these sites, 13 fell within OBRI boundaries (Figure 50). The Obed River and Daddy's Creek sites were visited primarily in the summer of 2004, while Clear Creek and Emory River sites were surveyed in the summer of 2005 (Russ 2006). Sampling at each site was conducted primarily by electroshocking, with the occasional addition of snorkeling trips, particularly in areas lacking previous data. Eight 200 m (656 ft) stream segments were selected for a more detailed study of spotfin chub habitat use; this habitat study was conducted strictly through snorkeling trips (Russ 2006).

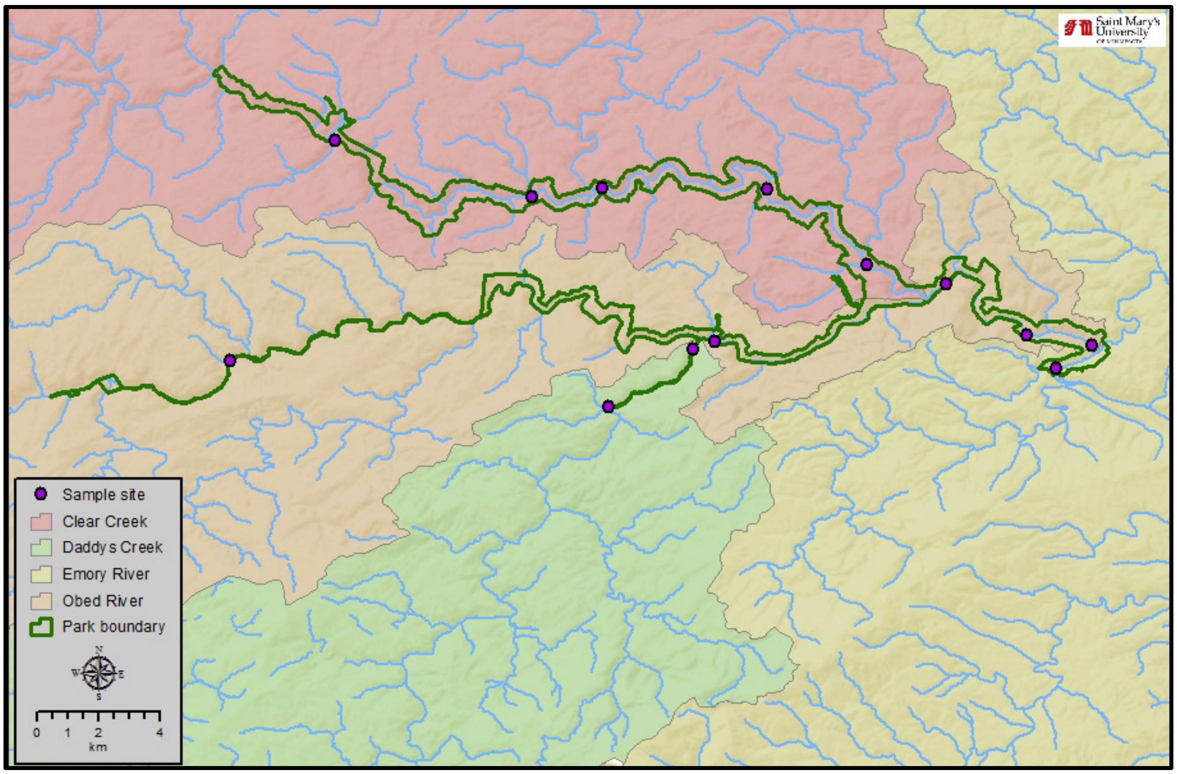

Figure 50. Locations of sampling points within OBRI visited by Russ (2006).

Scott (2010a) surveyed the fish communities of OBRI from June 2004 through September 2006. The goals of the survey were to document fish species occurring in the park and to describe their relative abundance, distribution, and habitat usage. Sampling methodologies included backpack electroshocking, dip nets, seines, and snorkeling, with some use of minnow traps, gill nets, and trot lines. Fifteen sample sites were selected on the Obed and Emory Rivers, along with two sites in Clear Creek and one in Daddy's Creek (Scott 2010a) (Figure 51). Snorkeling surveys were conducted at locations known to support federally protected fish and/or mussels in order to avoid any possible disturbance from electroshocking. Scott (2010a) also included data collected by the Tennessee Valley Authority (TVA) at six OBRI sites from 1995–2007. The TVA utilized boat electrofishing at some locations, allowing for sampling of deeper habitats than was possible in Scott's (2010a) survey.

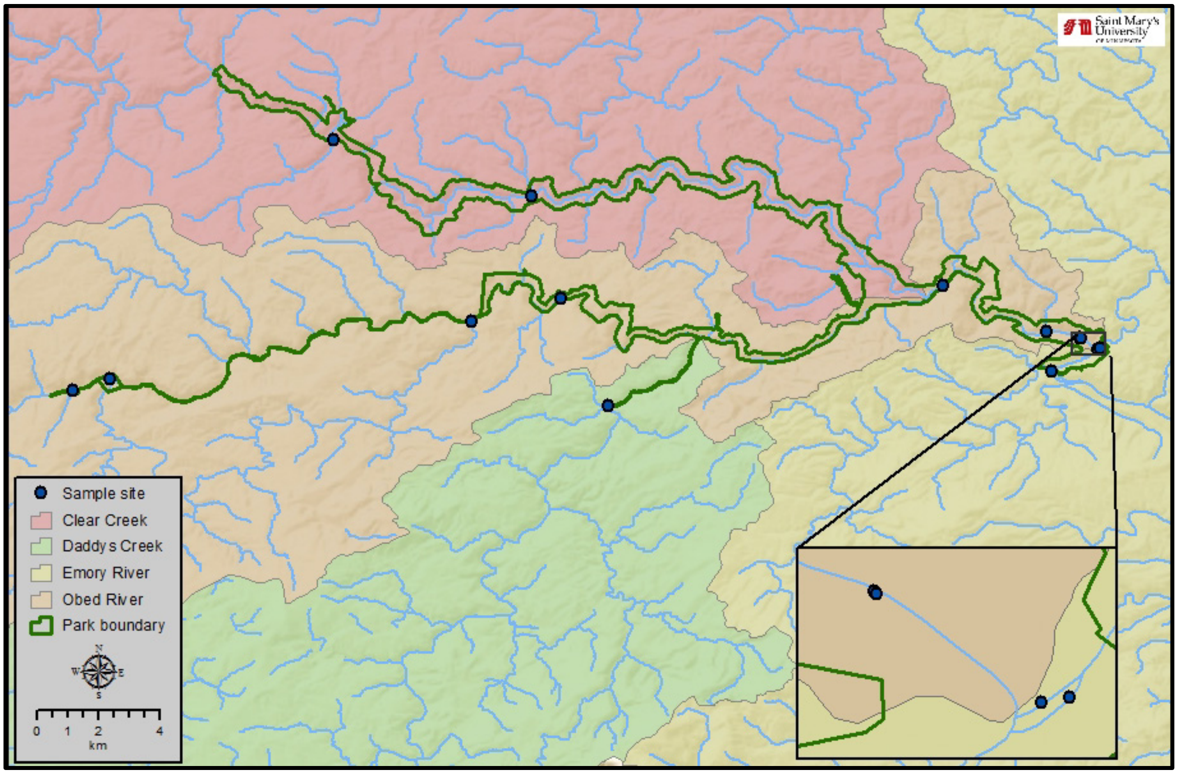

Figure 51. Locations of sampling points within OBRI visited by Scott (2010a, 2010b).

An IBI approach has been used by the TVA and other researchers to assess fish communities and habitat quality in Tennessee streams (Russ 2006, Scott 2010a). The IBI classes utilized by the TVA are based on a system developed by Karr et al. (1986); a description of these classes is given in Table 35 below. Twelve metrics were used to calculate the IBI, including: number of native species, number of pollution/degradation-intolerant species, percentage of fish that are pollution/degradation-tolerant species, percentage of fish that are specialized insectivores, percentage of piscivores, catch rate, and percentage of fish with disease, fin damage, or other anomalies (Russ 2006). Russ (2006) and Scott (2010a) report IBI scores for OBRI locations calculated during their studies and by the TVA and between 1995 and 2007.

Table 35. Biotic integrity classes used to assess fish communities (Karr et al. 1986) (table reproduced from Russ 2006).

Class	Attributes	Score Range
Excellent	Comparable to the best situations without influence of man; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with full array of age and sex classes; balanced trophic structure.	58–60
Good	Species richness somewhat below expectation, especially due to loss of most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some signs of stress.	48–52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); older age classes of top predators may be rare.	40–44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.	28–34
Very Poor	Few fish present, mostly introduced or tolerant form; hybrids common; disease, parasites, fin damage, and other anomalies regular.	12–22
No Fish	Repetitive sampling fails to turn up any fish.	<12

The APHN is initiating a monitoring program for rare fish species that includes the spotfin chub at OBRI (Emmott and Hughes 2013). The goals of this monitoring program are to identify any trends in spotfin chub population abundance at selected sites and to correlate any changes in abundance or distribution with changes in physical and chemical habitat parameters (Emmott and Hughes 2013). Data collected include abundance, density, and catch per unit effort (CPUE). When possible, distinctions are made between juveniles, adults, and males in breeding colors. Four sites in the Obed/Emory watershed were quantitatively sampled during a 2012 pilot study, and qualitative searches were performed at four upstream sites where spotfin chub were documented previously (in the early 2000s) (Emmott and Hughes 2013).

4.5.5. Current Condition and Trend

Species Diversity

The number of fish species known to occur within OBRI has increased over the years. However, this is most likely due to increased survey efforts rather than actual changes in species richness. As of 2005, 28 fish species had been documented within OBRI (Riddle 1975, Emmott et al. 2005). After the Scott (2010a, 2010b) survey, this number increased to 55 known fish species (Appendix G). Forty-nine of these species are native (Scott 2010a, NPS 2015a).

Clear Creek Watershed

Russ (2006) sampled five locations along Clear Creek within OBRI during the summer of 2005. A total of 24 species were documented, including a variety of darters, sunfish, bass, and shiners (Appendix H). Only one species, the redbreast sunfish (*Lepomis auritus*; Photo 14), was non-native (Russ 2006).

Photo 14. The non-native redbreast sunfish (NPS photo by E.M. Scott).

During 2005 sampling at two Clear Creek locations, 18 fish species were documented (Scott 2010b) (Appendix I). The species identified were similar to those found by Russ (2006), with the addition of the blacknose dace (*Rhinichthys atratulus*) (Scott 2010b).

Daddy's Creek Watershed

Russ (2006) sampled two locations along Daddy's Creek within OBRI during 2004, and identified a total of 19 species (Appendix H). The general species composition was similar to Clear Creek, and the redbreast sunfish was again the only non-native species found (Russ 2006).

Thirteen fish species were documented by Scott (2010b) during 2004 sampling at one Daddy's Creek location (Appendix I). Fewer species were observed, particularly shiners, than during Russ (2006), likely due to the fact that Scott (2010b) sampled only one upstream location.

Obed River Watershed

Russ (2006) sampled five locations on the Obed River during 2004–2005 and identified a total of 32 species (Appendix H). In addition to the species found in Clear and Daddy's Creeks, the Obed also supported longnose gar (*Lepisosteus osseus*), freshwater drum (*Aplodinotus grunniens*), and largemouth bass (*Micropterus salmoides*). The river also contained an additional non-native species: the redear sunfish (*Lepomis microlophus*) (Russ 2006).

During 2004–2006 sampling at ten Obed River sites, Scott (2010b) documented 40 fish species (Appendix I). In addition to species identified by Russ (2006), Scott (2010b) found smallmouth buffalo (*Ictiobus bubalus*) and the non-natives redeye bass (*Micropterus coosae*) and striped shiner (*Luxilus chrysocephalus*) (Scott 2010b).

Emory River Watershed

Russ (2006) sampled just one location on the Emory River within OBRI boundaries during the summer of 2005, and identified 29 different species (Appendix H). This was the only OBRI location where Russ (2006) found logperch (*Percina caprodes*), spotted bass (*Micropterus punctulatus*), ashy darter (*Etheostoma cinereum*), and gilt darter (*Percina evides*). Two non-native species were documented: the redbreast sunfish and striped shiner (Russ 2006).

Thirty-four fish species were documented by Scott (2010b) during 2004 and 2006 sampling at five Emory River sites (Appendix I); four sites were in close proximity but different sampling methods were used at each (e.g., gill net vs. minnow trap) (Scott 2010b). Only two species were non-native: the redbreast sunfish and the striped shiner. During this survey effort, the Emory was the only OBRI watershed found to support the muskellunge, channel catfish (*Ictalurus punctatus*; Photo 15), and logperch. It is unclear if this indicates that those species are not present in the other watersheds or if they simply were not found because of differences in the sampling methods used.

Photo 15. Channel catfish (NPS photo by E.M. Scott).

Abundance

The NPS (2015a) provides relative abundance information for the majority of fish species confirmed within OBRI (Appendix G). Of the 48 species with abundance information, 27 are considered common or abundant, 15 are uncommon or rare, and six are considered occasional (i.e., observed at least once every few years) (NPS 2015a).

Russ (2006) documented nearly 4,000 fish during 2004–2005 sampling at 13 sites within OBRI. The most abundant species were the telescope shiner (686 fish), the Tennessee shiner (534 fish), and the largescale stoneroller (527 fish) (Appendix H). Seven different species were represented by only one individual, although two of these species were non-natives (redear sunfish and golden shiner [*Notemigonus crysoleucas*]) (Russ 2006).

During 2004–2006 sampling at 18 sites, Scott (2010b) observed over 5,600 total fish. The most abundant species were the whitetail shiner (Photo 16) (1,220 fish), the telescope shiner (1,088 fish), and the largescale stoneroller (788 fish) (Scott 2010b) (Appendix I). Conversely, five species were each represented by one individual (Scott 2010b).

Photo 16. Whitetail shiner (NPS photo by E.M. Scott).

Clear Creek Watershed

During the summer of 2005, Russ (2006) documented 1,597 total fish across five Clear Creek locations. The most abundant species were the largescale stoneroller (353 fish), the warpaint shiner (257 fish), and the telescope shiner (210 fish). Four species were each represented by one individual (Appendix H) (Russ 2006).

Scott (2010b) sampled a total of 672 fish at two Clear Creek locations in 2005 (Appendix I). The most abundant species were the largescale stoneroller (169 fish), the warpaint shiner (137 fish), and the whitetail shiner (111 fish). Three species were each represented by one individual (Scott 2010b).

Daddy's Creek Watershed

Russ (2006) documented 334 total fish at two locations along Daddy's Creek during 2004. The most abundant species were whitetail shiner (80 fish), telescope shiner (54 fish), and rock bass (*Ambloplites rupestris,* 44 fish). Only two species were each represented by single individuals (Appendix H) (Russ 2006).

During 2004 sampling at one site on Daddy's Creek, Scott (2010b) observed 158 total fish (Appendix H). The whitetail shiner was by far the most abundant species, with 68 individuals observed. The next most abundant species were the rock bass (18 fish) and river chub (*Nocomis micropogon*, 16 fish) (Scott 2010b). Just one species (yellow bullhead [*Ameiurus natalis*]) was represented by one individual (Appendix I).

Obed River Watershed

Russ (2006) documented 1,622 fish across five Obed River sites (Appendix H). The most abundant species were the telescope shiner (379 fish), Tennessee shiner (350 fish), and whitetail shiner (156 fish). Eight different species were each represented by one individual (Russ 2006).

The Obed River produced the highest number of fish observations during Scott's (2010b) 2004–2006 sampling (3,579 individuals), likely because this stream had the greatest number of sampling locations (10 sites) (Appendix H). The most abundant species were the whitetail shiner (951 fish), the telescope shiner (566 fish), and the largescale stoneroller (454 fish). Despite the large number of fish, four different species were each represented by one individual (Scott 2010b) (Appendix I).

Emory River Watershed

At just one Emory River sampling site within OBRI, Russ (2006) observed 385 total fish. The most abundant species were the Tennessee shiner (151 fish), the largescale stoneroller (53 fish), and the telescope shiner (43 fish). Seven species were each represented by one individual (Appendix H) (Russ 2006).

During 2004 and 2006 sampling at five Emory River sites, a total of 1,262 fish were observed (Scott 2010b) (Appendix H). The most abundant species were the telescope shiner (426 fish), Tennessee shiner (235 fish), and largescale stoneroller (155 fish). Nine species were each represented by one individual (Appendix I).

Density

Of the two fish surveys conducted in the OBRI region (Russ 2006, Scott 2010a), only Russ (2006) reported the length of transect surveyed. There were 13, 200 m (656 ft) transects that fell within park boundaries for a total length of 2.6 km (1.6 mi). Using this information and abundance data, average densities can be calculated overall and for each watershed. The average density across all park watershed sampling locations was 1.5 fish/m (Russ 2006). The species with the highest park-wide density was the telescope shiner, averaging 0.3 fish/m (Appendix H) (Russ 2006).

Clear Creek Watershed

Russ (2006) sampled five Clear Creek transects for a total length of 1 km (0.6 mi) and recorded 1,597 total fish. This yields an average density of 1.6 fish/m (Appendix H). Densities per site ranged from 1.0 fish/m at Hegler Ford to 2.1 fish/m at Norris Ford, the farthest-upstream sampling location within OBRI (Russ 2006). The species with the highest density was the largescale stoneroller, with an average of 0.4 fish/m across the watershed (Russ 2006).

Daddy's Creek Watershed

Along two Daddy's Creek transects totaling 400 m (0.25 mi), Russ (2006) observed 300 individual fish. The resulting average density was 0.8 fish/m (Russ 2006). Density was slightly higher at the downstream location (Obed Junction: 0.9 fish/m) than at the upstream location (Devil's Breakfast Table: 0.8 fish/m). The whitetail shiner had the highest density, with 0.2 fish/m (Russ 2006).

Obed River Watershed

Russ (2006) sampled five transects totaling 1 km (0.6 km) on the Obed River and documented 1,622 individual fish; the average density along these transects was 1.6 fish/m. Densities per site ranged from 2.3 fish/m at Emory Junction, the farthest-downstream sampling location, to 1.1 fish/m at Daddy's Junction (Russ 2006). The species with the highest average density was the telescope shiner, at 0.4 fish/m across the watershed (Russ 2006).

Emory River Watershed

Russ (2006) sampled one, 200 m (0.12 mi) transect on the Emory River and observed 385 fish. The resulting density was 1.9 fish/m (Appendix H). The Tennessee shiner had the highest-density with 0.8 fish/m (Russ 2006).

Age Class Distribution/Recruitment

An analysis of age class distribution in fish populations can provide insight into recruitment success and the likelihood that a population will persist (Brunel 2010). Low numbers of fish in young age classes suggests a reduction in reproduction or in egg/hatchling survival, which could contribute to overall population decline or even extirpation. If larger, older age classes are absent or reduced, the number of reproducing fish may be in decline, which could lead to reduced recruitment in the near future (Brunel 2010). Age class distribution may be impacted by many factors, including overfishing, changes in environmental quality or habitat, or disease. Although some fish-length data are available for various bass and sunfish species collected by the USGS at OBRI sampling locations from 1996–2004 (available through http://waterqualitydata.us/portal/), an evaluation of age class distribution based on these raw data is beyond the scope of this NRCA.

Index of Biotic Integrity

Clear Creek Watershed

IBI scores were calculated for three Clear Creek locations within OBRI between 1996 and 2007 (Russ 2006, Scott 2010a). The majority of scores fell within the good range, with only one score of fair/good for Norris Ford (2002) and one fair score for Lilly Bridge (2002) (Table 36).

Table 36. IBI scores for Clear Creek watershed locations within OBRI (Russ 2006, Scott 2010a).

Site	July 1996	June/August 2002	June-Sept. 2005	2007
Norris Ford	50 (good)	46 (fair/good)	50 (good)	–
Barnett Bridge (Waltman Ford)	52 (good)	56 (good/excellent)	48 (good)	–
Lilly Bridge	–	40 (fair)	48 (good)	48 (good)

Daddy's Creek Watershed

IBI scores have only been calculated for one location on Daddy's Creek within OBRI (Russ 2006, Scott 2010a). All three scores between 1996 and 2005 fell in the good or good/excellent ranges (Table 37).

Table 37. IBI scores for Daddy's Creek watershed locations within OBRI (Russ 2006, Scott 2010a).

Site	24 July 1996	8 June 2004	2005
Devil's Breakfast Table	54 (good/excellent)	48 (good)	52 (good)

Obed River Watershed

IBI scores are available for Potters Ford on the Obed River for four dates between 1996 and 2006 (Russ 2006, Scott 2010a). All scores fell in the good range (Table 38).

Table 38. IBI scores for Obed River watershed locations within OBRI (Russ 2006, Scott 2010a).

Site	25 July 1996	8 May 2001	22 July 2004	2006
Potters Ford	48 (good)	48 (good)	50 (good)	48 (good)

Emory River

Only two IBI scores are available for a single location on the Emory River within OBRI (Russ 2006, Scott 2010a). The 1995 score was in the good/excellent range and the 2005 score was in the good range (Table 39).

Table 39. IBI scores for Emory River watershed locations within OBRI (Russ 2006, Scott 2010a).

Site	11 September 1995	25 August 2005
Nemo	56 (good/excellent)	52 (good)

<u>Trends in Rare Fish Spatial Distribution</u>

For this assessment, two rare fish species within OBRI will be evaluated: the federally-threatened spotfin chub and the state-threatened ashy darter. According to available sources, the ashy darter has only been documented within OBRI in the Emory River at Nemo (Russ 2006). The remainder of this section will focus on spotfin chub distribution. Russ (2006) reported the species' historic distribution in the OBRI region (as determined by Jenkins and Burkhead [1984]) and the distribution as of 2004–2005.

Spotfin chub typically inhabit moderate-gradient streams with average widths of 15 m (49 ft) and are commonly found at depths of 0.3–1.0 m (1.0–3.3 ft) (Jenkins and Burkhead 1984, Russ 2006). In general, Russ (2006) found that spotfin chub occurred most frequently in run habitats (deep and fast waters with little surface agitation) over boulder or bedrock substrates. The species was only observed in pools during the winter and was rarely found in riffle habitat. The fish was also rare in areas with gravel or sand substrates (Russ 2006).

Clear Creek

According to Russ (2006), spotfin chub distribution in Clear Creek decreased from a historic distribution of 14 river km (8.7 mi) (Jenkins and Burkhead 1984) to 8.5 river km (5.3 mi) by 2005. The decrease occurred at the upper end of the historic distribution, just downstream of the White Creek confluence (Russ 2006).

From 2004–2005, Russ (2006) observed spotfin chub at Jett Bridge during all seasons, although they were most abundant in the fall (Table 40, Figure 52). The species was observed at Lilly Bridge during all seasons except winter, and was most abundant during the summer and fall of 2005.

Table 40. Number of spotfin chub observed during snorkeling at Clear Creek sampling locations, 2004–2005 (Russ 2006).

Site	2004			2005			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Jett Bridge	2	1	36	4	6	6	10
Lilly Bridge	2	2	2	0	6	34	47

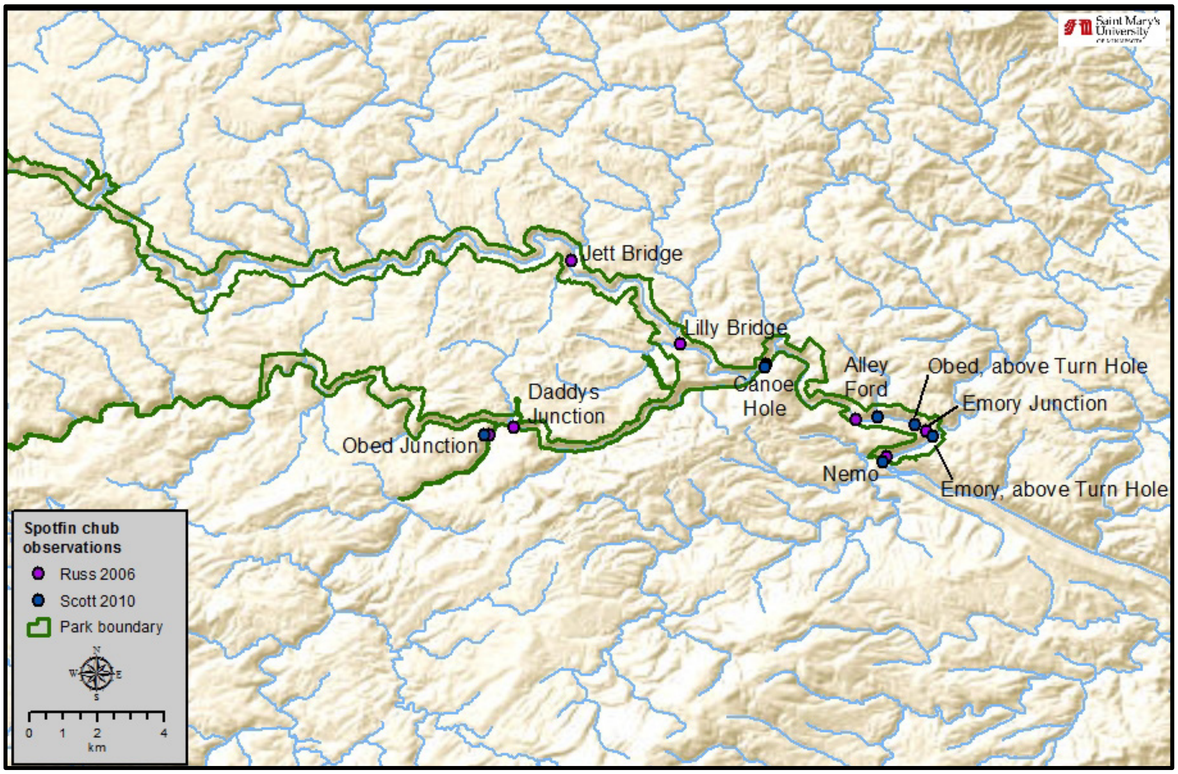

Figure 52. Sampling locations where spotfin chub have been observed by Russ (2006) and/or Scott (2010b).

Daddy's Creek

Spotfin chub distribution in Daddy's Creek also decreased, from a historical distribution of 3.7 river km (2.3 mi) (Jenkins and Burkhead 1984) to 0.5 km (0.3 mi) by 2005. As with Clear Creek, the decrease occurred at the upper end of the historic distribution (Russ 2006). Russ (2006) observed spotfin chub at Obed Junction during all seasons except winter, with highest abundances in the fall (Table 41, Figure 52). Snorkeling surveys were conducted for a total of 14 hours at Devil's Breakfast Table, farther upstream in the watershed, but no spotfin chub were observed (Russ 2006).

Table 41. Number of spotfin chub observed during snorkeling at Daddy's Creek sampling locations, 2004–2005 (Russ 2006).

Site	2004			2005			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Obed Jct.	9	18	47	0	1	17	41

Obed River

Spotfin chub distribution showed no change over time in the Obed River, at 13 river km (8.1 mi) historically (Jenkins and Burkhead 1984) and as of 2005 (Russ 2006). Between Russ (2006) and Scott (2010b), spotfin chub have been observed on the Obed River at Daddy's Junction, Canoe Hole, Alley Ford, above Turn Hole, and at the Emory Junction (Figure 52).

Similar to previous watersheds, Russ (2006) observed spotfin chub at Daddy's Junction during all seasons except winter, and the species was most abundant during fall (Table 42).

Table 42. Number of spotfin chub observed during snorkeling at Obed River sampling locations, 2004–2005 (Russ 2006).

Site	2004			2005			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Daddy's Jct	3	2	16	0	4	2	12

Emory River

According to Russ (2006), spotfin chub distribution increased in the upper Emory River from 47 river km (29.2 mi) historically (Jenkins and Burkhead 1984) to 52.5 river km (32.6 mi) by 2005. It should be noted that not all of this distribution falls within OBRI boundaries. The increase occurred upstream of the Emory's confluence with the Obed River (Russ 2006).

Between Russ (2006) and Scott (2010b), spotfin chub have been observed on the Emory River within OBRI at Nemo and just upstream of Turn Hole (Figure 52). As with the Obed River, Russ (2006) observed the species at Nemo during all seasons except winter, and the species was most abundant during fall (Table 43).

Table 43. Number of spotfin chub observed during snorkeling at Emory River sampling locations, 2004–2005 (Russ 2006).

Site	2004			2005			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Nemo	26	58	115	0	62	91	452

<u>Threats and Stressor Factors</u>

Threats to OBRI's fish communities, as identified by the NRCA project team, include changes in water quantity (e.g., upstream urban withdrawals, impoundments) and water quality, oil and gas development, impacts from historic mining waste, competition from non-native fish species, and drought. Factors that may alter or have already altered water quantity and water quality in the OBRI region will be discussed in detail in Chapters 4.8 and 4.9 of this assessment. Reductions or alterations in water quantity (i.e., disruption of the natural flow regime) can reduce or alter fish habitat (Russ 2006). Impoundments are thought to reduce spotfin chub habitat by replacing riverine or "run" stretches with pools and cool tailwaters with water temperatures below the species' preferred range (Russ 2006). Impoundments and flow alterations, in combination with land clearing and certain agricultural practices, can increase sedimentation/siltation in rivers, which further reduces the spotfin chub's preferred habitat (Russ 2006, Candlish 2010).

Drought conditions are common on the Cumberland Plateau and often contribute to low flow conditions in the region's streams (Jenkins and Burkhead 1984, Russ 2006). Lower water levels reduce available habitat for fish and can increase interspecific competition for valuable resources (e.g., food sources, spawning habitat) (Russ 2006). For example, Russ (2006) observed whitetail shiners and spotfin chub competing for spawning sites, and whitetail shiners have previously been documented consuming the eggs of spawning spotfin chub (Matthews 1997, as cited in Russ 2006). Reduced water levels during droughts can also impact water quality by increasing pollutant/contaminant concentrations. During low flows on the upper Obed River, specific conductance (an indicator of chemical loading) often exceeds 200 μs/cm; a conductance above this level may be harmful to sensitive freshwater fish species (NPS 2015b).

Although coal mining no longer occurs within the OBRI watersheds, historic mining wastes are still impacting some streams (see Chapter 4.8.5 for more details). Contaminated drainage often contributes heavy metals to aquatic systems, which can accumulate in fish tissues over time (Emmott et al. 2005). Acids from mining waste also reduce stream pH, causing stream acidification (Hutton 2009). Stream acidification can cause elevated aluminum levels in the water, to a point that may be toxic to fish and macroinvertebrates (Baker and Schofield 1982, Emmott et al. 2005). Extreme fluctuations in pH, as may occur after precipitation brings acidic runoff from mine wastes into streams, can interfere with the respiration of aquatic organisms, including fish (NPS 2015b).

Contamination from oil and gas development is also a risk for OBRI's fish communities. In 2002, an oil spill just outside OBRI contaminated the waters of Clear and White Creeks (Trustees 2008). Following the spill, primary productivity of the downstream benthic algal community decreased and "sublethal stress" (e.g., organ dysfunction, reduced condition indices) was detected in redbreast sunfish and rock bass near the spill site (Trustees 2008, p. 3–4). Sampling suggested that the immune systems were compromised in these fish as well. While no acute, lethal impacts to the fish community were observed from the spill, the sublethal impacts could reduce survival, growth, and reproduction. These impacts appeared to be short-term, as measures of stress in sampled fish were dramatically lower in 2003 and 2004 (Trustees 2008).

Additional changes in water quality from other anthropogenic sources (e.g., agriculture, development) are also a concern. These sources often contribute excess nutrients to streams; this condition is particularly serious in streams that are naturally nutrient-poor, such as those within OBRI (Russ 2006). Higher nutrient levels typically increase algal growth in an aquatic system, which can favor herbivorous fish over other species, potentially altering fish community composition (Russ

2006). As this excessive algal growth decomposes, dissolved oxygen levels in the water can drop to dangerously low levels (USGS 2013, 2015). Anthropogenic land uses can also increase siltation and cause higher stream turbidity levels. This can impact food availability for some fish species and also impede feeding strategies of the many stream fish that rely on visually locating their food (Jenkins and Burkhead 1984, Russ 2006).

Six non-native fish species are currently on the NPSpecies list for OBRI (Appendix G) (NPS 2015a). Some of these species may have been historically stocked by resource managers to enhance recreational fishing opportunities (e.g., redeye bass) (Russ 2006). No specific information is available regarding the impact non-natives have on native fish in the OBRI region, but there may be increased competition for habitat and food resources. Grass carp (*Ctenopharyngodon idella*), for example, are voracious herbivores that can impact the entire aquatic food web through their influence on aquatic plant density and community composition (Bain 1993, USGS 2016).

Data Needs/Gaps

A fish survey similar to those of Russ (2006) and Scott (2010a, 2010b) should be conducted to determine if any changes have occurred in species diversity, abundance, or density over the past decade. Additional data could be collected on age class distribution during this survey in order to assess recruitment among OBRI's various fish populations. The recently-initiated APHN monitoring program for rare fish species will provide much-needed insight into the spatial distribution and overall status of spotfin chub within OBRI.

Overall Condition

Species Diversity

The project team assigned this measure a *Significance Level* of 3. A total of 55 fish species occur throughout OBRI's waters (Appendix G). Twenty-four of these species have been documented in the Clear Creek watershed, 19 in the Daddy's Creek watershed, and 40 in both the Obed and Emory River watersheds (Russ 2006, Scott 2010b). These numbers are about what would be expected given the size of each stream and watershed (Russ 2006). Therefore, all OBRI watersheds are assigned a *Condition Level* of 1 for this measure, indicating low concern.

Abundance

Species abundance was assigned a *Significance Level* of 2 by the project team. During surveys in the mid-2000s, Russ (2006) documented nearly 4,000 fish at 13 sites within OBRI and Scott (2010a, 2010b) observed over 5,600 fish at 18 sampling sites. Abundances were highest on the Obed River, likely due to the largest number of sampling sites being located in this watershed (Appendix H, Appendix I). Smaller fish such as shiners and darters were often more abundant than larger fish (e.g., catfish, longnose gar), as may be expected given habitat/range needs. At this time, there is no major concern regarding fish abundance within OBRI streams. As a result, all watersheds are assigned a *Condition Level* of 1.

Density

A *Significance Level* of 2 was also assigned for this measure by the project team. Density data for OBRI fish populations are limited to just the Russ (2006) study. The average density across all park watershed sampling locations was 1.51 fish/m, with densities per watershed ranging from 0.84 fish/m (Daddy's Creek) to 1.93 fish/m (Emory River) (Russ 2006). Variation in densities between watersheds is normal, as the stream sizes and therefore amount and type of available habitat vary. However, given that data are limited to one study, a *Condition Level* cannot be assigned to this measure for any of the OBRI watersheds.

Age Class Distribution/Recruitment

The project team assigned this measure a *Significance Level* of 3. Although age class distribution can be a useful metric in assessing recruitment success and population persistence, information for OBRI watersheds is limited to raw fish length data for several species from 1996–2004, making an age class assessment beyond the scope of this NRCA. As a result, a *Condition Level* cannot be assigned at this time.

Index of Biotic Integrity

The IBI measure was also assigned a *Significance Level* of 3. The availability of IBI data varies by watershed. For example, three locations on the Clear Creek watershed within OBRI were scored on multiple occasions between 1996 and 2007, while just one location on the Emory River within OBRI was scored, and only twice (1995 and 2005) (Russ 2006, Scott 2010a). All available IBI scores for Daddy's Creek and the Emory River are in the good or good/excellent range. Therefore, a *Condition Level* of 0 or no concern is assigned to this measure for these two watersheds. While the majority of IBI scores for Clear Creek were in the good range, two were in the fair or fair/good range (Table 36). Although all of the available IBI scores were in the good range, three of the four were at the very bottom of the range (Table 38). As a result, a *Condition Level* of 1, indicating low concern is assigned for the Clear Creek and Obed River watersheds.

Trends in Rare Fish Spatial Distribution

This measure was assigned a *Significance Level* of 3. Information regarding rare fish distribution in OBRI is largely limited to data on spotfin chub. A survey of seasonal distribution by Russ (2006) suggested that spotfin chub distribution had decreased in the Clear and Daddy's Creek watersheds, remained the same in the Obed River, and increased in the Emory River. The Emory River is also the only watershed in OBRI where the ashy darter has officially been documented. Based on this, *Condition Levels* of 2 (moderate concern) are assigned to the Clear and Daddy's Creek watersheds. The Obed River watershed is assigned a *Condition Level* of 1 (low concern) for this measure, and the Emory River is assigned no concern (*Condition Level* = 0) (Table 44).

Table 44. A summary of Condition Levels for each measure by watershed and Weighted Condition Scores (WCS) for each watershed.

Measure	Significance Levels	Condition Levels			
		Clear Creek	Daddy's Creek	Obed River	Emory River
Species diversity	3	1	1	1	1
Abundance	2	1	1	1	1
Density	2	N/A	N/A	N/A	N/A

Table 44 (continued). A summary of Condition Levels for each measure by watershed and Weighted Condition Scores (WCS) for each watershed.

Measure	Significance Levels	Condition Levels			
		Clear Creek	**Daddy's Creek**	**Obed River**	**Emory River**
Age class distribution/recruitment	3	N/A	N/A	N/A	N/A
Index of Biotic Integrity	3	1	0	1	0
Trends in rare fish spatial distribution	3	2	2	1	0
WCS	**–**	**0.29**	**0.23**	**0.23**	**0.10**

Watershed Summaries

Clear Creek Watershed

Based on the measures selected for this NRCA, fish communities in the Clear Creek watershed are in *good condition* (*WCS* = 0.29) (Table 44). Species diversity, abundance, and IBI are all of low concern. Rare fish spatial distribution is of moderate concern, due to a possible decrease in spotfin chub distribution documented by Russ (2006). This watershed was impacted by an oil spill in 2002 but appears to be recovering.

Daddy's Creek Watershed

Fish communities in the Daddy's Creek watershed are also in *good condition*, with a *WCS* of 0.23. Species diversity and abundance are of low concern, while IBI is currently of no concern. Rare fish spatial distribution is of moderate concern, also due to a possible decrease in spotfin chub distribution documented by Russ (2006).

Obed River Watershed

Fish communities in the Obed River watershed are in *good condition* as well (*WCS* = 0.23) (Table 44). Species diversity, abundance, IBI, and rare fish spatial distribution are all rated of low concern. Park management is concerned that impacts on water quality and quantity from growing upstream developments (e.g., Crossville, Crab Orchard) may threaten the Obed River's fish communities.

Emory River Watershed

Emory River fish communities are in *good condition* with a *WCS* of 0.10. Species diversity and abundance are currently of low concern. IBI scores are rated of no concern, as is rare fish spatial distribution, based largely on an expansion in spotfin chub distribution documented by Russ (2006).

Weighted Condition Score

An overall score for OBRI was calculated by averaging the individual *WCS*s for each watershed. The resulting *WCS* for OBRI's fish communities was 0.21, indicating good condition. While some of the measures seem stable (e.g., diversity, abundance), there is some concern that rare fish distribution is declining. As a result, no overall trend was assigned. A low confidence border was applied, given that condition could not be determined for two of the selected measures (density, age class distribution) and several measures have data that is in excess of 10 years old.

Fish Communities		
Watershed	**WCS**	**Overall WCS = 0.21**
Clear Creek	0.29	
Daddy’s Creek	0.23	
Obed River	0.23	
Emory River	0.1	

4.5.6. Sources of Expertise

- Robert Emmott, APHN Biologist
- Evan Raskin, APHN Assistant Data Manager/Biologist

4.5.7. Literature Cited

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4.6. Cobble Bars/River Scour Prairies

4.6.1. Description

Cobble bar or river scour prairies are plant communities that occur on flood-scoured alluvial bars along the rivers and creeks of OBRI (Murdock et al. 2013). A variety of alluvial bars occur throughout the river system and are typically classified by sediment composition (e.g., boulder, cobble, or sand) (Wolfe et al. 2007). Cobble bars typically consist primarily of rocks greater than 25 cm (9.8 in) but less than 1 m (3.3 ft) in diameter, with gaps filled by smaller cobbles (6–25 cm [2.4–9.8 in] diameter) and sandy alluvium (Murdock et al. 2013). The slope of cobble bars is generally less than 30%, with the highest surface of the bar generally no more than 1–1.5 m (3.3–4.9 ft) above summer base-flow of the river or stream (Photo 17) (Murdock et al. 2013). All 72.4 river km (45 river mi) within OBRI have been surveyed for cobble bars, and 168 unique cobble bar areas have been identified and mapped (Murdock 2008, NPS 2015b).

Photo 17. A cobble bar at OBRI (NPS photo by Nora Murdock).

The riverine vegetation community supported by cobble bars is endemic to the Cumberland Plateau of Tennessee and Kentucky and is considered globally imperiled throughout its range (Murdock et al. 2013, NatureServe 2015). Less than 200 ha (500 ac) are thought to remain, the majority of which fall within OBRI and BISO (Murdock et al. 2013). This community is characterized by native warm-season grasses and forbs with short, flood-tolerant shrubs, producing a prairie-like appearance (Estes and Fleming 2009, Murdock et al. 2013). While many prairie ecosystems are maintained by fire, river scour prairies depend on disturbance from frequent, high-energy flooding for their continued existence (Wolfe et al. 2007, Wofford et al. 2008, Murdock et al. 2013). The force of these floods wipes out vegetation not adapted to such disturbance, particularly large, woody species (Murdock et al. 2013).

Cobble bar habitats support a relatively large number of rare plants, including some endemic species that grow nowhere else in the world (Wolfe et al. 2007, Murdock et al. 2013). At OBRI, these include one species classified as federally-threatened (Cumberland rosemary) and two species under consideration for federal-listing (Cumberland sandreed [*Calamovilfa arcuata*] and Monongahela Barbara's buttons [*Marshallia grandiflora*]). Additional rare species found on OBRI's cobble bars are listed in Appendix J. Cobble bars also provide habitat for wildlife such as river otters, muskrats, spotted sandpipers (*Actitis macularia*), turtles (order Testudines), and timber rattlesnakes (*Crotalus horridus*) (Murdock et al. 2013).

OBRI is considered critical to the survival of the imperiled Cumberland rosemary (Photo 18), as it supports almost 75% of the known remaining populations, as well as the single largest population left in existence (Murdock and Emmott 2013). The species is known to occur along the Obed River and on Clear and Daddy's Creeks (USFWS 2011). Cumberland rosemary tends to inhabit open, sandy areas on cobble bars, sometimes forming dense colonies (Wofford et al. 2008, Estes and Fleming 2009). As with other cobble bar species, Cumberland rosemary depends on regular flooding to prevent the open habitats where it thrives from being overgrown and shaded by woody species (Murdock and Emmott 2013).

Photo 18. Cumberland rosemary (NPS photo by Nora Murdock).

4.6.2. Measures

- Percent cover of large shrubs and trees
- Percent cover of grasses and herbs
- Number of Cumberland rosemary clumps
- Overall coverage of Cumberland rosemary
- Trends in Element Occurrences

4.6.3. Reference Conditions/Values

The reference condition for this component will be based on baseline surveys of the community completed by the NPS (Murdock and Emmott 2013, APHN 2015). The results of these surveys are presented here and can be used for comparison in future assessments of OBRI's cobble bar communities.

4.6.4. Data and Methods

The APHN initiated a cobble bar community monitoring program in 2007. The primary goal is to determine whether habitat quality/structure and successional patterns in these communities are changing over time (Murdock et al. 2013). Efforts began by identifying and mapping all cobble bar locations within OBRI and BISO (Murdock 2008). Twelve sites within OBRI were selected for regular monitoring (Figure 53); half of the sites are visited each year in the late summer/early fall, so that each site is sampled every other year (Murdock et al. 2013). The monitoring program documents substrate composition (e.g., sand, gravel, cobble), vegetation community structure, abundance of selected rare plant species, and presence/abundance of invasive exotic species (Murdock et al. 2013). A line intercept method is used to measure cover of shrubs and trees over 1 m (3.3 ft) tall while a point intercept method is used for vegetation less than 1 m in height and for substrate classes (Murdock et al. 2013). Data from these monitoring efforts through 2015 were provided by the APHN (2015).

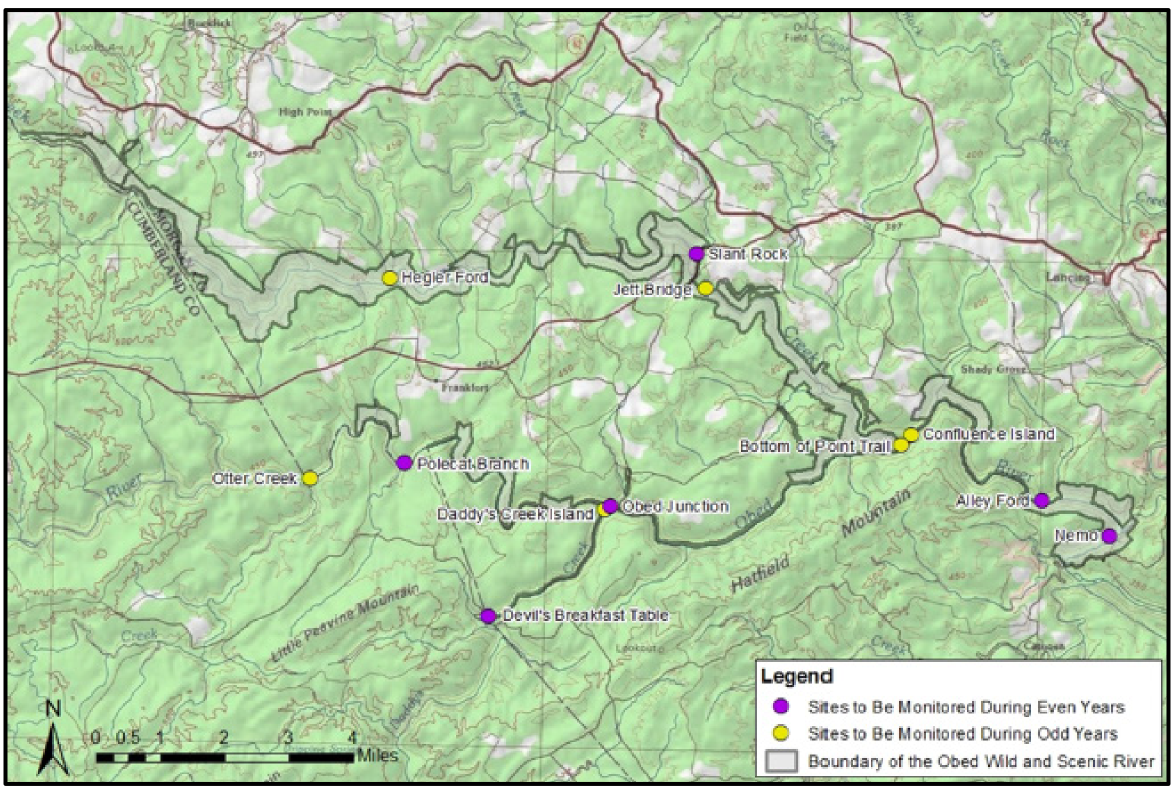

Figure 53. The locations of APHN cobble bar monitoring sites within OBRI; note that the park boundary shown here is no longer accurate (reproduced from Murdock et al. 2013).

Cumberland rosemary monitoring has been occurring at OBRI since 2001. As time and resources allowed, NPS and TDEC employees conducted complete censuses (counting and measuring all plants) of a select number of accessible populations in the park (Murdock and Emmott 2013). During these visits, the presence and cover of invasive exotic species were also documented. From the start of monitoring through 2014, 10 different populations have been sampled at OBRI (Murdock and Emmott 2013, APHN 2015). Data from OBRI for 2001 and 2005 were presented by the TDEC (2006) and summarized by the U.S. Fish and Wildlife Service (USFWS) (USFWS 2011). More recently, APHN staff have incorporated Cumberland rosemary monitoring into their cobble bar monitoring protocol. Data from 2007–2015 monitoring efforts were provided by the APHN (2015).

Over 3 days in 2007–2008, Wofford et al. (2008) conducted a survey of riparian habitats along the Obed River for rare (threatened and endangered) plants and exotic invasive species. Field visits occurred during July in 2007 and in September of 2008 along the river section from Obed Junction to the Clear Creek confluence (Wofford et al. 2008). Observations included the approximate population size, vigor, and habitat of both rare species and exotic invasive species. In addition, small populations of invasive species were removed by hand if feasible (Wofford et al. 2008).

EOs are one way of surveying, mapping, and assessing populations of high priority species (NatureServe 2016). EO data provide information on where specific species exist on the ground, and their populations are ranked based on their overall viability or probability of persistence (NatureServe 2016). In the State of Tennessee, these data were originally maintained by the NHIP, but are now collected and maintained by the TWRA (in collaboration with TNC); park specific data was provided to SMUMN GSS analysts by the TWRA. The EO ranking system is described in Table 22 in Chapter 4.2.4.

4.6.5. Current Condition and Trend

Percent Cover of Large Shrubs and Trees

Large shrubs and trees can shade out native cobble bar/river scour prairie vegetation; therefore, a low percent cover of these woody species is desirable for the health of cobble bar communities. Throughout APHN sampling, percent cover of woody species at the 12 OBRI cobble bar sites has ranged from 13.7–99.8% (Table 45) (APHN 2015). Woody cover has decreased over time at six of 12 sites, increased at three sites, and remained relatively stable (with some fluctuations) at three sites. During the most recent round of sampling (2014–2015), percent woody cover was >50% at seven of 12 sites (APHN 2015). The percent cover of large shrubs and trees at OBRI cobble bar sites, on average, is higher than coverage at BISO sampling sites, which average around 20% (NPS 2015b).

Table 45. Percent cover of woody species by cobble bar sampling site, 2010–2015 (note that all sampling sites are not visited every year and no OBRI sites were sampled in 2013) (APHN 2015). Site codes correspond to the sample sites mapped in Figure 53.

Site Code	2010	2011	2012	2014	2015	Trend
ALFO	55.2	–	49.6	50.7	–	Decrease
BOPO	–	62.4	–	–	99	Increase
COIS	–	39.4	–	–	39.2	Stable

Table 45 (continued). Percent cover of woody species by cobble bar sampling site, 2010–2015 (note that all sampling sites are not visited every year and no OBRI sites were sampled in 2013) (APHN 2015). Site codes correspond to the sample sites mapped in Figure 53.

Site Code	2010	2011	2012	2014	2015	Trend
DACR	–	28.4	–	–	13.7	Decrease
DEBR	69.2	–	56.6	69.1	–	Stable
HEFO	–	52.5	–	–	60.4	Increase
JEBR	–	99.8	–	–	55.9	Decrease
NEMO	39.6	–	56.3	61.0	–	Increase
OBJU	40.9	–	37.9	30.7	–	Decrease
OTCR	–	47.8	–	–	29.8	Decrease
POBR	53.7	–	74.7	54.8	–	Stable (with fluctuation)
SLRO	42.8	–	36.2	28.1	–	Decrease

Percent Cover of Grasses and Herbs

A decrease in the percent cover of grasses and herbs on a cobble bar may suggest a need for further investigation to determine if site degradation is occurring. Temporary reductions in vegetative cover could also be caused by natural processes such as flood disturbance or drought. Throughout APHN sampling, grass and herbaceous percent cover at the 12 OBRI cobble bar sites has ranged from 8.2–73.6% (Table 46) (APHN 2015). Grass and herbaceous cover increased at five sites, decreased at six sites, and remained relatively stable at one site (APHN 2015). However, decreases were slight (<3%) at three of six sites. During the most recent round of sampling (2014–2015), grass and herbaceous cover was >50% at five of the twelve sites and <15% at two sites (APHN 2015). Graphs of grass cover and herbaceous cover by OBRI site for all years of APHN monitoring can be found in Appendix K.

Table 46. Percent cover of grass and herbaceous vegetation combined by cobble bar sampling site, 2010–2015 (note that all sampling sites are not visited every year and no OBRI sites were sampled in 2013) (APHN 2015). Site codes correspond to the sample sites mapped in Figure 53.

Site Code	2010	2011	2012	2014	2015	Trend
ALFO	43.7	–	46.8	51.1	–	Increase
BOPO	–	15.5	–	–	33.0	Increase
COIS	–	52.6	–	–	50.4	Decrease
DACR	–	53.2	–	–	63.0	Decrease
DEBR	10.6	–	8.2	8.8	–	Decrease
HEFO	–	37.3	–	–	42.0	Increase
JEBR	–	30.7	–	–	37.5	Increase
NEMO	26.8	–	22.9	13.1	–	Decrease
OBJU	73.6	–	58.5	63.2	–	Decrease
OTCR	–	19.5	–	–	18.6	Stable

Table 46 (continued). Percent cover of grass and herbaceous vegetation combined by cobble bar sampling site, 2010–2015 (note that all sampling sites are not visited every year and no OBRI sites were sampled in 2013) (APHN 2015). Site codes correspond to the sample sites mapped in Figure 53.

Site Code	2010	2011	2012	2014	2015	Trend
POBR	39.2	–	32.1	26.1	–	Decrease
SLRO	58.1	–	41.5	56.2	–	Decrease

Number of Cumberland Rosemary Clumps

Due to the clonal nature of Cumberland rosemary, researchers attempt to count "clumps" of the species rather than individual plants (Wofford et al. 2008). The ability to detect Cumberland rosemary can vary with season, as the relatively small plant may be obscured by taller vegetation during the growing season (Raskin, written communication, 10 August 2016). During 2001 monitoring at OBRI, the TDEC (2006) counted 214 total clumps of Cumberland rosemary (USFWS 2011). In 2005, the total number of clumps increased to 336 (USFWS 2011).

Within OBRI, 10 sites were selected by the APHN in 2007 for regular monitoring of Cumberland rosemary populations. The number of clumps at each site ranges from one to 501, the largest known population of the species (Murdock and Emmott 2013, APHN 2015). Among sites that have been sampled more than once, four populations have increased, one has declined (from one clump to zero), and one has remained stable (Figure 54). When the most recent counts from each site are combined, the total known number of rosemary clumps within OBRI adds up to 911 (APHN 2015).

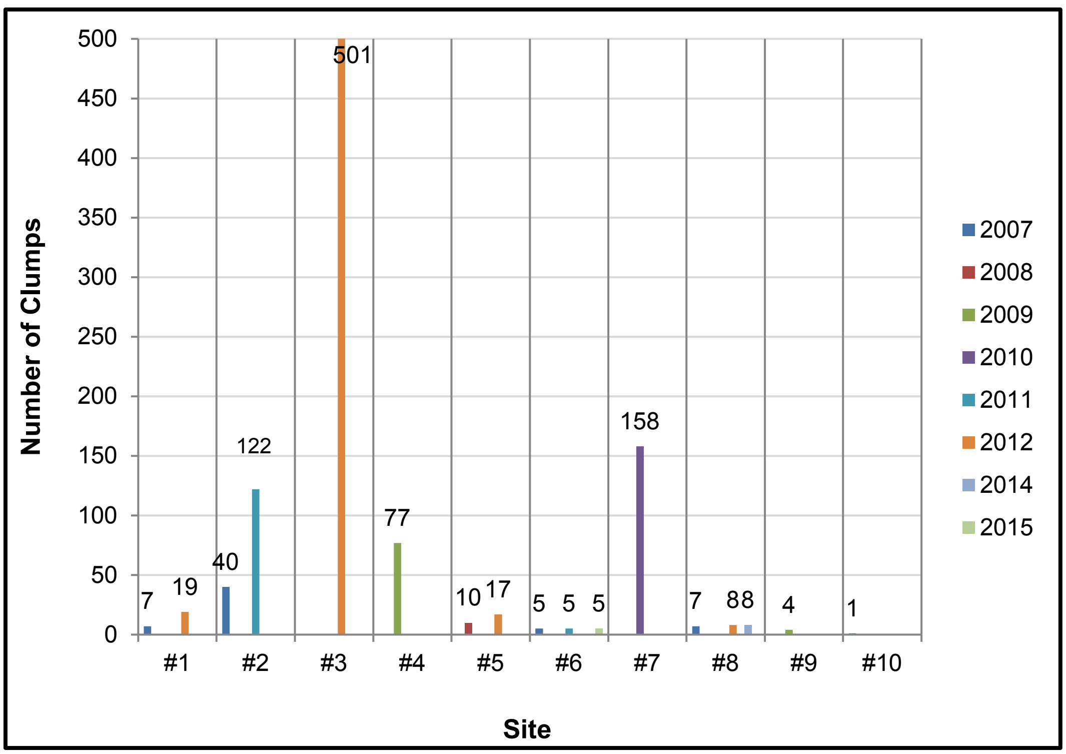

Figure 54. Number of Cumberland rosemary clumps per OBRI site, 2007–2015 (modified from APHN 2015). Site #10 was also surveyed in 2010 and 2012 but no Cumberland rosemary was found.

Overall Coverage of Cumberland Rosemary

Because clumps of Cumberland rosemary often vary in size, it can also useful (and more efficient when time is limited) to estimate overall coverage (in m^2) of the species (Wofford et al. 2008). In 2001, the TDEC (2006) reported 33.9 m^2 (364.6 ft^2) of total area covered by Cumberland rosemary within OBRI (USFWS 2011). In 2005, documented coverage increased to 35.3 m^2 (379.9 ft^2) (USFWS 2011).

The APHN did not begin estimating aerial coverage of Cumberland rosemary as part of their monitoring protocol until 2010. Estimates have only been made at seven of the ten sites, and only two sites have estimates from more than one year (APHN 2015). Coverage at sites where Cumberland rosemary was found has ranged from 0.2 m^2 (2.2 ft^2) to 64.7 m^2 (696.4 ft^2) for the largest known population of the species (Table 47) (APHN 2015). Based on the available data, total known coverage of Cumberland rosemary within OBRI is estimated to be at least 90.7 m^2 (976.3 ft^2). The coverage of two sites with high rosemary clump numbers (sites #2 and #4) have not yet been estimated and will likely increase the known total. Both of the sites with more than one coverage estimate have shown decreases, although the decrease at site #6 was only by 0.1 m^2 (1 ft^2).

Table 47. Estimates of Cumberland rosemary overall coverage (in m^2) by OBRI sample site. Note that coverage has not yet been estimated at sites #2, #4, and #9, and that no Cumberland rosemary clumps have been found at site #10 since 2007 (APHN 2015).

Site	2010	2011	2012	2014	2015
#1	–	–	4.1	–	–
#3	–	–	64.7	–	–
#5	–	–	3.0	–	–
#6	–	0.3	–	–	0.2
#7	18.4	–	–	–	–
#8	–	–	0.6	0.3	–
#10	0	–	0	–	–

Trends in Element Occurrences (EOs)

According to TWRA data obtained in early 2016, there are currently 109 EOs for plant species known to occur in cobble bar communities within OBRI boundaries (TWRA 2015). The majority of these (70) are for Cumberland rosemary. EO ranks for all species ranged from A (excellent viability) to E (verified extant) or H (historical) for older observations, before viability was ranked (TWRA 2015). Forty total EOs were ranked as excellent or good viability (A, B, AB) and 20 were ranked as fair to poor or poor viability (CD, D) (TWRA 2015). Thirty-five of the EOs with excellent or good viability were Cumberland rosemary; eleven Cumberland rosemary EOs were ranked as fair to poor or poor viability. Twenty-one EOs were ranked as E or H, meaning no viability information is available (TWRA 2015). All EOs for cobble bar plant species, with rankings and last observation years, are included in Appendix L.

Threats and Stressor Factors

Threats to the cobble bar community include changes in the frequency, timing, and volume of flood events, and the presence of invasive species. Since these unique communities rely upon frequent, high-energy flooding for their continued existence, any shifts in flood regime could have negative impacts (Wolfe et al. 2007, Murdock et al. 2013). If upstream water withdrawal or climate change led to a decrease in flood frequency, magnitude, or duration, more woody species could survive on cobble bars, leading to increased competition for native herbaceous and short shrub species (Wolfe et al. 2007, Murdock et al. 2013). Endemic species, such as Cumberland rosemary, would be particularly impacted by reduced flooding and increased woody competition and shading (USFWS 2011, Murdock and Emmott 2013). Cobble bar communities also rely upon regular flooding to deposit silt and nutrients, which impact the productivity of vegetation in these habitats (Murdock et al. 2013).

Non-native invasive species are a growing threat to cobble bar communities, as they are capable of shading or otherwise out-competing native plant species (Murdock et al. 2013). The frequent, scouring floods experienced by cobble bars may disturb and clear ground where invasive plant species could easily become established (Murdock et al. 2013). As of 2008, 11 non-native invasive species had been documented in OBRI riverine communities and nine were confirmed specifically on cobble bars (Table 48) (Wofford et al. 2008). In recent years, APHN staff have documented seven additional non-native plant species on cobble bars for a total of 18 species (Raskin, written communication, 10 August 2016). All but four of these 18 species are considered severe or significant threats to native plant communities (TN-IPC 2009). During 2008 surveys, the most widespread invasive species on cobble bars was Chinese lespedeza; the plant was primarily present as scattered individuals and was not forming dense patches, which it is noted for doing elsewhere (Wofford et al. 2008). While invasive species often spread naturally through wind, water, and wildlife, they can also be transported unintentionally by recreational visitors (Estes and Fleming 2009). The NPS has mapped known infestations of invasive plants at OBRI and has initiated eradication efforts. In 2013–2014, staff cleared woody non-native species from cobble bar habitat along 24 km (15 mi) of the Obed River and tributary streams (NPS 2015b). According to APHN monitoring, non-native invasive species cover is presently <3% at all cobble bar monitoring sites (NPS 2015a).

Table 48. Invasive exotic plant species documented on OBRI cobble bars by Wofford et al. (2008). Ranks are determined by the TN-IPC) (TN-IPC 2009).

Scientific Name	Common Name	# of Occurrences	Rank*
Lespedeza cuneata	Chinese lespedeza	15	Severe threat
Persicaria longiseta	Oriental lady's thumb	4	Significant threat
Rosa multiflora	Multiflora rose	3	Severe threat
Spiraea japonica	Japanese meadowsweet	2	Significant threat
Daucus carota	Queen Anne's lace	1	Alert
Ailanthus altissima	Tree of heaven	1	Severe threat
Elaeagnus umbellata var. *parvifolia*	Autumn olive	1	Severe threat
Paulownia tomentosa	Princess tree	1	Severe threat
Microstegium vimineum	Japanese stiltgrass	1	Severe threat

*Additional "severe threat" species documented by APHN staff since 2008 are mimosa (*Albizia julibrissin*), shrubby lespedeza (*Lespedeza bicolor*), Japanese honeysuckle (*Lonicera japonica*), Japanese knotweed (*Polygonum cuspidatum*), and kudzu (*Pueraria montana* var. *lobate*) (Raskin, written communication, 10 August and 30 November 2016).

Data Needs/Gaps

Until recently, few studies had focused on the unique geographic and physical characteristics of cobble bar communities or the role of hydrology in their creation and maintenance (Wolfe et al. 2007). While some basic information has been gathered, many questions remain regarding these important plant habitats. For example, more research is needed on rare plant populations and whether or not they are being impacted by hydrologic changes, water quality impairments (e.g., nutrients, contaminants), invasive species, and recreational use (Emmott et al. 2005, Wolfe et al. 2007). Monitoring of the hydrologic regime and water quality will help managers detect any changes in these environmental factors and potential increased risks to the cobble bar communities. In addition, EOs without viability information (E or H ranks) could be revisited to confirm the continued existence and determine status of these populations.

Overall Condition

Percent Cover of Large Shrubs and Trees

The project team assigned this measure a *Significance Level* of 3. Woody species such as large shrubs and trees can compete with and shade out native cobble bar vegetation. Although woody species cover has decreased at six of 12 APHN monitoring sites over time and increased at only three sites, woody cover is generally higher on OBRI cobble bars (≈49%) than on similar habitats at the nearby BISO (~20%) (APHN 2015, NPS 2015b). This is a cause for moderate concern (*Condition Level* = 2).

Percent Cover of Grasses and Herbs

This measure was also assigned a *Significance Level* of 3 by the project team. A decline in grass and herbaceous cover on cobble bars may indicate a need for closer investigation, to determine if changes are due to site degradation or natural causes (e.g., drought, flooding disturbance). During APHN monitoring (2010–2015), grass and herbaceous cover has increased at five of 12 sites, decreased at six sites, and remained relatively stable at one site. However, decreases were small (<3%) at three sites, and the greatest decrease observed was just under 14% (APHN 2015). As a result, this measure is currently of low concern (*Condition Level* = 1).

Number of Cumberland Rosemary Clumps

A *Significance Level* of 3 was assigned for this measure by the project team. The number of documented rosemary clumps at OBRI has increased from 214 in 2001 to 911 during 2014–2015 APHN sampling (USFWS 2011, APHN 2015). This is primarily due to the discovery of the largest known population of the species (501 clumps), but some individual populations (e.g., site #2) have also shown increases (Figure 54) (APHN 2015). Therefore, this measure is assigned a *Condition Level* of 1, indicating low concern.

Overall Coverage of Cumberland Rosemary

The project team assigned the cover of Cumberland rosemary measure a *Significance Level* of 3. Limited data are available for this measure, given that APHN staff did not incorporate it into their monitoring efforts until 2010. However, the known total coverage of Cumberland rosemary within OBRI based on APHN sampling is estimated to be at least 90.7 m^2 (976.3 ft^2), and coverage has not yet been estimated at three of 10 sites (APHN 2015). This is higher than the 2005 estimate for OBRI of 35.3 m^2 (379.9 ft^2) (TDEC 2006, USFWS 2011), again primarily due to the addition of the large population at site #3. Despite the limited data, researchers currently feel there is little cause for concern with this measure (Murdock and Emmott 2013, NPS 2015a), and it is assigned a *Condition Level* of 1.

Trends in Element Occurrences

This measure was also assigned a *Significance Level* of 3 by the project team. According to recent data from the TWRA, there are 109 element occurrences of plants in cobble bar communities within OBRI boundaries. Although many of the EOs received excellent or good viability rankings (40), some were ranked as poor or fair to poor (20) (TWRA 2015). Several EOs are considered historical, with no recent status information available. As a result, this measure is considered of moderate concern (*Condition Level* = 2).

Weighted Condition Score

The *Weighted Condition Score* for OBRI's cobble bars/river scour prairies is 0.47, indicating moderate concern. The concern is primarily regarding encroachment by woody vegetation, including exotic, invasive species. Since monitoring of cobble bar communities (including Cumberland rosemary populations) began relatively recently, an overall trend cannot yet be determined and a medium confidence border is applied.

Cobble Bars/River Scour Prairies			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.47**
Percent Cover of Large Shrubs & Trees	3	2	
Percent Cover of Grasses & Herbs	3	1	
Number of Cumberland Rosemary Clumps	3	1	
Overall Cover of Cumberland Rosemary	3	1	
Trends in Element Occurrences	3	2	

4.6.6. Sources of Expertise

- Robert Emmott, APHN Biologist
- Evan Raskin, APHN Assistant Data Manager/Biologist

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4.7. Freshwater Invertebrates

4.7.1. Description

Freshwater invertebrates within OBRI are an integral part of the park's ecological diversity (Ahlstedt et al. 2001). There are diverse assemblages of crayfish, mussels, and aquatic insects whose existence depends on the good water quality found in the rivers and creeks inside the park. Freshwater invertebrates and other aquatic species are imperiled in North America and Canada at a far greater rate than terrestrial species (Williams et al. 1993). Native freshwater mussels, in particular, are experiencing severe declines in both diversity and abundance (Williams et al. 1993). Freshwater mussel assemblages are of particular interest to the park, especially the federally-listed endangered purple bean, a species which is present in the park. Freshwater mussels are semi-sessile, benthic filter feeders that syphon water through modified gill structures in order to filter feed on algae, bacteria, and other organic matter suspended in the water column and in interstitial spaces within their aquatic substrate habitats. Freshwater mussels also provide an important food source for several species of fish and wildlife.

Aquatic invertebrate species, in general, are commonly used as indicators of water quality, since many are sensitive to changes in water quality and, in the instance of native freshwater mussels, are reliant on the presence of host fish to carry out their reproductive cycle (Williams et al. 1993, Ahlstedt et al. 2001, Ahlstedt and Bakaletz 2006). The vulnerable larvae of most mussel species attach to and draw nutrients from a host fish's gills for days or months, and will not survive in the absence of these host fish (Ahlstedt and Bakaletz 2006). Insects are commonly used in aquatic health assessments following instances of short-term pollution (Cook and Hutton 2009). Diversity among aquatic insect taxa is particularly high in the southeastern U.S. relative to the rest of North America; OBRI's aquatic insect community likely plays a critical role in sustaining rare and endangered species that are known to occur in the park (Cook and Hutton 2009).

The park also hosts several species of native crayfish, including a group of highly endemic crayfish species which includes the hairyfoot crayfish and two closely-related species that have yet to be described (NPS 2006). Crayfish are largely understudied at OBRI, but play important ecological roles in both the aquatic and terrestrial ecosystem, and are important components of community biodiversity in the park's freshwater rivers and creeks (Reynolds et al. 2013). Crayfish are considered broadly omnivorous because they consume a range of foods including other aquatic invertebrates, vegetation, and, in some cases, small/juvenile fish and fish eggs (Reynolds et al. 2013). Crayfish can also substantially alter the habitats they occupy. They feed on both living and dead vegetation, which impacts habitat structure and influences detrital processing (Reynolds et al. 2013).

4.7.2. Measures

- Species diversity
- Species abundance
- Listed species abundance
- Listed species density
- Listed species shell size (as an indicator of recruitment and age class distribution)

- Index of Biotic Integrity

4.7.3. Reference Conditions/Values

Freshwater Mussels

The reference condition for the freshwater mussels at OBRI will be the results reported by Ahlstedt et al. (2001). This study provides reference conditions for the species diversity, species abundance, and listed species abundance measures in this assessment. Because of the rarity of mussels in the park, and the general nature of the channel gradient, hydrology, and rocky substrates, sampling for density using quadrats was not practical during Ahlstedt et al. (2001).

Two federally-listed mussels have been documented in the Obed River: the purple bean and the Alabama lampmussel. However, shell length data are only available for the purple bean at this time. Purple bean shell lengths were recorded during the Ahlstedt et al. (2001) mussel surveys and serve as the reference condition for the listed species shell size measure to address age class structure of the purple bean.

Other Aquatic Invertebrates

The reference condition for other aquatic invertebrates at OBRI comes from Cook and Hutton's (2009) aquatic insect inventory, which was conducted from 2007–2009. Data from the inventory provide a baseline for the species diversity, species abundance, and IBI measures. Additionally, NPSpecies (NPS2015a) lists eight species of crayfish as present in the park: hairyfoot crayfish, boxclaw crayfish, mountain midget crayfish, beautiful crayfish, triangleclaw crayfish, hay crayfish, blackbarred crayfish, and placid crayfish. Two additional species, Obey crayfish and rusty crayfish, have not been reported in the park but are present in adjacent waters. No federally- or state-listed aquatic invertebrates (other than mussels) have been observed at OBRI.

4.7.4. Data and Methods

The NPSpecies database (NPS 2015a) documents the occurrence and status of flora and fauna in national park units. NPSpecies is accessible from the IRMA portal. Species listed as present in the park have been verified through direct observations, voucher specimens, or official reports that document a species' presence. Park species occurrences are generally categorized as present, probably present, unconfirmed, not in park.

Mussels

Ahlstedt et al. (2001) investigated the park's freshwater mussel assemblages throughout the Obed River and upper reaches of the Emory River, Daddy's Creek, Clear Creek, and White Creek. Ahlstedt et al. (2001) determined species composition, abundance, and whether or not mussels were breeding successfully in the park. Surveys were conducted using visual searches, digging, and substrate fanning at bank sites accessible by road or foot trails, using a mask and snorkel (Ahlstedt et al. 2001). Researchers also searched beneath large flat rocks, boulders, and in bedrock crevices for mussels, and searched stream banks for shell middens (Ahlstedt et al. 2001). Each individual mussel (live or dead) was identified, measured with a digital caliper (total length in mm), and photographed, before being returned to where it was found (Ahlstedt et al. 2001). Voucher specimens were kept only for species not previously documented and were curated into collections at the McClung Museum of

Natural History and Culture in Knoxville, Tennessee (Ahlstedt et al. 2001). Timed searches were used to determine CPUE within 0.25 m^2 (2.7 ft^2) quadrats and used to quantify relative abundances of species (Ahlstedt et al. 2001). Each sampling location was also recorded using a Global Positioning System (GPS) device (Figure 55).

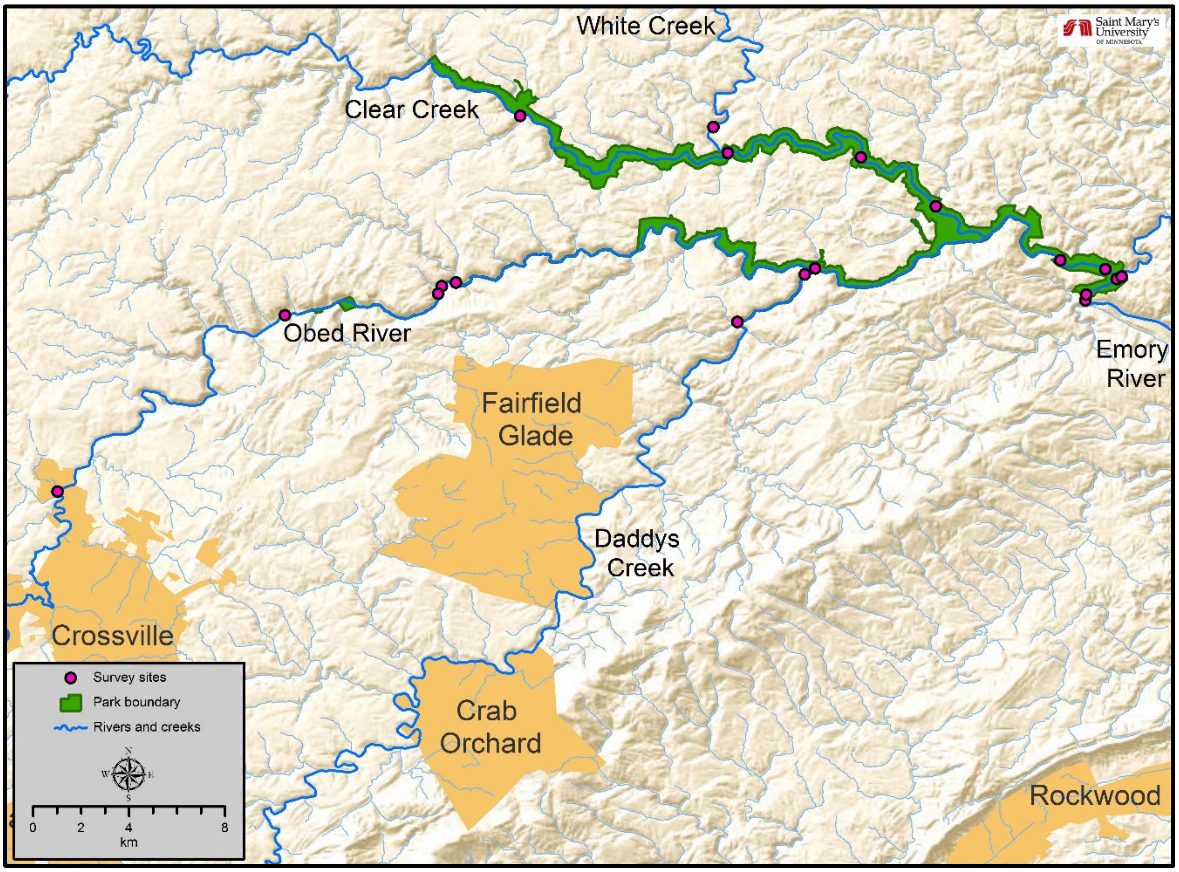

Figure 55. Freshwater mussel survey sites in OBRI, conducted 2000–2001 (Ahlstedt et al. 2001).

Ahlstedt and Bakaletz (2006) conducted a study on the mussel taxa within Clear Creek and White Creek to assess any impacts from an oil spill that occurred in 2002. The mussel surveys occurred from 15–16 August 2005 at one site on White Creek and two sites along Clear Creek, one above the spill site (control) and one below the spill, in order to compare the condition of mussels. Searches were conducted by snorkeling, using the same substrate sampling techniques used by Ahlstedt et al. (2001). Searches were focused on finding juvenile mussels, as the objective of the study was to determine the short- and long-term effects of the spill on recruitment and reproduction. All mussels found, dead or alive, were measured for length (mm) using a Vernier caliper. CPUE was also recorded, but timed searches were limited to one hour increments due to the scarcity of suitable mussel habitat and mussel rarity (Ahlstedt and Bakaletz 2006). This study also looked at mussel densities and CPUE values by sampling 0.25 m^2 (2.7 ft^2) quadrats (Ahlstedt and Bakaletz 2006).

Dinkins and Faust (2015) surveyed 26 sites along the Obed River, Emory River, Clear Creek, and Daddy's Creek between 30 July 2013 and 8 August 2014 in search of native freshwater mussels.

Surveys were conducted with mask and snorkel in order to visually search the substrate while checking for mussels beneath large rocks where habitat appeared suitable (Dinkins and Faust 2015). Survey crews recorded substrate composition, stream depth, current velocity, and whether or not aquatic gastropods were present at each sample location. Each individual live mussel was identified, measured (in mm), and then returned to where it was found. Dead shells were identified and counted but not measured, and collected for cataloging at the McClung Museum. During searches, time was carefully tracked to generate CPUE data for each location (Dinkins and Faust 2015). Sampling locations were recorded with a GPS unit and a photograph (Figure 56).

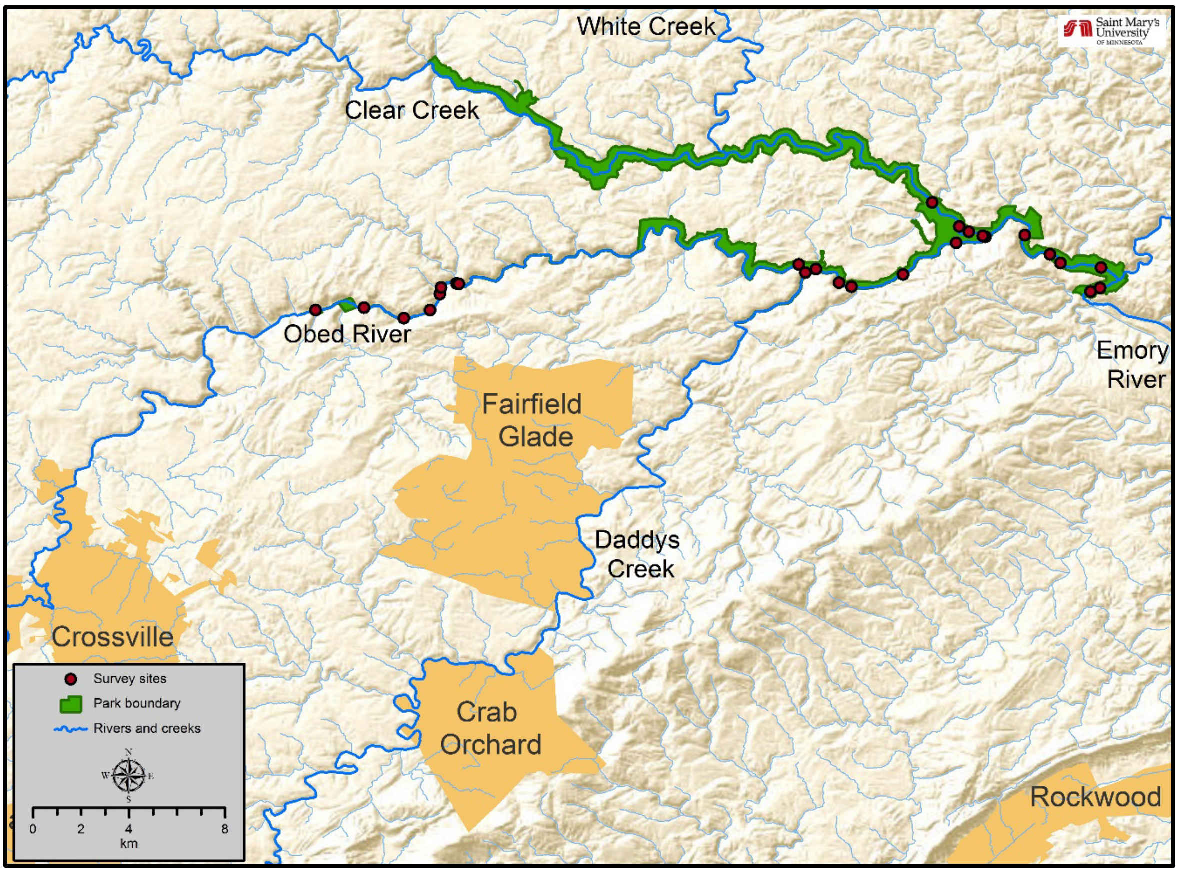

Figure 56. Freshwater mussel survey sites at OBRI (Dinkins and Faust 2015).

<u>Other Aquatic Invertebrates</u>

Cook and Hutton (2009) conducted aquatic insect surveys at 36 sites in OBRI between the spring of 2007 and the summer of 2009. Other types of aquatic invertebrates (e.g., crustaceans, worm, leeches) were collected as well. Sampling sites included the Obed River, Clear Creek, White Creek, Daddy's Creek, and several 1st- through 6th-order stream drainages within the Emory River watershed (Cook and Hutton 2009). Sampling events were timed to obtain data on seasonal variation of aquatic insect presence. Locations were recorded using a GPS, and measurements of stream width, depth, and substrate composition were also included in the study (Figure 57). Additionally, several water quality parameters were collected, including temperature, dissolved oxygen (DO), conductivity, pH, and turbidity (Cook and Hutton 2009).

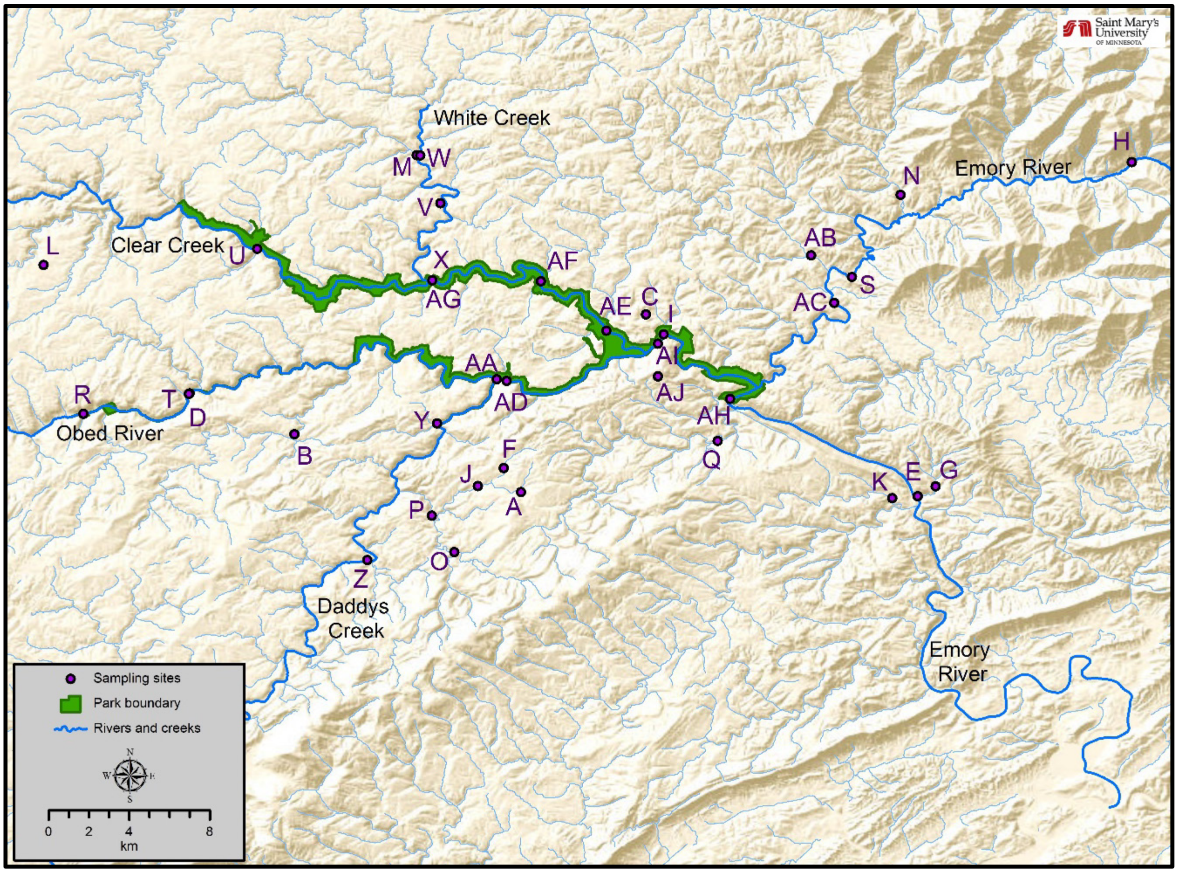

Figure 57. Aquatic insect survey sites in OBRI conducted 2007–2009 (Cook and Hutton 2009).

Cook and Hutton's (2009) methodology for determining biological condition involved several parameters to assess the aquatic insect assemblages observed in the park. This included a calculation of the pollution-tolerance of certain species and an analysis of the percentages and the number of species of several taxonomic groups of aquatic insects: Ephemeroptera/Plecoptera/Tricoptera (EPT) richness, taxa richness, percent Oligochaetes and Chironomids, percent EPT, percent nutrient tolerant organisms, percent clingers, Biotic Score (BSc), and the North Carolina Biotic Index (NCBI). The BSc is a measure of taxa richness (number of species/genera) and was determined for each watershed sampling location, from which a mean BSc was calculated (Cook and Hutton 2009). This may serve as a surrogate for an IBI, as an aquatic insect IBI has not been conducted within the park.

Sampling methods for aquatic invertebrates were semi-quantitative and varied depending on habitat type (Cook and Hutton 2009). In riffle habitats, a 1 m^2 (10.8 ft^2) semi-quantitative riffle kick net with a 500 micron mesh was used. When leaf pack or coarse woody debris were present, a D-frame kick-net was used instead (Cook and Hutton 2009). Large rocks within the sample areas were lifted and clinging invertebrates were collected by hand, while woody debris was disturbed by hand and dislodged materials were collected with the D-net as they drifted downstream (Cook and Hutton 2009). Samples were preserved in 3.8 liter (1 gallon) freezer bags with a 10% formalin and 70% ethanol preservative solution to be transported to the laboratory for identification and counting (Cook and Hutton 2009). Individuals were identified to genus level, and to species level when possible (Cook and Hutton 2009).

4.7.5. Current Condition and Trend

Species Diversity

Mussels

The NPS Certified Species List (NPS 2015a) identifies 28 freshwater mussel species as either present, probably present, or unconfirmed at OBRI. When excluding the unconfirmed species from the total, the number of freshwater mussel species at OBRI drops to 14 (12 present, two probably present; Appendix M). Ahlstedt et al. (2001) identified nine freshwater mussel species during surveys conducted in 2000 and 2001. All nine species were observed in the Obed River, while the number of mussel taxa observed in other streams varied (Table 49). Three species were observed in the Emory River and Daddy's Creek, while two species were observed in Clear Creek and White Creek (Table 49). The purple bean, a federally-listed endangered species, was observed in the Obed River during this survey (Ahlstedt et al. 2001).

Table 49. Freshwater mussel species observed in OBRI during surveys conducted in 2000–2001 (Ahlstedt et al. 2001).

Scientific Name	Common Name	Obed River	Emory River	Daddy's Creek	Clear Creek	White Creek
Elliptio dilatata	Spike	X	–	–	–	–
Lampsilis cardium	Plain pocketbook	X	–	–	–	–
Lampsilis fasciola	Wavy-rayed lampmussel	X	X	X	X	X
Medionidus conradicus	Cumberland moccasinshell	X	–	–	–	–
Pleurobema oviforme	Tennessee clubshell	X	–	X	–	–
Pleuronaia barnesiana	Tennessee pigtoe	X	–	–	–	–
Potamilus alatus	Pink heelsplitter	X	X	–	–	–
Villosa iris	Rainbow mussel	X	X	X	X	X
Villosa perpurpurea	Purple bean	X	–	–	–	–

Ahlstedt and Bakaletz (2006) observed two freshwater mussel species (wavy-rayed lampmussel [*Lampsilis fasciola*] and rainbow mussel [*Villosa iris*]) at all three sites sampled during mussel surveys conducted in Clear Creek and White Creek in 2005. These same species were observed in those creeks during the 2000–2001 surveys (Appendix M) (Ahlstedt et al. 2001, Ahlstedt and Bakaletz 2006). The 2005 survey was conducted to assess damage that may have occurred to native mussels as a result of an oil spill in the area. Since this was the purpose of the survey, no other creeks or rivers were surveyed at that time. The non-native Asian clam was also observed in high numbers (number of individuals collected was not provided) at each site surveyed; this species is discussed briefly in the threats and stressors section below (Ahlstedt and Bakaletz 2006).

Dinkins and Faust (2015) identified ten freshwater mussel species in the park during 2013–2014 mussel surveys; this included the same nine species observed by Ahlstedt et al. (2001) plus the purple lilliput (*Toxolasma lividum*), which was observed only in Clear Creek (Table 50). Seven species were observed in the Obed River, six in Clear Creek, three in the Emory River, and two in Daddy's Creek; White Creek was not included in this survey (Table 50). While Dinkins and Faust (2015) found a lower number of freshwater mussel species in three (Obed River, Emory River, and Daddy's Creek) of the four rivers and creeks also surveyed by Ahlstedt et al. (2001), they observed four more species in Clear Creek than Ahlstedt et al. (2001): purple bean, purple lilliput, Cumberland moccasinshell (*Medionidus conradicus*), and Tennessee clubshell (*Pleurobema barnesiana*).

Table 50. Freshwater mussel species observed at OBRI during surveys conducted in 2013–2014 (Dinkins and Faust 2015).

Scientific Name	Common Name	Obed River	Emory River	Daddy's Creek	Clear Creek
Elliptio dilatata	Spike	X	X	–	–
Lampsilis cardium	Plain pocketbook	X	–	–	–
Lampsilis fasciola	Wavy-rayed lampmussel	X	X	–	X
Medionidus conradicus	Cumberland moccasinshell	X	–	–	X
Pleurobema oviforme	Tennessee clubshell	X	–	X	X
Pleuronaia barnesiana	Tennessee pigtoe	X	–	–	–
Potamilus alatus	Pink heelsplitter	–	X	–	–
Toxolasma lividum	Purple lilliput	–	–	–	X
Villosa iris	Rainbow mussel	X	–	X	X
Villosa perpurpurea	Purple bean	–	–	–	X

Other Aquatic Invertebrates

From 2007 to 2009, Cook and Hutton (2009) collected 5,931 aquatic invertebrate specimens in the park. A total of 167 invertebrate taxa were identified to species level within 117 genera. There were 12 individual crayfish identified to genus level: eight *Orconectes* sp. and four *Cambarus* sp. (Appendix N). Not all individuals collected during the inventory were identified to species level due to the difficulty of species-level identification during aquatic (larval) stages of some insect taxa; these organisms are often very difficult or impossible to distinguish at species level until they have morphed into their adult form (Cook and Hutton 2009). Here, aquatic invertebrate species richness is discussed in terms of species richness, followed by genus richness, among the collections inventoried around OBRI.

Four HUC-10 watersheds (as defined by the USGS) drain to the park's major creeks and rivers: Obed River, Emory River, Clear Creek, and Daddy's Creek watersheds. Although there is only a short section of White Creek's lower reach within the park, this subwatershed (HUC-12) was also included in the inventory effort since it is a major tributary of Clear Creek. Several tributaries were sampled during this inventory, as shown in Figure 57. Site codes in the following tables correspond with the sampling sites shown in Figure 57.

Taxa richness reported at the species level (TR-S) was greatest within the Daddy's Creek watershed, where a total of 101 species were collected (Table 51) (Cook and Hutton 2009). The next highest TR-S value was reported in the Clear Creek watershed, where 95 species were collected. The Emory River had the next highest TR-S value with a total of 79 species collected, and the Obed River and White Creek each had a total of 75 species (Cook and Hutton 2009).

Table 51. Taxa richness identified to species level (TR-S) at OBRI and in the surrounding area (recreated from Cook and Hutton [2009]).

Watershed	Location	Site code	TR-S
Daddy's Creek	Daddy's Creek at Antioch Bridge	Z	50
	Daddy's Creek at Obed Junction	AA	47
	Yellow Creek at Hebbertsburg Rd	P	42
	Devils Breakfast Table	Y	35
	Yellow Creek	O	26
	Total number of species	**–**	**101**
Clear Creek	Jett Bridge	AF	59
	Barnett Bridge	AG	38
	Lilly Bridge	AE	36
	Norris Ford	U	34
	Total number of species	**–**	**95**
Emory River	Nemo	AH	38
	Rock Creek at Highway 62	AB	37
	Island Creek at Catoosa Rid	Q	33
	Emory River at Montgomery Rd	AC	25
	Total number of species	**–**	**79**
White Creek	White Creek Mouth	X	43
	White Creek at Twin Bridge Rd	W	42
	Lavender Bridge	V	38
	Total number of species	**–**	**75**
Obed River	Obed River at Obed Junction	AD	34
	Obed River at Canoe Hole	AI	34
	Adams Bridge	R	28
	Alley Ford	AJ	27
	Potters Ford	T	22
	Total number of species	**–**	**75**
Total number of species inventoried			**167**

Taxa richness reported to the genus level (TR-G) among the 117 genera collected during the inventory was highest in the Daddy's Creek watershed, where 78 genera were identified (Table 52) (Cook and Hutton 2009). The next-highest TR-G was in the Emory River watershed with a total of 66 genera present (Cook and Hutton 2009). The remaining sample sites varied in TR-G values, with Clear Creek reporting 65 genera, White Creek reporting 59 genera, and the Obed River with 58 genera (Table 52).

Table 52. Taxa richness identified to genus level (TR-G) at OBRI and in the surrounding area (recreated from Cook and Hutton [2009], Table 8).

Watershed	Location	Site code	TR-G
Daddy's Creek	Daddy's Creek at Antioch Bridge	Z	46
	Yellow Creek at Hebbertsburg Rd	P	38
	Daddy's Creek at Obed Junction	AA	38
	Devils Breakfast Table	Y	27
	Yellow Creek	O	25
	Total number of genera	–	**78**
Emory River	Island Creek at Catoosa Rid	Q	31
	Nemo	AH	31
	Rock Creek at Highway 62	AB	24
	Emory River at Montgomery Rd	AC	23
	Total number of genera	–	**66**
Clear Creek	Jett Bridge	AF	30
	Barnett Bridge	AG	29
	Norris Ford	U	28
	Lilly Bridge	AE	27
	Total number of genera	–	**65**
White Creek	White Creek Mouth	X	40
	White Creek at Twin Bridge Rd	W	35
	Lavender Bridge	V	32
	Total number of genera	–	**59**
Obed River	Obed River at Obed Junction	AD	30
	Obed River at Canoe Hole	AI	28
	Adams Bridge	R	23
	Alley Ford	AJ	23
	Potters Ford	T	16
	Total number of genera	–	**58**
Total number of genera inventoried			**117**

Species Abundance

Mussels

Ahlstedt et al. (2001) collected 585 individual freshwater mussels of nine species in the park during surveys in 2000 and 2001. The most abundant species park-wide was the rainbow mussel (55% of all collections) (Table 53). The next most abundant species, from greatest to least, were the wavy-rayed lampmussel, Cumberland moccasinshell, spike (*Elliptio dilatata*), and purple bean. Both the Tennessee pigtoe (*Pleuronaia barnesiana*) and plain pocketbook (*Lampsilis cardium*) were each observed as one individual (Ahlstedt et al. 2001). The greatest number of individuals was found in the Obed River, with 253 mussels, followed by Clear Creek (203 mussels), White Creek (112 mussels), the Emory River (nine mussels), and Daddy's Creek (eight mussels) (Ahlstedt et al. 2001). The most abundant species in the Obed River was the Cumberland moccasinshell, comprising 32% of all collections (Table 53). The pink heelsplitter (*Potamilus alatus*) was most abundant in the Emory River, and the rainbow mussel was most abundant in Clear, White, and Daddy's Creeks (Ahlstedt et al. 2001).

Table 53. Freshwater mussel abundances documented by Ahlstedt et al. (2001) during surveys conducted between 25 July 2000 and 26 September 2001 (R=relict; not living).

Scientific Name	Common Name	Obed River	Emory River	Clear Creek	Daddy's Creek	White Creek	CPUE	%
Elliptio dilatata	Spike	38	–	–	–	–	0.34	6.5
Lampsilis cardium	Plain pocketbook	1	–	–	–	–	0.01	0.2
Lampsilis fasciola	Wavy-rayed lampmussel	75	2	27	2	4	0.97	18.8
Medionidus conradicus	Cumberland moccasinshell	81	–	–	–	–	0.72	13.8
Pleurobema oviforme	Tennessee clubshell	3	–	–	2	–	0.04	0.9
Pleuronaia barnesiana	Tennessee pigtoe	1	–	–	–	–	0.01	0.2
Potamilus alatus	Pink heelsplitter	R	6	–	–	–	0.05	1.0
Villosa iris	Rainbow mussel	35	1+R	176	4	108	2.87	55.4
Villosa perpurpurea	Purple bean	19	–	–	–	–	0.17	3.2
Totals		**253**	**9**	**203**	**8**	**112**	–	–

Ahlstedt and Bakaletz (2006) collected 154 live freshwater mussels of two species (rainbow mussel, wavy-rayed lampmussel) during 2005 surveys of Clear and White Creeks (Table 54). The more abundant of the two species overall (79%) and at each individual site was the rainbow mussel (Ahlstedt and Bakaletz 2006).

Table 54. Freshwater mussel abundances documented by Ahlstedt and Bakaletz (2006) during 2005 surveys of Clear and White Creeks.

Scientific Name	Common Name	Clear Creek: Above Oil Spill	Clear Creek: Below Oil Spill	White Creek (below oil spill)	%
Lampsilis fasciola	Wavy-rayed lampmussel	30	2	1	21.4
Villosa iris	Rainbow mussel	51	36	34	78.6
Totals		**81**	**38**	**35**	–

Dinkins and Faust (2015) collected 266 individual freshwater mussels from 10 taxa in 2013–2014 surveys of four park streams (Table 55). Similar to Ahlstedt et al. (2001), mussels were most abundant in the Obed River (175 mussels), followed by Clear Creek (74 mussels), with few mussels found in the Emory River and Daddy's Creek (Dinkins and Faust 2015). The most abundant species overall was the rainbow mussel (33%), followed closely by the Cumberland moccasinshell (31%). The rainbow mussel was also the most abundant species in Clear and Daddy's Creeks, while the Cumberland moccasinshell was most abundant in the Obed River (Table 55).

Table 55. Freshwater mussel abundances documented by Dinkins and Faust (2015) during 2013–2014 surveys.

Scientific Name	Common Name	Obed River	Emory River	Clear Creek	Daddy's Creek	%
Elliptio dilatata	Spike	23	2	–	–	9.4
Lampsilis cardium	Plain pocketbook	–	1	–	–	0.4
Lampsilis fasciola	Wavy-rayed lampmussel	31	3	12	–	17.3
Medionidus conradicus	Cumberland moccasinshell	75	–	7	–	30.8
Pleurobema oviforme	Tennessee clubshell	7	–	6	2	5.6
Pleuronaia barnesiana	Tennessee pigtoe	1	–	–	–	0.4
Potamilus alatus	Pink heelsplitter	–	2	–	–	0.8
Toxolasma lividum	Purple lilliput	–	–	1	–	0.4
Villosa iris	Rainbow mussel	38	–	44	7	33.4
Villosa perpurpurea	Purple bean	–	–	4	–	1.5
Totals		**175**	**8**	**74**	**9**	**–**

Other Aquatic Invertebrates

Currently, the only data available related to other aquatic invertebrate abundances are from Cook and Hutton (2009). Many of the various taxa identified to species level do not have common names assigned to them and are mentioned by genus and species nomenclature only. The five most abundant orders collected in the inventory were, in descending order: Trichoptera (caddisflies), Ephemeroptera (mayflies), Plecoptera (stoneflies), Diptera (true flies), and Coleoptera (beetles) (Table 56). All of these are insect orders, and together they comprised 94% of the total individuals collected. The total number of individuals by taxa, along with the most abundant taxa within each order, are shown in Table 56.

Table 56. Invertebrate abundance by order, and the most abundant taxa within each order (Cook and Hutton 2009).

Order	Total Individuals	Most Abundant Taxa (total individuals)
Trichoptera (caddisflies)	1,322	*Cheumatopsyche* sp. (552)
Ephemeroptera (mayflies)	1,284	*Baetis intercalaris* (246)
Plecoptera (stoneflies)	1,182	*Leuctra* sp. (456)
Diptera (true flies)	959	*Polypedilum flavum* (343)
Coleoptera (beetles)	838	*Stenelmis* sp. (172)
Megaloptera (alderflies, fish flies)	144	*Nigronia serricornis* (78)
Odonata (dragonflies, damselflies)	126	*Lanthus vernalis* (58)
Lumbriculida (blackworms)	34	*Lumbriculus variegatus* (34)
Isopoda (woodlice)	18	*Lirceus* sp. (18)
Decapoda (crayfish)	12	*Orconectes* sp. (8)
Hemiptera (true bugs)	8	*Microvelia* sp. (7)
Acari (mites, ticks)	2	N/A
Lepidoptera (moths, butterflies)	1	*Petrophila fulicalis*
Rhynchobdellida (leeches)	1	*Placobdella* sp.

<u>Listed Species Abundance</u>

Listed freshwater mussel species collected in the park include one federally-listed endangered species, the purple bean (Dinkins and Faust 2015). There were 19 individual purple bean mussels collected by Ahlstedt et al. (2001) in 2000–2001. None were observed by Ahlstedt and Bakaletz (2006), but four individuals were collected by Dinkins and Faust (2015) in 2013–2014. Ahlstedt et al. (2001) collected the purple bean in the Obed River only, while Dinkins and Faust (2015) collected this mussel only in Clear Creek. Dinkins and Faust (2015) concluded from their surveys that the purple bean had been extirpated from the Obed River, and their observation of this species in Clear Creek was the first report of its existence within that reach.

One other federally-listed species, the Alabama lampmussel, occurred in the Obed River within the park at one time or may potentially occur in the park presently. The Alabama lampmussel was recently observed in the Emory River above its confluence with the Obed River, but has not been detected in the park in well over 10 years (Ahlstedt et al. 2001, Dinkins and Faust 2015, NPS 2015b).

<u>Listed Species Density</u>

Density of collected freshwater mussels was not directly assessed in Ahlstedt et al. (2001) or Dinkins and Faust (2015). Ahlstedt and Bakaletz (2006) recorded freshwater mussel density, but listed species were not observed during survey efforts. Density (number of individuals/area) of freshwater mussels is measured using quadrat sampling as described in the methodology used by Ahlstedt and Bakaletz (2006). This is not practical in OBRI for several reasons: freshwater mussels are rare in the park, and the aquatic habitat where mussels are usually found is characterized by small gravel patches between huge boulders (Steve Ahlstedt, retired TVA Malacologist, email communication, 15 April 2016). This makes quadrat sampling difficult, time intensive, and usually results in zeros due to freshwater mussel rarity. The amount of effort and time required to use the quadrat methods exceeded the available budget for mussel surveys in the park as well, making CPUE the primary method of quantifying abundance and species richness. The CPUE method is also considered the best way to detect rare species, such as the purple bean, because it allows surveyors to cover more area than quadrat sampling allows (Ahlstedt, email communication, 15 April 2016).

Listed species of other aquatic invertebrates were not observed during the 2007–2009 inventory conducted by Cook and Hutton (2009), so density data are not available for this measure. There may be listed species of aquatic insects in the park, but none have yet been observed.

Listed Species Shell Size

Shell size among listed species was measured by both Ahlstedt et al. (2001) in 2000–2001 and Dinkins and Faust (2015) in 2013–2014. Ahlstedt et al. (2001) measured purple bean individuals collected in the Obed River and observed that the majority of the these individuals were between 40–60 mm (1.6–2.4 in), with only one individual measuring between 20–30 mm (0.8–1.2 in) (Figure 58). Shell-length measurement data appeared to be skewed towards larger mussels, with the lack of small specimens suggesting low reproductive and recruitment rates in recent years (Ahlstedt et al. 2001).

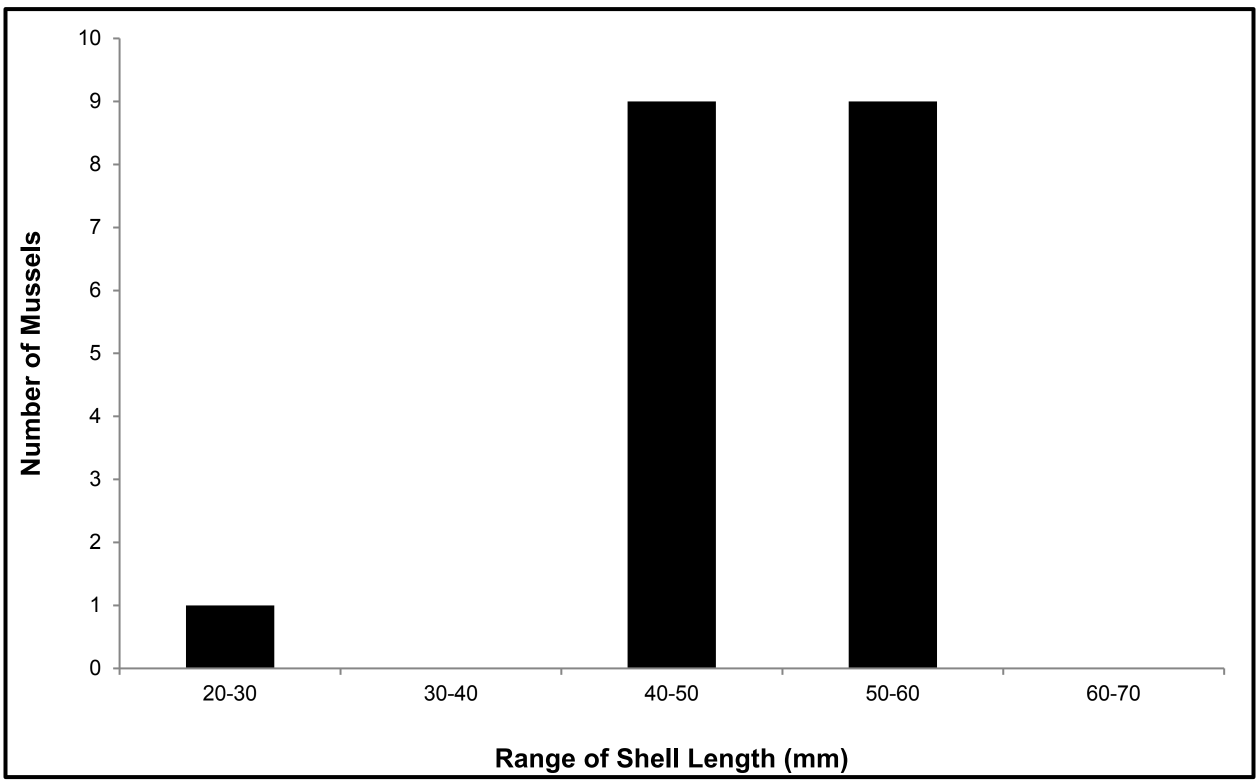

Figure 58. Shell length range (in mm) of purple bean mussel individuals collected from the Obed River inside the park.

Dinkins and Faust (2015), who did not find any purple bean species in the Obed River, did collect individuals of this species in Clear Creek. Of the four mussels collected (two live, two recently dead), one fell in the 30–40 mm (1.2–1.6 in) shell length range and three were in the 50–60 mm (2.0–2.4 in) range. As mentioned previously, there were no observations of the Alabama lampmussel during the three mussel surveys conducted in the park between 2000 and 2015 (Ahlstedt et al. 2001, Ahlstedt and Bakaletz 2006, Dinkins and Faust 2015).

Index of Biotic Integrity

IBIs typically involve the assessment of fish and benthic invertebrate assemblages, along with the habitat condition of a stream or watershed. For this measure, in place of IBI, the BSc values listed in Cook and Hutton (2009) will be used to assess the condition of aquatic invertebrate communities in the park's watersheds. BSc values were calculated for the Emory and Obed River as well as Clear Creek, White Creek, and Daddy's Creek watersheds, based on the aquatic insect taxa collected at each sampling location (Figure 57). These BSc scores were calculated based on both aquatic invertebrate species-level identification (BSc-S) and genus level identification (BSc-G) for each watershed. BSc values ≥32 indicated non-impaired biological conditions.

For the most part, the BSc values for both categories did not indicate impairment of biological conditions within park streams during the inventory period (2007–2009) (Cook and Hutton 2009). The mean BSc-S values differed only slightly from BSc-G values within each watershed. The watershed that scored highest in BSc was Daddy's Creek, with a mean BSc-S of 41.2 and a mean BSc-G of 40.4 (Table 57) (Cook and Hutton 2009). Out of the five locations sampled, two were slightly lower in genus score than species score, which was typical across all five park watersheds. All locations and identification levels in the Daddy's Creek watershed were above thresholds for impairment, indicating good health and condition of macroinvertebrates.

Table 57. BSc calculated from the aquatic insect inventory in Daddy's Creek watershed (Cook and Hutton 2009).

Site Location	Site Code	BSc-S	BSc-G
Daddy's Creek at Antioch Bridge	Z	42	42
Daddy's Creek at Obed Junction	AA	42	42
Devils Breakfast Table	Y	42	40
Yellow Creek at Hebbertsburg Rd	P	40	40
Yellow Creek	O	40	38
Mean	–	**41.2**	**40.4**

The next-highest BSc was observed in Clear Creek watershed, with a mean BSc-S of 40.5 and BSc-G of 39 (Table 58). Clear Creek's mean BSc was calculated from four sample sites, three of which had the same BSc-S and BSc-G; one site had a slightly lower BSc-G than BSc-S (Cook and Hutton 2009).

Table 58. BSc calculated from the aquatic insect inventory in Clear Creek watershed (Cook and Hutton 2009).

Site Location	Site Code	BSc-S	BSc-G
Barnett Bridge	AG	42	40
Lilly Bridge	AE	42	40
Jett Bridge	AF	40	38
Norris Ford	U	38	38
Mean	–	**40.5**	**39**

White Creek watershed had the third-highest BSc (Cook and Hutton 2009). The White Creek watershed mean BSc-S and BSc-G were also slightly different based on the three sites sampled during the inventory (Table 59). The BSc-S mean was 38.7 while the BSc-G mean was 37.3; two of the three sites scored lower BSc-G than BSc-S (Cook and Hutton 2009).

Table 59. BSc calculated from the aquatic insect inventory in White Creek watershed (Cook and Hutton 2009).

Location	Site Code	BSc-S	BSc-G
White Creek Mouth	X	42	40
Lavender Bridge	V	40	40
White Creek at Twin Bridge Rd	W	34	32
Mean	**–**	**38.67**	**37.33**

The Obed River watershed scored fourth in biological conditions among watersheds with a mean BSc-S of 36 and a BSc-G of 34.4 (Table 60) (Cook and Hutton 2009). Five locations in the Obed River watershed were sampled and ranged in BSc-S from 34 to 40, while the BSc-G ranged from 30 to 40. One site in the Obed River watershed (Potters Ford [site T]) indicated slight impairment of biological conditions only in terms of BSc-G (30), while BSc-S (34) did not indicate any biological impairment (Cook and Hutton 2009).

Table 60. BSc calculated from the aquatic insect inventory in the Obed River watershed (Cook and Hutton 2009).

Location	Site Code	BSc-S	BSc-G
Alley Ford	AJ	40	40
Obed River at Canoe Hole	AI	36	36
Adams Bridge	R	36	34
Obed River at Obed Junction	AD	34	32
Potters Ford	T	34	30
Mean	**–**	**36**	**34.4**

The Emory River watershed had the lowest mean BSc of all five watersheds in the area. The mean BSc-S was 33.5 and mean BSc-G was 32.5 (Table 61). There was one location in the Emory River, located downstream of the park boundary (Site AC at Montgomery Rd), that had a BSc (16) indicating moderate impairment (Cook and Hutton 2009).

Table 61. BSc calculated from the aquatic insect inventory in the Emory River watershed (Cook and Hutton 2009).

Location	Site Code	BSc-S	BSc-G
Nemo	AH	40	38
Rock Creek at Highway 62	AB	40	38
Island Creek at Catoosa Rid	Q	38	38
Emory River at Montgomery Rd	AC	16	16
Mean	–	**33.5**	**32.5**

Threats and Stressor Factors

Human activities beyond OBRI boundaries contribute to impaired and degraded water quality and quantity, and are a major threat to sensitive aquatic invertebrates (Ahlstedt et al. 2001). Coal mining, oil and gas exploration, quarrying, sewage discharge, residential development, and garbage disposal are concerns around the park, since they can all contribute to decreased water quality (Ahlstedt et al. 2001). Other human-caused threats to freshwater invertebrates just outside the park includes the development of water supply ponds and impoundments, agriculture, and forestry practices (e.g., causing erosion/sediment loading), which can reduce water quality and/or quantity (Ahlstedt et al. 2001). Agriculture, forestry, and residential developments can increase sedimentation/siltation and nutrient inputs to surface waters. Upstream water impoundments and increased anthropogenic demand make less water available downstream for wildlife, both aquatic and terrestrial (Ahlstedt et al. 2001). Ahlstedt et al. (2001) described heavy siltation and thick algal cover in the Obed River starting at the confluence of Black Drowning Creek and continuing downstream for just over 4.8 km (3 mi). This algal cover indicates nutrient enrichment, and was thought to be from dairy farm wastes originating upstream of Black Downing Creek (Ahlstedt et al. 2001).

Oil spills are a concern to managers and a threat to freshwater invertebrates that are sensitive to elevated levels of volatile organic compounds (VOCs) found in oil (e.g., benzene, toluene) (NPS 2004). An oil spill occurred on 19 July 2002, 2.2 km (1 mi) outside the park, and an undetermined amount of crude oil was released into White Creek and Clear Creek in Morgan County (NPS 2004, Trustees 2008). A well that was test-drilled for production of oil began leaking during drilling, and crude oil flowed downhill into the two creeks shortly before the well caught fire (NPS 2004). The damage caused included soil contamination, burned vegetation and surface litter, severe tree mortality, destruction of the soil seed bank, water contamination, and heat-fractured rocks (NPS 2004, Trustees 2008). Damage to the riparian zone soils, tree canopy, and stream bank vegetation directly impacts the water quality as this area serves as a filtration barrier for water entering the channel and also regulates water temperature by shading the water surface (Machtinger et al. 2007). Loss of vegetation increases runoff and erosion during precipitation events causing elevated sediment load and nutrient levels in the water from erosion and temperature increases, which are a threat to benthic inhabitants as well (Machtinger et al. 2007). Ahlstedt and Bakaletz (2006) surveyed both creeks impacted by the 2002 spill in order to assess whether mussels were impaired as a result of the contamination. Mussels are particularly vulnerable to contamination at the juvenile stage (Ahlstedt and Bakaletz 2006). Contamination can indirectly impact mussel fauna if fish are eliminated because they require fish hosts to carry out their life cycle (Ahlstedt and Bakaletz 2006).

Ahlstedt and Bakaletz (2006) observed size class distributions upstream of the spill site that indicated impairment within the mussel populations; this was thought to have resulted from past or ongoing dumping of oil brine waste into Clear Creek. At the two surveyed sites just below the oil spill site there was some recruitment occurring as indicated by the shell size classes in both Clear Creek and White Creek (Ahlstedt and Bakaletz 2006). However, when exposed to contamination or increased sediment load, freshwater mussels respond by closing their valves and, in some cases, abort their eggs as a mechanism of defense (Ahlstedt and Bakaletz 2006). When this mechanism is employed for an extended period, the freshwater mussel will die, and recruitment is reduced (Ahlstedt and Bakaletz 2006). Although there were more individual mussels collected at the site upstream of the oil spill location, there was a smaller range in shell sizes suggesting limited recruitment (Ahlstedt and Bakaletz 2006). This is likely a result of oil brine contamination, and the impacts to the mussels in White Creek and Clear Creek from the actual oil spill were not determined (Ahlstedt and Bakaletz 2006). Cook and Hutton (2009) calculated BSc values to assess the biological conditions of several locations in the park, including Clear Creek. According to the results of Cook and Hutton (2009), Clear Creek and White Creek appear to be in good condition.

Asian clams were present within each quadrat sampled by Ahlstedt and Bakaletz (2006). Asian clams are a non-native species that is much more tolerant of contaminants than native species, and they do not require a host to carry out their life cycle (Ahlstedt and Bakaletz 2006). Asian clams were found in large numbers as well as in a wide range of shell size classes. Hydrilla, also called water thyme, is an invasive aquatic plant species found in the park. First discovered in Daddy's Creek in 2004, this noxious plant may pose a threat to freshwater invertebrates, although its potential impact on native fauna is not well understood. The infestation at the park is considered severe and poses a considerable threat to park biota (Estes et al. 2010).

Data Needs/Gaps

Cook and Hutton (2009) suggest the need for quarterly monitoring of water levels, water chemistry, discharge, and macroinvertebrates in all four watersheds associated with the park in order to maintain habitat quality and community health within the park. Ahlstedt et al. (2001) suggested that the NPS establish permanent monitoring sites in order to establish a baseline for long-term freshwater mussel monitoring. Continued freshwater mussel survey efforts are needed in order to identify trends in mussel abundance, recruitment, and number of species that are surviving in the various reaches within OBRI. The APHN is in the process of developing a mussel monitoring program, which will include OBRI, to help address these needs. The impacts of non-native Asian clams are not understood and require additional research and monitoring, alongside native mussel surveys, to identify any negative impacts to native mussel fauna.

Considering the recent collection (2013–2014) of new mussel records (three species not recorded in the park previously), continued monitoring of native freshwater mussels may detect additional species, or those that were thought to be extirpated by expanding surveys to new areas in search of listed species. The density of mussels is a known and acknowledged data gap, as mussels in the park are typically found in small numbers and the habitats are difficult to sample for density since mussels often inhabit spaces beneath large rocks in small patches of gravel and sand (Ahlstedt et al. 2001).

Overall Condition

Species Diversity

The project team assigned the species diversity measure a *Significance Level* of 3. Freshwater insects have been poorly studied to date, with the most recent inventory concluding in 2009. While there was no baseline to compare the results of that inventory to, the authors noted that the health of the aquatic macroinvertebrates in OBRI is excellent and that areas affected by oil spills in 2002 had no continued signs of degradation.

Until recently (within the last 15 years), very little was known about the park's mussel diversity. As described by Ahlstedt et al. (2001), the park's mussel fauna are limited and rare, and it may be the case that the park's rivers were not ever very diverse in terms of mussel species. The lack of diversity observed during recent surveys (Ahlstedt et al. 2001, Ahlstedt and Bakaletz 2006, Dinkins and Faust 2015) may be attributable to the nature of the park's rivers, as the shale and sandstone found in most streams on the Cumberland Plateau are biologically non-productive. Additionally, the rugged terrain of the park's rivers and streams, combined with periods of high flow or strong weather events, makes sampling difficult. It is possible that the extent of the park's mussel diversity may never be fully known or understood (Dinkins and Faust 2015). While diversity estimates have been low in the last two decades, this appears to be due to the nature of the streams and rivers of the park, and not necessarily exclusively due to declining environmental conditions and/or human impacts. Due to these reasons, a *Condition Level* of 2, indicating moderate concern, was assigned to the species diversity measure.

Species Abundance

A *Significance Level* of 3 was assigned to the species abundance measure by the project team. Freshwater invertebrates in the park have been studied sporadically, leaving much of this large fauna group a data gap. Many fewer mussels were collected in the most recent study than were observed in 2000, suggesting a large decrease in abundance of freshwater mussels. Based on comparison of these two freshwater mussel studies the *Condition Level* has been assigned a 3, or of high concern.

Listed Species Abundance

This measure was assigned a *Significance Level* of 3. Listed species abundance is based on the federally endangered purple bean. Two mussel surveys conducted in the park observed the purple bean. Dinkins and Faust (2015) determined that this species had been extirpated from the Obed River during their 2013–2014 survey, but they detected the species in Clear Creek for the first time on record. The apparent extirpation of the purple bean and Alabama lampmussel from the Obed River merits a high concern for these federally endangered species and is the basis for assigning a *Condition Level* of 3.

Listed Species Density

The listed species density *Significance Level* was also assigned a 3 for the park. This measure is a data gap, since density of freshwater mussels was not assessed. The decision not to gather density data was made by researchers based on the general rarity of mussels in the park, habitat structure, and budget constraints (Ahlstedt, email communication, 15 April 2016). Due to the lack of data, this measure was not assigned a *Condition Level*.

Listed Species Shell Size

This measure was also assigned a *Significance Level* of 3. Measurements of purple bean shell sizes from the Obed River in 2000 and Clear Creek in 2013–2014 indicate that this endangered mussel has low recruitment and may not be reproducing successfully in the park; as only a single juvenile-sized purple bean was observed during each survey. Presence of younger (smaller) mussels in greater numbers of this species would be indicative of recruitment and successful reproduction. Considering that shell length data is only available for the purple bean from two different streams in the park and the surveys are over 10 years apart, this measure is considered a data gap, and a *Condition Level* was not assigned.

Index of Biotic Integrity

A *Significance Level* of 3 was defined for IBI by the project team. However, there are no data available for the IBI of invertebrates in the park. In place of IBI, the BSc values from Cook and Hutton (2009) were used to assess aquatic insect communities in the park as a measure of biological conditions in watersheds associated with the park. These are considered a baseline with no reference for comparison, but are recent enough and considered a current condition of aquatic invertebrates to merit a *Condition Level* of 1. The assignment of low concern was chosen since there were only isolated signs of biological impairment in the Emory River.

Weighted Condition Score

Based on the *Condition Levels* that were assigned to four of the six measures, the *Weighted Condition Score* is 0.75. Freshwater invertebrates have been studied in a sporadic fashion, both spatially and temporally. A comparison of two studies (Ahlstedt et al. 2001 and Dinkins and Faust 2015) suggest a drastic decline in the abundance of mussels in OBRI, and the purple bean is now likely extirpated from the Obed River (occurring sometime between 2000 and 2013–2014) (Dinkins and Faust 2015). This assessment used freshwater mussels as the focal taxa for rating the condition of freshwater invertebrates. However, it should be noted that other aquatic invertebrates appear to be in better condition than mussels, based on Cook and Hutton's (2009) inventory results. Due to the lack of data for two measures and the limited amount of data for the remaining measures, a medium confidence border is applied.

Freshwater Invertebrates			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.75**
Species Diversity	3	2	
Species Abundance	3	3	
Listed Species Abundance	3	3	
Listed Species Density	3	N/A	
Listed Species Shell Size	3	N/A	
Index of Biotic Integrity	3	1	

4.7.6. Sources of Expertise

- Robert Emmott, APHN Biologist
- Steve Ahlstedt, retired TVA Malacologist

4.7.7. Literature Cited

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4.8. Water Quality

4.8.1. Description

The Obed River system was protected as a Wild and Scenic River due to its exceptional waters which support high levels of biological diversity, including rare and unique species (NPS 2015a). Maintaining the high water quality of the river system, considered among the best in the State of Tennessee, is key to supporting such high diversity (Hughes 2011, NPS 2015a). The portion of the Obed River from the western edge of OBRI to the Emory River has been designated as an "Outstanding National Resource Water" by the State of Tennessee (Laster et al. 2014). Additionally, the full length of Clear Creek and portions of Otter and Daddy's Creeks (Figure 59) are designated as "Exceptional Tennessee Waters" (TDEC 2015). Under the Wild and Scenic Rivers Act, the NPS is required to preserve the Obed River system in "free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes" (82 Stat. 906) (Knight et al. 2014).

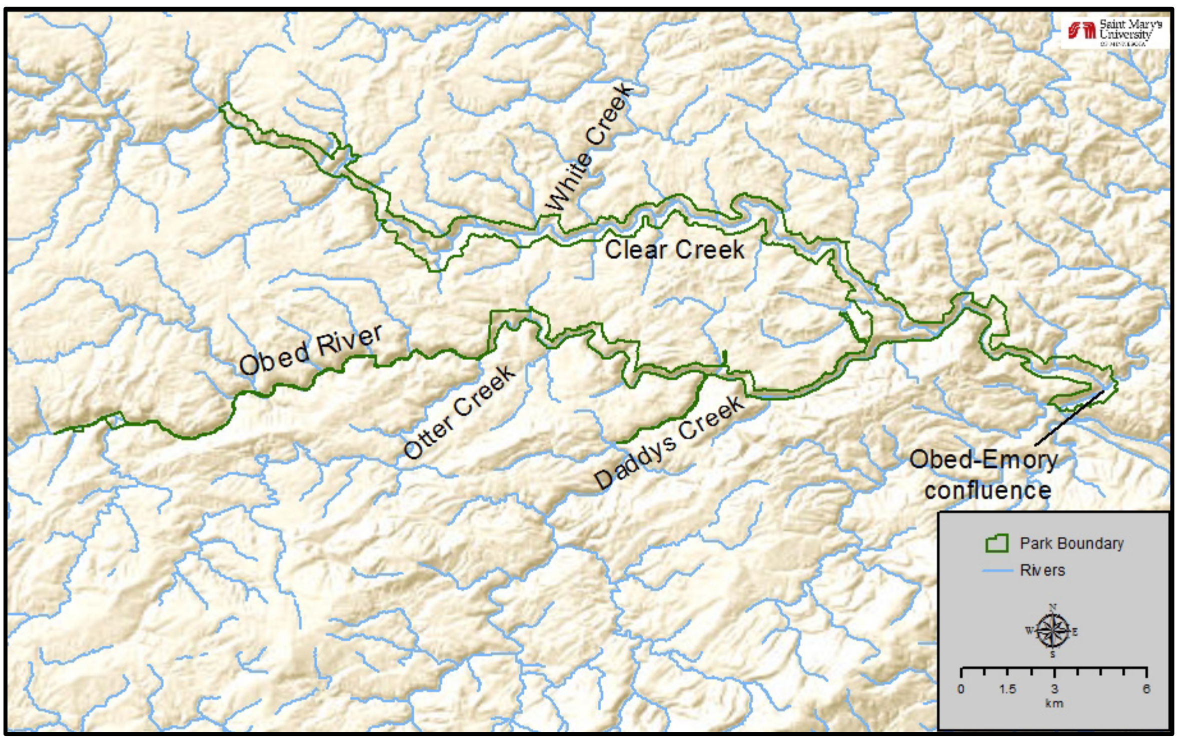


Figure 59. Map showing the Obed River and various tributaries.

Water quality was selected as a Vital Sign by the APHN and is considered one of the most significant natural resource management issues for Network parks (Emmott et al. 2005). The portion of the Obed River system designated as Wild and Scenic represents only 3% of the drainage area (up to its confluence with the Emory River) (Knight et al. 2014). Therefore, most of the influences upon the water quality of OBRI are outside the control of NPS managers. A portion of the Obed River above its confluence with Daddy's Creek has been designated as impaired on the state 303(d) list due to excessive nutrients (P and N) from the Crossville area (TDEC 2014a, b). This includes nearly 25 km

(15.4 mi) of the river within OBRI boundaries. Just over 2 km (1.4 mi) of Clear Creek are also listed as impaired due to contamination from a 2002 oil spill (TDEC 2014a, b).

4.8.2. Measures

- Water temperature
- pH
- Dissolved oxygen
- Conductivity
- Turbidity
- Acid-neutralizing capacity
- Nutrients

Water Temperature

Water temperature greatly influences water chemistry and the organisms that live in aquatic systems. Not only can temperature affect the ability of water to hold oxygen, but it also affects biological activity and growth within water systems (USGS 2015d). All aquatic organisms, from fish to insects to zoo- and phytoplankton, have a preferred or ideal temperature range for existence (USGS 2015d). As temperature increases or decreases beyond this range, the number of species and individuals able to survive eventually decreases. In addition, higher temperatures allow some compounds or pollutants to dissolve more easily in water, making them more toxic to aquatic life (USGS 2015d).

pH

pH is a measure of the level of acidity or alkalinity of water and is measured on a scale from 0 to 14, with 7 being neutral (USGS 2015d). Water with a pH of less than 7.0 indicates acidity, whereas water with a pH greater than 7.0 indicates alkalinity. Aquatic organisms have a preferred pH range that is ideal for growth and survival (USGS 2015d). Chemicals in water can change the pH and harm animals and plants living in the water; thus, monitoring pH can be useful for detecting natural and human-caused changes in water chemistry (USGS 2015d).

Dissolved Oxygen

DO is critical for organisms that live in water. In order to survive, fish and zooplankton filter out or "breathe" DO from the water (USGS 2015d). Oxygen enters water from the air, when atmospheric oxygen mixes with water at turbulent, shallow riffles in a waterway, or when released by algae and other plants as a byproduct of photosynthesis. As the amount of DO drops, it becomes more difficult for aquatic organisms to survive (USGS 2015d). The concentration of DO in a water body is temperature-related, in that cold water holds more DO than warm water (USGS 2015d). Thus, DO concentrations are subject to seasonal fluctuations as low temperatures in the winter and spring allow water to hold more oxygen, and warmer temperatures in the summer and fall allow water to hold less oxygen (USGS 2015d). DO concentrations also fluctuate on a daily basis, due to photosynthetic activity by aquatic plants and microorganisms during daylight hours and respiration by the same organisms at night (Jim Hughes, APHN Hydrologist, written communication, September 2016).

Conductivity

Specific conductance (SpC) is a measure of the ability of water to conduct electrical current, which depends largely on the amount of dissolved ions in the water (Allan and Castillo 2007). Water with low amounts of dissolved ions (such as purified or distilled water) will have a low SpC, while water with high amounts of dissolved solids (such as salty sea water) will have a higher SpC (Allan and Castillo 2007). SpC is an important water quality parameter to monitor because high levels can indicate that water is unsuitable for drinking or aquatic life (USGS 2015d). SpC can also quickly and reliably estimate dissolved solids in water (Meiman 2007).

Turbidity

Turbidity assesses the amount of fine particle matter (such as clay, silt, plankton, microscopic organisms, or finely divided organic or inorganic matter) that is suspended in water by measuring the scattering effect they have on light that passes through water (USGS 2015d); the more light that is scattered, the higher the turbidity measurement. Turbidity often increases following rainstorms, when sediments are washed into the water from adjacent lands and stream velocity increases (USGS 2015d). High turbidity decreases light penetration, which can reduce the productivity of aquatic plants and other organisms (USGS 2015c).

Acid Neutralizing Capacity

Acid neutralizing capacity (ANC) is the ability of solutes and particulates in an unfiltered water sample to buffer acids, measured in mg/l (milligrams per liter) as calcium carbonate ($CaCO_3$) (Rounds 2012). Waters with low ANC are more at risk of reductions in pH due to acid deposition, such as from acid rain or mining waste runoff (Meiman 2007).

Nutrients

Nutrients, such as N and P, are crucial in supporting healthy aquatic environments. However, elevated concentrations of these nutrients can negatively impact water quality and threaten the ability of plants and aquatic organisms to thrive (USGS 2013). Naturally occurring N in the atmosphere and in soils and is deposited into surface waters through precipitation and runoff; N deposition is increased by human inputs such as sewage, fertilizers, and livestock waste (USGS 2015a). Nitrate (NO_3) can cause a host of water quality related problems when present in high concentrations including, but not limited to, excessive plant and algae growth, eutrophication, and depleted DO available to aquatic organisms (USGS 2015a). NO_3 in drinking water can be harmful to humans, particularly young children, and livestock (USGS 2015a). Phosphorus is commonly found in agricultural fertilizers, manure, organic wastes in sewage, and sometimes industrial effluent (USGS 2015b). In excess, P in water systems can increase the rate of eutrophication, encourage overgrowth of aquatic plants, deplete DO, and threaten fish and macroinvertebrate populations (USGS 2015b). Soil erosion is the primary contributor of P input into surface waters, in which enriched soils are deposited into waterways through runoff during heavy precipitation events (USGS 2015b).

4.8.3. Reference Conditions/Values

The NRCA project team selected water quality conditions on Clear Creek as the reference for this component, since Clear Creek is considered to have outstanding water quality. The reference ranges for this NRCA are based on available data from Clear Creek and are presented in Table 62.

Tennessee state water quality standards for the protection of aquatic life (TDEC 2013) are also included to provide additional context.

Table 62. Water quality reference conditions for this NRCA based on available data from Clear Creek (from Spradlin and Rikard 1998 unless otherwise noted), along with Tennessee state water quality standards for the protection of aquatic life (TDEC 2013). NTU = nephelometric turbidity unit.

Parameter	Clear Creek Ranges	TN State Standard
Temperature	0–30 °C (32–86 °F)	Not to exceed 30.5 °C (86.9 °F)
pH	4.8–7.7	6.0–9.0 in wadeable streams; ≤ 1.0 maximum diurnal fluctuation
Dissolved oxygen	>6.0 mg/l	Not less than 5.0 mg/l
Specific conductance	<150 μS/cm	No standard
Turbidity	<40 NTU	No standard
Acid neutralizing capacity	>4.5 mg/l $CaCO_3$[A]	No standard
Nutrients	nitrogen (NO_2 + NO_3) ≤ 0.12 mg/l [B] phosphorus ≤ 0.005 mg/l [B]	Proposed for Ecoregion 68a[C]: nitrogen (NO_2 + NO_3) ≤ 0.23 mg/l, phosphorus ≤ 0.02 mg/l

[A] Based on APHN (2016) data.

[B] Based on Arnwine et al. (2005).

[C] Draft TDEC standards, as cited in Hughes 2015.

4.8.4. Data and Methods

From 1982–1998, the NPS conducted regular water quality monitoring (8–10 visits per year) at 11 stations throughout OBRI (Emmott et al. 2005). These included three sites along Clear Creek, two on the Obed River, two on the Emory River, and one on Daddy's Creek (Spradlin and Rikard 1998). Sampling also occurred at a single location on White Creek (in the Clear Creek watershed) and one location on Rock Creek (Emory River watershed). Parameters sampled included water temperature, pH, conductivity, DO, and turbidity.

In 2002 and 2004, the Tennessee Division of Water Pollution investigated diurnal (i.e., daily) fluctuations of DO in streams across various ecoregions of Tennessee (Arnwine et al. 2005). In addition to DO, several other water quality parameters were recorded at selected streams, including temperature, pH, SpC, and nutrients (N and P). Streams sampled included OBRI's Clear Creek and Daddy's Creek.

Hutton (2009) collected water quality data during 2007 as part of a study of OBRI's aquatic macroinvertebrate communities. Sampling locations were spread along the Obed and Emory Rivers as well as Clear, White, and Daddy's Creeks. Parameters sampled included temperature, pH, DO, SpC, and turbidity (Hutton 2009).

The APHN initiated a water quality monitoring program in 2009. Data have been gathered at OBRI in 2009, 2012–2013, and 2015–2016. Parameters measured include discharge, water temperature, pH, DO, conductivity, turbidity, ANC, coliform bacteria (*E. coli*), and nutrients. For this NRCA, results from nine sampling locations within or very near OBRI will be used to assess the park's water quality (Figure 60). Many of these locations coincide with sites utilized during previous sampling efforts (Spradlin and Rikard 1998, Hutton 2009). The NRCA project team requested that water quality be assessed by watershed, as shown in Figure 60. Of the APHN sampling points utilized here, three are within the Clear Creek watershed, two in the Obed River watershed, one in the Daddy's Creek watershed, and three in the Emory River watershed. Nutrients data from 2009 sampling were obtained through the EPA's Storage and Retrieval (STORET) data warehouse (http://www.epa.gov/storet/dw_home.html).

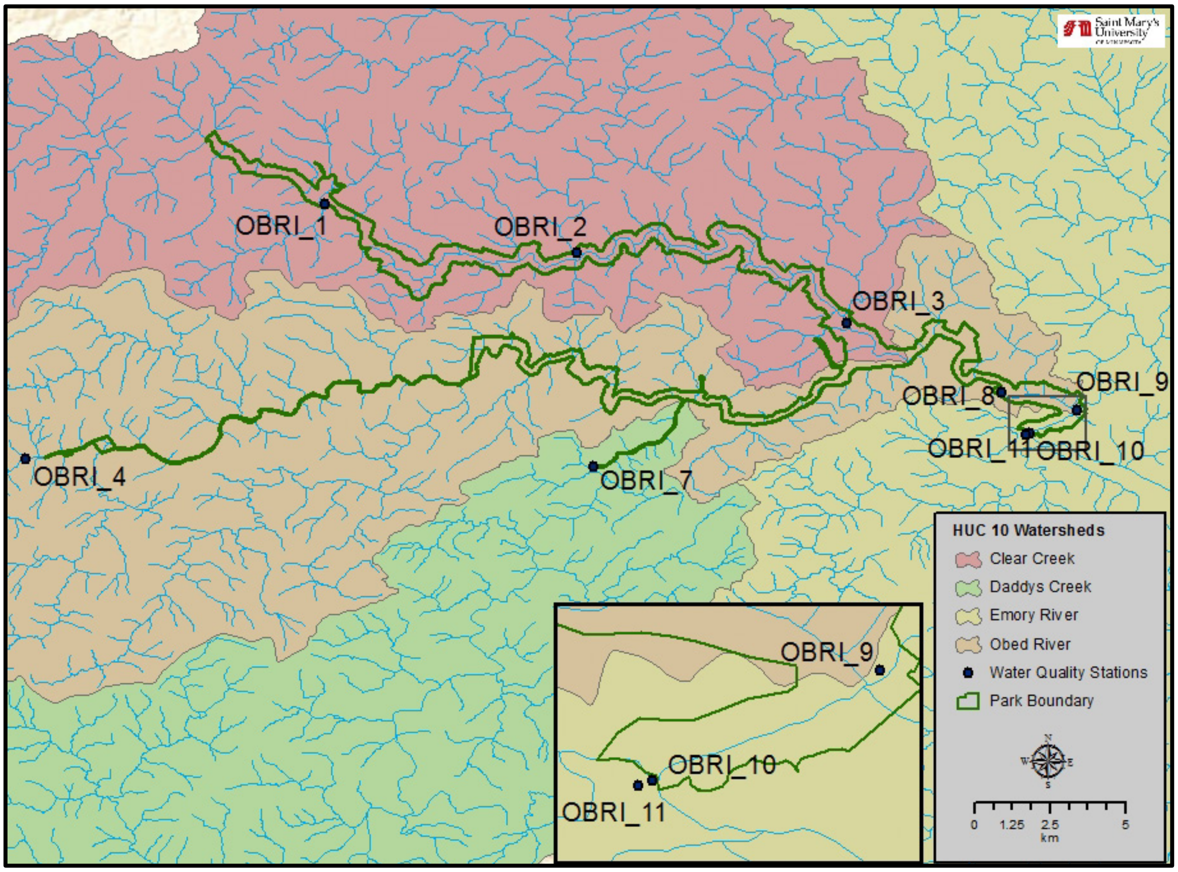


Figure 60. The four watersheds within OBRI and locations of APHN water quality sampling points.

Continuous water quality data (recorded every half-hour) are available for three stations in or near the park, from October 2013 through September 2016 (USGS 2016). These stations are Clear Creek at Lilly Bridge (OBRI_3), Daddy's Creek near Hebbertsburg (OBRI_7), and Obed River at Adams Bridge (OBRI_4). Parameters measured include water temperature, pH, DO, SpC, and turbidity. Because continuous data are collected around-the-clock rather than at a single point during the day, they are more likely to record extreme events (e.g., heavy rain and subsequent runoff) and to capture a wider range of values than instantaneous sampling. These data are available through the USGS National Water Information System (NWIS) website (http://waterdata.usgs.gov/nwis/inventory). Data are considered provisional and may be subject to revision (USGS 2016). Additionally, turbidity is measured in Formazin Nephelometric Units (FNU), so results are not directly comparable to turbidity measurements in NTU (nephelometric turbidity unit) from other sources. Because of the provisional nature of this data and differences in sampling methodology from reference condition data (continuous vs. instantaneous), these results may be given less weight in determining current condition than other sources.

4.8.5. Current Condition and Trend

<u>Water Temperature</u>

Clear Creek Watershed

During 1982–1998 sampling, Clear Creek water temperatures ranged from 0.3–29.2 °C (32.5–84.6 °F) (Spradlin and Rikard 1998). The lowest temperatures were recorded in January and the highest in June or July. The mean water temperature for this entire period of record across all three sampling locations was 13.9 °C (57.0 °F). Water temperatures in White Creek, which falls within the Clear Creek watershed, ranged from 0.1–27 °C (32.2–80.6 °F) with a mean of 13.0 °C (55.4 °F) during the same time period (Spradlin and Rikard 1998).

Arnwine et al. (2005) collected continuous water temperature measurements (every 30 minutes) from Clear Creek during a 2004 study of DO levels. From 1–15 September, temperatures ranged from just below 19 °C (66 °F) to 24.6 °C (76.3 °F) (Arnwine et al. 2005).

Hutton (2009) presented mean water temperature values from spring-fall 2007 sampling at four locations along Clear Creek (Appendix O). Site means ranged from 19.9–24.8 °C (67.8–76.6 °F) with an overall mean for Clear Creek of 22.6 °C (72.6 °F). Hutton (2009) also collected samples at three locations along White Creek, ranging from 16.0–21.9 °C (60.1–71.4 °F) with a mean of 19.4 °C (66.9 °F) (Appendix O).

During 2009–2016 APHN monitoring, water temperatures at two locations in Clear Creek ranged from 1.7–27.5 °C (35.1–81.5 °F) with an overall mean of 13.4 °C (56.1 °F) (APHN 2016). Temperatures in White Creek near its mouth ranged from 1.8–19.4 °C (35.2–66.9 °F) with a mean of 12.5 °C (54.5 °F) (APHN 2016) (Table 63). The lower temperature range for White Creek reflects a lack of sampling during summer months (Table 63) and does not necessarily indicate an actual difference between Clear and White Creeks. The overall mean temperatures were similar to those calculated from 1982–1998 sampling (Spradlin and Rikard 1998).

Table 63. Water temperature results in °C from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	9.1	–	–
April 2009	16.4	17.8	17.0
June 2009	22.1	–	–
August 2009	24.4	–	–
October 2009	16.0	16.2	14.5
February 2012	1.7	3.1	1.8
May 2012	18.9	19.0	19.4
July 2012	–	27.5	–
November 2012	7.8	8.5	8.0
April 2013	12.9	–	12.6
June 2013	–	23.8	–
October 2015	13.7	16.5, 9.3	13.9
December 2015	–	7.6	–
January 2016	–	2.6	–
February 2016	–	5.0	–
March 2016	–	9.5	–

Continuous data recorded on Clear Creek at Lilly Bridge from October 2013 through September 2016 show temperatures ranging from approximately 0 °C (32 °F) during winter/early spring to just above 30 °C (86 °F) during the summer of 2016 (Appendix Q) (USGS 2016). As mentioned previously, it is normal for continuous data, which is collected around-the-clock", to capture a wider range of values than instantaneous sampling.

Daddy's Creek Watershed

During 1982–1998 sampling, water temperatures in Daddy's Creek ranged from 0.3–28.4 °C (32.5–83.1 °F) (Spradlin and Rikard 1998). Low temperatures were recorded in January and December with the highest temperatures in July and September. The mean water temperature for this entire period of record was 14.1 °C (57.4 °F).

Arnwine et al. (2005) collected water temperature measurements (every 30 minutes) from Daddy's Creek during 2002 and 2004 studies of DO levels. From 31 August–13 September 2004, temperatures ranged from just above 19 °C (66 °F) to 24.9 °C (76.8 °F). For the 2002 study, only the maximum water temperature reading of 29.9 °C (85.8 °F) is given (Arnwine et al. 2005).

Hutton (2009) presented mean water temperature values for five locations in the Daddy's Creek watershed from spring-fall 2007 sampling (Appendix O). Site means ranged from 17.0–27.1 °C (62.6–80.8 °F) with an overall mean for Daddy's Creek of 22.5 °C (72.5 °F).

During more recent APHN monitoring, water temperatures in Daddy's Creek (at Antioch Bridge, OBRI_7) ranged from 3.6–25.6 °C (38.5–78.1 °F) with a mean of 13.7 °C (56.7 °F) (Table 64) (APHN 2016). This mean was similar to the mean of 14.1 °C (57.4 °F) from 1982–1998 sampling (Spradlin and Rikard 1998).

Table 64. Water temperature results in °C from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	Temperature	Date	Temperature
February 2012	6.9	June 2013	20.9
April 2012	21.1	October 2015	15.1, 9.5
May 2012	18.8	December 2015	9.7
July 2012	25.6	January 2016	3.6
November 2012	8.3	March 2016	11.4

Continuous data recorded on Daddy's Creek near Hebbertsburg from October 2013 through September 2016 show temperatures ranging from 0 °C (32 °F) during winter/early spring to around 30 °C (86 °F) during the summer of 2016 (Appendix Q) (USGS 2016).

Obed River Watershed

During 1982–1998 sampling, Obed River water temperatures ranged from 0.5–28.6 °C (32.9–83.5 °F) (Spradlin and Rikard 1998). The lowest temperatures were recorded in January and the highest from late June-August. The mean water temperature for this period of record was 13.8 °C (56.8 °F).

Hutton (2009) presented mean water temperature values from spring-fall 2007 sampling at five locations along the Obed River (Appendix O). Site means ranged from 18.7–27.0 °C (65.7–80.6 °F) with an overall mean for the Obed River of 21.7 °C (71.0 °F).

During more recent APHN monitoring, water temperatures at two locations on the Obed River ranged from 2.6–24.8 °C (36.7–76.6 °F) with an overall mean of 14.5 °C (58.1 °F) (APHN 2016) (Table 65). This mean was not far from the mean temperature for 1982–1998 sampling of 13.8 °C (56.8 °F) (Spradlin and Rikard 1998).

Table 65. Water temperature results in °C from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	at Alley Ford (OBRI_8)
March 2009	10.7	11.4
April 2009	18.0	18.2
June 2009	22.1	24.4
August 2009	24.7	–
October 2009	14.6	15.9
February 2012	6.2	3.8
April 2012	21.1	–
May 2012	17.7	18.7
July 2012	24.8	–
November 2012	8.4	9.5
May 2013	–	14.0
June 2013	21.5	–
October 2015	14.6, 9.4	14.3
December 2015	7.8	–
January 2016	2.6	–
March 2016	9.3	–

Continuous data from the Obed River at Adams Bridge between October 2013 and September 2016 show temperatures ranging from 0 °C (32 °F) during winter/early spring to approximately 28 °C (82.4 °F) during the summer months (Appendix Q) (USGS 2016).

Emory River Watershed

Emory River water temperatures during 1982–1998 sampling ranged from 0.2–28.5 °C (32.4–83.3 °F) (Spradlin and Rikard 1998). Low temperatures were recorded in January and December and the highest temperatures in July. The mean water temperature for this period of record across two sampling locations was 14.1 °C (57.4 °F). Water temperatures in Rock Creek, which falls within the Emory River watershed, ranged from 0–24.7 °C (32.0–76.5 °F) with a mean of 11.8 °C (53.2 °F) over the same time period (Spradlin and Rikard 1998).

Hutton (2009) presented mean water temperature values for four locations in the Emory River watershed from spring-fall 2007 sampling (Appendix O). Site means ranged from 15.7–27.3 °C (60.3–81.1 °F) with an overall mean for Emory watershed locations of 21.4 °C (70.5 °F).

During 2009–2016 APHN monitoring, water temperatures at two Emory River locations ranged from 4.4–26.1 °C (39.9–79.0 °F) with an overall mean of 14.1 °C (57.4 °F) (Table 66) (APHN 2016). This was the same as the mean temperature from 1982–1998 sampling (Spradlin and Rikard 1998). Rock Creek was only sampled twice in 2009, with both results falling between 15–16 °C (59–60.8 °F) (Table 66) (APHN 2016).

Table 66. Water temperature results in °C from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed R. (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	10.1	–	–
April 2009	14.8	18.2	15.9
June 2009	24.9	–	–
August 2009	26.1	–	–
October 2009	15.5	15.4	15.3
February 2012	4.8	4.4	–
May 2012	19.4	–	–
November 2012	10.0	14.9	–
October 2015	14.9	–	–
February 2016	–	4.6	–

pH

Clear Creek Watershed

During 1982–1998 sampling, pH values from Clear Creek ranged from 4.8 to 7.7 (Spradlin and Rikard 1998). Values were generally lower (i.e., more acidic) during the winter months and higher during summer and early fall. The mean pH of all samples over this time period was 6.9. pH in White Creek during the same sampling period ranged from 5.9 to 7.5, also with a mean of 6.9 (Spradlin and Rikard 1998).

Arnwine et al. (2005) collected two pH samples from Clear Creek in September 2004. These samples had pH values of 6.6 and 6.8 respectively (Arnwine et al. 2005). Hutton (2009) reported mean pH values for four locations along Clear Creek from spring-fall 2007 sampling (Appendix O). Site means ranged from 7.03–7.6 with a transformed mean pH value for Clear Creek of 7.31. Hutton (2009) also collected samples at three locations along White Creek, ranging from 6.93–7.81 with a transformed mean of 7.15 (Appendix O).

During 2009–2016 APHN monitoring, pH values from two Clear Creek locations ranged from 5.29–7.15 with a mean of 6.44 (Table 67) (APHN 2016). This was slightly lower (i.e., more acidic) than the mean from 1982–1998 sampling (Spradlin and Rikard 1998). White Creek pH ranged from 5.55–7.45 with a mean of 6.35, also lower than the mean from 1982–1998 sampling (APHN 2016). All pH values <6 in Clear and White Creeks occurred in winter and spring (Table 67).

Table 67. pH results from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	6.39	6.65	–
April 2009	6.56	–	6.73
June 2009	6.71	–	–
August 2009	7.01	–	–
October 2009	6.80	6.62	7.45
February 2012	5.41	6.03	5.60
April 2012	–	7.15	–
May 2012	6.03	6.10	5.83
July 2012	–	6.35	–
November 2012	6.40	6.82	6.53
April 2013	5.29	–	5.55
June 2013	–	6.98	–
October 2015	6.65	6.97, 6.98	6.74
December 2015	–	6.10	–
January 2016	–	5.51	–
February 2016	–	6.17	–
March 2016	–	6.85	–

Continuous data from Clear Creek at Lilly Bridge between 2013 and 2016 documented a pH range of approximately 6.3–8.7, with the highest values and extreme fluctuations occurring during the summer of 2016 (Appendix Q) (USGS 2016).

Daddy's Creek Watershed

Daddy's Creek pH values from 1982–1998 sampling ranged from 5.3 to 7.9 (Spradlin and Rikard 1998). The highest values generally occurred in summer or early fall, with the lowest values in winter and spring. The mean pH of all samples over this period of record was 6.9.

Arnwine et al. (2005) collected two pH samples from Daddy's Creek in August-September 2004. The pH value for both samples was 7.7 (Arnwine et al. 2005). Hutton (2009) reported mean pH values for five locations in the Daddy's Creek watershed from spring-fall 2007 sampling (Appendix O). Site means ranged from 7.14–8.13 with a transformed mean pH value of 7.45 for all watershed locations.

During more recent APHN monitoring, Daddy's Creek pH ranged from 6.55–7.73 with a mean of 7.1 (Table 68) (APHN 2016). This was slightly higher (i.e., less acidic) than the mean of 6.9 from 1982–1998 sampling.

Table 68. pH results from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	pH	Date	pH
February 2012	6.71	June 2013	7.00
April 2012	7.73	October 2015	7.41, 7.51
May 2012	6.55	December 2015	7.22
July 2012	7.12	January 2016	6.74
November 2012	7.42	March 2016	7.01

Continuous data from Daddy's Creek near Hebbertsburg between 2013 and 2016 documented a pH range of approximately 6.8–9.5, with the highest values occurring during the late summer of 2016 (Appendix Q) (USGS 2016). Extreme fluctuations in pH values seem common during late summer/early fall.

Obed River Watershed

pH values from the Obed River during 1982–1998 sampling ranged from 6.3 to 8.4, making it the least acidic of the four targeted watersheds during this time period (Spradlin and Rikard 1998). The lowest values occurred in winter and spring with higher values during summer and early fall. The mean pH of all samples over this period of record was 7.1 (Spradlin and Rikard 1998).

Hutton (2009) reported mean pH values for five locations along the Obed River from spring-fall 2007 sampling (Appendix O). Site means ranged from 7.23–7.71 with a transformed mean pH value for the Obed River of 7.45.

During more recent APHN monitoring, pH values at two Obed River sampling locations ranged from 6.25–8.74 with a mean of 7.28 (Table 69) (APHN 2016). This was slightly higher than the mean value from 1982–1998 sampling (7.1) (Spradlin and Rikard 1998).

Table 69. pH results from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	at Alley Ford (OBRI_8)
March 2009	8.26	6.82
April 2009	8.74	7.38
June 2009	7.73	7.23
August 2009	7.79	7.91
October 2009	7.45	7.85
February 2012	6.70	5.96
April 2012	7.82	–
May 2012	6.25	6.35
July 2012	7.01	–
November 2012	7.86	7.37
May 2013	–	6.19

Table 69 (continued). pH results from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	at Alley Ford (OBRI_8)
June 2013	7.21	–
October 2015	7.62, 7.63	7.45
December 2015	7.07	–
January 2016	6.79	–
March 2016	6.86	–

Continuous data from the Obed River at Adams Bridge between 2013 and 2016 documented a pH range of approximately 5.8–8.6, with the lowest values occurring during the winter and summer of 2016 (Appendix Q) (USGS 2016).

Emory River Watershed

During 1982–1998 sampling, Emory River pH values ranged from 5.4 to 8.0 (Spradlin and Rikard 1998). The mean pH of all samples over this time period was 7.0, and seasonal patterns in pH were not particularly distinct. pH readings from Rock Creek over the same period of record ranged from 3.3 to 5.8 with a mean of 4.5 (Spradlin and Rikard 1998). These low values are due to acidic runoff from coal mine waste in the upper reaches of Rock Creek (Hughes, email communication, 5 April 2016).

Hutton (2009) reported mean pH values for four locations in the Emory River watershed from spring-fall 2007 sampling (Appendix O). Means ranged from 6.48–7.87 with a transformed mean pH value for Emory watershed sites of 6.78.

During 2009–2016 APHN monitoring, pH at two Emory River sampling locations ranged from 6.32–8.08 with a mean of 7.25 (Table 70) (APHN 2016). As with the previous watersheds, this mean was slightly higher (e.g., less acidic) than the mean of 7.0 from 1982–1998 sampling (Spradlin and Rikard 1998). Two samples taken from Rock Creek in 2009 (Table 70) fell within the range of values observed from 1982–1998.

Table 70. pH results from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed R. (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	6.92	–	–
April 2009	7.14	7.20	4.62
June 2009	7.48	–	–
August 2009	7.83	–	–
October 2009	7.43	8.08	5.0
February 2012	6.41	6.57	–
May 2012	7.25	7.22	–
November 2012	7.15	7.36	–
October 2015	7.85	7.85	–
February 2016	–	6.32	–

Dissolved Oxygen

Clear Creek Watershed

DO levels in Clear Creek during 1982–1998 sampling ranged from 3.5 mg/l to 13.5 mg/l, but with only one value below 6.0 mg/l (Spradlin and Rikard 1998). Levels were generally lower during July-August and highest in January-February. Mean DO for the entire 1982–1998 period of record was 9.8 mg/l. White Creek DO levels during this same period ranged from 2.2 mg/l to 13.3 mg/l with a mean of 9.5 mg/l (Spradlin and Rikard 1998).

Arnwine et al. (2005) collected continuous DO measurements (every 30 minutes) from Clear Creek in September 2004. From 1–15 September, DO readings ranged from 6.7 mg/l to approximately 8.6 mg/l with diurnal fluctuations around 1 mg/l (Figure 61).

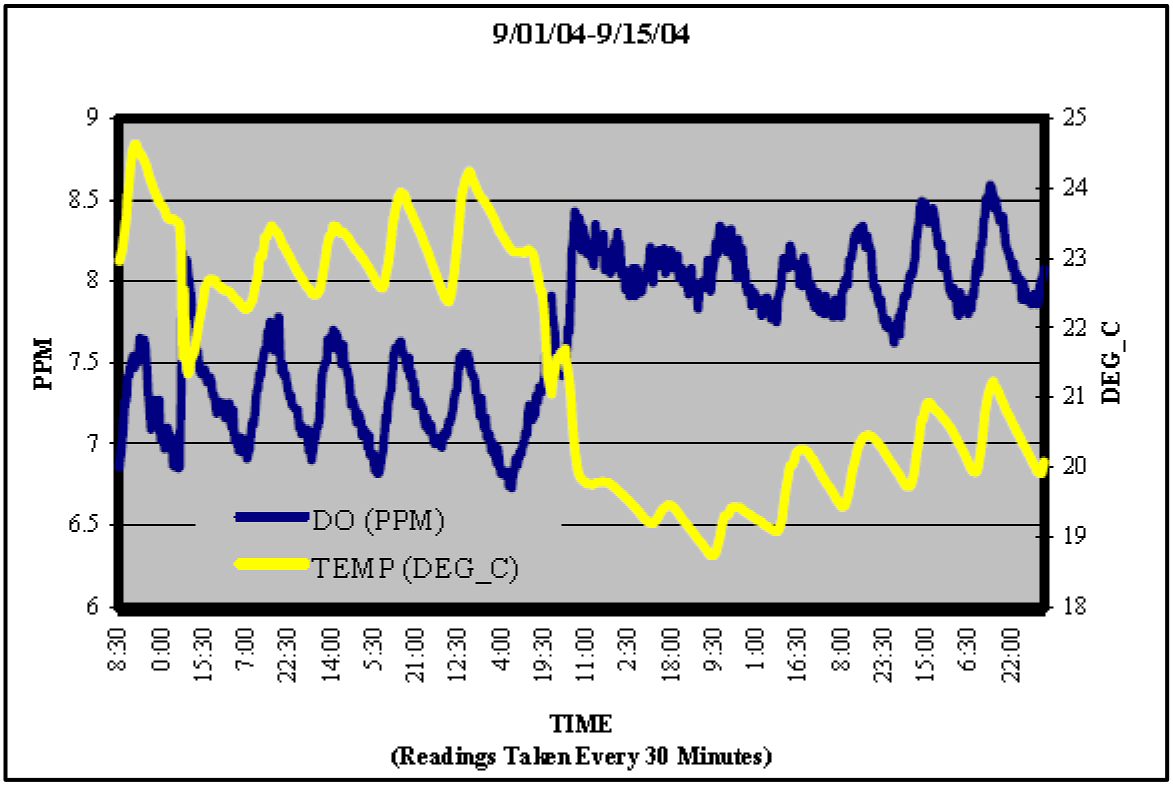


Figure 61. Continuous dissolved oxygen (DO) and water temperature readings from Clear Creek, 1–15 September 2004 (reproduced from Arnwine et al. 2005). Note that ppm is equivalent to mg/l. Distinct peaks and troughs represent diurnal fluctuations.

Hutton (2009) presented mean DO values from spring-fall 2007 sampling at four locations along Clear Creek (Appendix O). Site means ranged from 6.10–7.38 mg/l with an overall mean for Clear Creek of 7.01 mg/l. Hutton (2009) also collected samples at three locations along White Creek, ranging from 5.73–8.35 mg/l with a mean of 6.92 mg/l (Appendix O).

During 2009–2016 APHN monitoring, DO in Clear Creek ranged from 6.7–15.6 mg/l with a mean of 10.2 mg/l (Table 71) (APHN 2016). White Creek DO levels ranged from 7.0–13.5 mg/l with a mean of 10.0 mg/l (APHN 2016).

Table 71. Dissolved oxygen results (mg/l) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	12.0	–	11.5
April 2009	11.2	9.9	–
August 2009	7.5	–	–
October 2009	8.6	9.0	9.8
February 2012	13.4	12.1	13.5
April 2012	–	10.4	–

Table 71 (continued). Dissolved oxygen results (mg/l) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
May 2012	9.2	8.3	7.3
July 2012	–	7.2	–
November 2012	10.7	9.0	9.9
April 2013	10.8	–	10.9
June 2013	–	6.7	–
October 2015	8.5	7.84, 10.9	7.0
December 2015	–	12.0	–
January 2016	–	15.6	–
February 2016	–	12.8	–
March 2016	–	11.1	–

Continuous data recorded on Clear Creek at Lilly Bridge from October 2013 through September 2016 show DO ranging from approximately 3 mg/l (during late summer 2016) to nearly 15 mg/l (Appendix Q) (USGS 2016). During the summer of 2016, DO levels exhibited drastic fluctuations, which can be stressful for aquatic life.

Daddy's Creek Watershed

During 1982–1998 sampling, DO levels in Daddy's Creek ranged from 6.0 mg/l to 13.4 mg/l (Spradlin and Rikard 1998). The highest values occurred during winter months and the lowest values during summer months (July-August). The mean DO level for the entire time period was 9.9 mg/l (Spradlin and Rikard 1998).

Arnwine et al. (2005) collected continuous DO measurements from Daddy's Creek in 2002 and for 2 weeks in 2004. From 31 August–13 September, values ranged from 5.5 to just over 8.0 mg/l with diurnal fluctuations up to 2 mg/l (Figure 62). For the 2002 study, only the minimum DO level of 5.9 mg/l was provided (Arnwine et al. 2005).

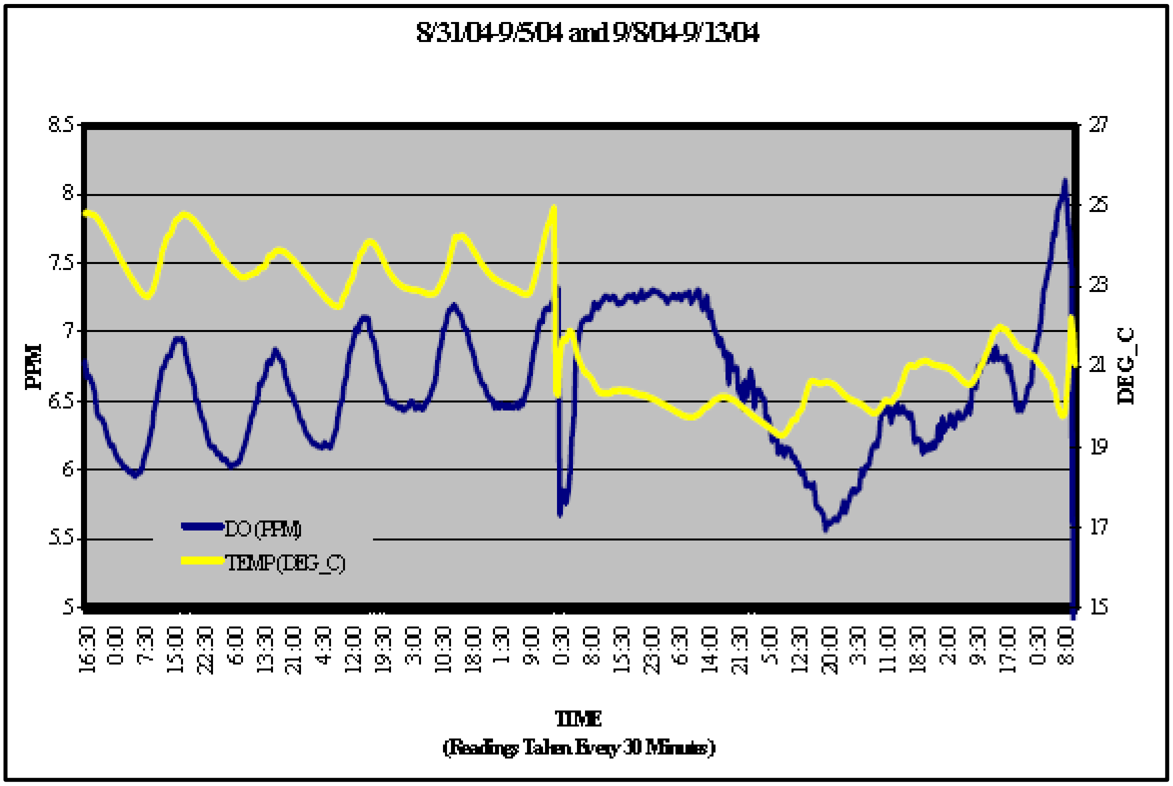


Figure 62. Continuous dissolved oxygen (DO) and water temperature readings from Daddy's Creek, 31 August-13 September (reproduced from Arnwine et al. 2005). Note that ppm is equivalent to mg/l. Distinct peaks and troughs represent diurnal fluctuations.

Hutton (2009) reported mean DO values at five locations in the Daddy's Creek watershed from spring-fall 2007 sampling (Appendix O). Site means ranged from 7.01–8.92 mg/l with an overall mean of 7.86 mg/l for Daddy's Creek watershed sites.

During more recent APHN monitoring, DO levels in Daddy's Creek ranged from 7.14–14.3 mg/l with a mean of 10.3 mg/l (Table 72) (APHN 2016). This range and mean were slightly higher than results from 1982–1998 sampling (Spradlin and Rikard 1998).

Table 72. DO results from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	DO (mg/l)	Date	DO (mg/l)
February 2012	11.5	June 2013	8.2
April 2012	10.25	October 2015	9.5, 11.0
May 2012	8.84	December 2015	11.0
July 2012	7.14	January 2016	14.3
November 2012	10.4	March 2016	10.8

Continuous data recorded on Daddy's Creek near Hebbertsburg from October 2013 through September 2016 show DO ranging from 0 mg/l (during summer months, likely due to no or low flow) to approximately 15 mg/l (Appendix Q) (USGS 2016). Similar to Clear Creek, DO levels showed wide fluctuations during the summer of 2016.

Obed River Watershed

During 1982–1998 sampling, Obed River DO levels ranged from 5.9 mg/l to 13.6 mg/l (Spradlin and Rikard 1998). Levels were highest in the winter and lowest in summer and fall. The mean DO level for the entire period of record was 9.9 mg/l (Spradlin and Rikard 1998).

Hutton (2009) presented mean DO values from spring-fall 2007 sampling at five locations along the Obed River (Appendix O). Means ranged from 6.95–8.90 mg/l with an overall mean for the Obed River of 7.66 mg/l.

During more recent APHN monitoring, Obed River DO levels ranged from 5.8–12.2 mg/l with a mean of 10.2 mg/l (Table 73) (APHN 2016). Lower levels occurred during summer months when temperatures are typically warmer and flows may be lower.

Table 73. DO results from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
March 2009	10.7	10.6
April 2009	12.2	10.4
August 2009	7.8	9.7
October 2009	8.6	9.9
February 2012	11.6	13
April 2012	10.25	–
May 2012	8.9	9.15
July 2012	5.8	–
November 2012	11.3	10.9
May 2013	–	9.76
June 2013	7.4	–
October 2015	8.31, 10.7	8.9
December 2015	10.8	–
January 2016	15.7	–
March 2016	12.2	–

Continuous data from the Obed River at Adams Bridge between October 2013 and September 2016 show DO ranging from 0 mg/l to approximately 15 mg/l (Appendix Q) (USGS 2016).

Emory River Watershed

DO levels in the Emory River during 1982–1998 sampling ranged from 6.6 mg/l to 13.6 mg/l (Spradlin and Rikard 1998). As with the previous watersheds, low levels typically occurred in July-August with the highest values observed in January. The mean DO of all samples during this period was 10.0 mg/l. Rock Creek DO levels during this sampling period ranged from 0 to 13.3 mg/l (only three measurements fell below 6 mg/l) with a mean of 10.0 mg/l (Spradlin and Rikard 1998).

Hutton (2009) reported mean DO values at four locations in the Emory River watershed from spring-fall 2007 sampling (Appendix O). Site means varied widely from 3.27–8.75 mg/l, with an overall mean for all watershed locations of 5.91 mg/l. These were the lowest observed DO means among all sampling locations during this sampling period. However, it should be noted that the Montgomery Road location is outside OBRI, approximately 8 river km (5 river mi) upstream of the Obed confluence.

During 2009–2016 APHN monitoring, DO levels at two Emory River locations ranged from 7.4–13.7 mg/l with a mean of 10.4 mg/l (Table 74) (APHN 2016). Two readings from Rock Creek in 2009 (Table 74) fell within the range of values reported during 1982–1998 sampling.

Table 74. DO results from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed River (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	10.8	–	–
April 2009	9.8	10.2	10.2
June 2009	–	–	–
August 2009	7.9	–	–
October 2009	9.9	8.3	8.5
February 2012	12.7	13.7	–
May 2012	9.2	7.4	–
November 2012	11.2	10.9	–
October 2015	10.0	10.0	–
February 2016	–	13.2	–

Conductivity

Clear Creek Watershed

During 1982–1998 sampling, SpC in Clear Creek ranged from 20 µS/cm (microsiemens per centimeter) to 138 µS/cm (Spradlin and Rikard 1998). Measurements were generally lower in the spring, perhaps due to higher flows from spring melt waters, and higher from late summer through early winter. The mean SpC for the entire 1982–1998 period of record was 49.3 µS/cm. White Creek SpC levels during this same period ranged from 6 µS/cm to 107 µS/cm with a mean of 40.9 µS/cm (Spradlin and Rikard 1998).

Arnwine et al. (2005) measured SpC in Clear Creek twice during September 2004. Recorded SpC levels were 52.0 and 49.1 µS/cm (Arnwine et al. 2005).

Hutton (2009) reported mean SpC values at four locations along Clear Creek from spring-fall 2007 sampling (Appendix P). Site means were relatively similar, ranging from 49.4–57.4 µS/cm with an overall mean of 53.1 µS/cm. Hutton (2009) also calculated means for three locations along White Creek within the Clear Creek watershed, which ranged from 62.9–65.4 µS/cm, with an overall mean of 64.2 µS/cm (Appendix P).

During 2009–2016 APHN monitoring, SpC measurements in Clear Creek ranged from 19–65 µS/cm with a mean of 45 µS/cm (Table 75) (APHN 2016). This range and mean were lower than the values from 1982–1998 sampling. White Creek SpC values during the same time period ranged from 21–50 µS/cm with a mean of 33 µS/cm (APHN 2016).

Table 75. SpC results (µS/cm) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	42	–	–
April 2009	41	35	30
June 2009	45	–	–
August 2009	56	–	–
October 2009	55	49	41
February 2012	40	35	28
April 2012	–	44	–
May 2012	31	40	38
July 2012	–	46	–
November 2012	65	62	50
April 2013	34	–	25
June 2013	–	51	–
October 2015	61	59, 62	21
December 2015	–	36	–
January 2016	–	19	–
February 2016	–	33	–
March 2016	–	38	–

Continuous data for SpC from Lilly Bridge between 2013 and 2016 ranged from 0 µS/cm to just over 100 µS/cm (Appendix Q) (USGS 2016). The vast majority of measurements appear to fall in the 25–90 µS/cm range.

Daddy's Creek Watershed

SpC measurements from Daddy's Creek during 1982–1998 sampling ranged from 4 µS/cm to 159 µS/cm (Spradlin and Rikard 1998). Here, values were lowest in spring and winter and highest during fall and late summer. Mean SpC over the time period was 68.5 µS/cm.

Arnwine et al. (2005) measured SpC in Daddy's Creek twice during August-September 2004, with results of 107.8 and 82.3 µS/cm. Hutton (2009) presented mean SpC values from spring-fall 2007 sampling at five locations in the Daddy's Creek watershed within OBRI (Appendix P). Mean SpC values ranged from 46.7 µS/cm to a strikingly high 887.5 µS/cm at Yellow Creek. However, it should be noted that Yellow Creek is a smaller tributary of Daddy's Creek outside OBRI boundaries. The overall mean for sites within the Daddy's Creek watershed was 247.9 µS/cm (Hutton 2009).

During more recent APHN monitoring, SpC in Daddy's Creek at Antioch Bridge ranged from 65–169 µS/cm with a mean of 93.3 µS/cm (Table 76) (APHN 2016). These values were higher than those observed during 1982–1998 sampling (Spradlin and Rikard 1998).

Table 76. SpC results (µS/cm) from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	SpC	Date	SpC
February 2012	65	June 2013	74
April 2012	93	October 2015	92, 85
May 2012	100	December 2015	67
July 2012	105	January 2016	169
November 2012	100	March 2016	76

The majority of continuous data readings for SpC near Hebbertsburg (2013–2016) fall in the 50–150 µS/cm range, but a single high reading just above 6,000 µS/cm was recorded during spring 2016 (Appendix Q) (USGS 2016). Given the provisional nature of this data, it is impossible to know if this reading is due to an actual temporary spike in SpC or if it is due to an equipment/sampling error.

Obed River Watershed

During 1982–1998 sampling, SpC at Obed River sites ranged from 11 µS/cm to 215 µS/cm (Spradlin and Rikard 1998). Values were again lowest in winter and spring and highest in the fall. Mean SpC over the entire time period was 83.7 µS/cm (Spradlin and Rikard 1998).

Hutton (2009) reported mean SpC values for five locations along the Obed River from spring-fall 2007 sampling (Appendix P). Site means ranged from 110.5–242.2 µS/cm with an overall mean of 169.8 µS/cm.

During more recent APHN monitoring, Obed River SpC measurements ranged from 42–213 µS/cm with a mean of 104 µS/cm (Table 77) (APHN 2016). Readings were consistently lower at Alley Ford, which is downstream from the Adams Bridge location, perhaps due to input from additional tributaries between the two sites. The overall mean for this period was higher than the mean from 1982–1998 sampling (Spradlin and Rikard 1998).

Table 77. SpC results (µS/cm) from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
March 2009	84	48
April 2009	81	50
June 2009	124	49
August 2009	123	71
October 2009	112	79
February 2012	85	50
April 2012	110	–
May 2012	95	75
July 2012	213	–
November 2012	197	95
May 2013	–	42
June 2013	135	–
October 2015	188, 195	93
December 2015	86	–
January 2016	132	–
March 2016	93	–

Continuous data for SpC from Adams Bridge between 2013 and 2016 ranged from 0 µS/cm to approximately 450 µS/cm (Appendix Q) (USGS 2016). The highest values typically occurred during late summer/early fall.

Emory River Watershed

In the Emory River, SpC ranged from 25 µS/cm to 192 µS/cm during 1982–1998 sampling (Spradlin and Rikard 1998). Values were lower in the winter and spring and higher during late summer and fall. The mean SpC over the period of record was 68.1 µS/cm. SpC measurements from Rock Creek during this time ranged from 0 µS/cm to 450 µS/cm with a mean of 160 µS/cm (Spradlin and Rikard 1998).

Hutton (2009) presented mean SpC values from spring-fall 2007 sampling at four locations in the Emory River watershed (Appendix P). While most site means were near or below 100 µS/cm, Island Creek yielded a mean of 1,342 µS/cm. As a result, the overall mean for the watershed was a relatively high 398.6 µS/cm (Hutton 2009).

During more recent APHN monitoring, SpC levels on the Emory River ranged from 24–94 µS/cm with a mean of 69 µS/cm (Table 78) (APHN 2016). This range was narrower (with a lower maximum) than during 1982–1998 sampling, but the mean was similar. The two SpC samples from Rock Creek in 2009 (Table 78) were below the mean from 1982–1998.

Table 78. SpC results (µS/cm) from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed River (OBRI_9)	at Nemo Bridge OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	52	–	–
April 2009	53	50	75
June 2009	71	–	–
August 2009	94	–	–
October 2009	76	77	108
February 2012	49	50	–
May 2012	71	91	–
November 2012	77	90	–
October 2015	93	93	–
February 2016	–	24	–

Turbidity

Clear Creek Watershed

Turbidity measurements from Clear Creek during 1982–1998 sampling ranged from 0 to 140 NTU, but with only one reading above 40 NTU (Spradlin and Rikard 1998). Values were typically lower during the fall and early winter and highest in late winter and spring, perhaps because of faster flows from meltwater runoff stirring up sediments. When including the single high outlying value of 140 NTU, the mean turbidity from 1982–1998 was 3.7 NTU; the mean turbidity over the same period was 3.2 NTU with the outlier excluded. Turbidity in White Creek during this same period ranged from 0.6 to 40 NTU with a mean of 4.5 NTU (Spradlin and Rikard 1998).

Hutton (2009) presented mean turbidity values from spring-fall 2007 sampling for four locations along Clear Creek (Appendix P). Site means ranged from 0.12–0.34 NTU with an overall mean of 0.19 NTU for all Clear Creek locations. Means were also calculated for three locations along White Creek and ranged from 0.25–1.42 NTU with an overall mean of 0.73 NTU (Appendix P).

During 2009–2016 APHN monitoring, Clear Creek turbidity ranged from 0.2–6.4 NTU with a mean of 2.3 NTU (Table 79) (APHN 2016). This range and mean are lower than results from 1982–1998 sampling. Turbidity in White Creek ranged from 1.0–3.9 NTU with a mean of 1.7 NTU (APHN 2016), which is also lower than previous sampling (Spradlin and Rikard 1998). Lower values could be due to differences in the timing of sampling with regards to flow speeds (influenced by precipitation/runoff events) rather than any changes in turbidity over time.

Table 79. Turbidity results (NTU) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	0.5	–	–
April 2009	1.0	2.0	1.5

Table 79 (continued). Turbidity results (NTU) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
June 2009	6.0	–	–
August 2009	2.0	–	–
October 2009	1.3	1.5	4.5
April 2012	–	0.2	–
May 2012	1.7	5.8	1.4
July 2012	–	3.0	–
November 2012	0.6	0.5	1.0
April 2013	6.4	–	3.9
June 2013	–	1.5	–
October 2015	3.4	1.3, 0.9	1.0
January 2016	–	3.0	–
February 2016	–	2.4	–

Continuous data collected at Lilly Bridge from October 2013 through September 2016 show that turbidity is typically low on Clear Creek, but with occasional spikes (Appendix P) (USGS 2016). During 2014 and 2016, these spikes remained below 300 FNU. During the summer and fall of 2015, several spikes exceeded 400 FNU, with readings near 700 FNU in early fall (USGS 2016).

Daddy's Creek Watershed

During 1982–1998 sampling, turbidity on Daddy's Creek ranged from 0 to 58 NTU, with no seasonal trends apparent (Spradlin and Rikard 1998). Mean turbidity during this sampling period was 3.6 NTU.

Hutton (2009) reported mean turbidity values for five locations in the Daddy's Creek watershed from spring-fall 2007 sampling (Appendix P). All site means were below 0.6 NTU with an overall mean of 0.30 NTU for all watershed sites.

During more recent APHN monitoring, turbidity in Daddy's Creek at Antioch Bridge ranged from 0.5–13.4 NTU with a mean of 3.1 NTU (Table 80) (APHN 2016). This mean and maximum were lower than those documented during 1982–1998 sampling (Spradlin and Rikard 1998).

Table 80. Turbidity results (NTU) from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	Turbidity	Date	Turbidity
May 2012	13.4	June 2013	1.5
July 2012	1.0	October 2015	1.5, 0.7
November 2012	0.5	January 2016	3.4

Continuous data recorded near Hebbertsburg between 2013 and 2016 show that turbidity is generally low in Daddy's Creek but experiences occasional spikes above 600 FNU and, on rare occasions, exceeds 1,000 FNU (Appendix P) (USGS 2016). These spikes have occurred during various seasons, including summer (2014–2015), early fall (2015–2016), and early winter (2015).

Obed River Watershed

During 1982–1998 sampling, turbidity on the Obed River ranged from 0.5 to 57 NTU (Spradlin and Rikard 1998). Readings were lowest in the fall and highest during late winter and spring. The mean turbidity over this period of record was 4.8 NTU (Spradlin and Rikard 1998).

Hutton (2009) presented mean turbidity values from spring-fall 2007 sampling for five locations along the Obed River within OBRI (Appendix P). Site means ranged from 0.05–1.33 NTU with an overall mean of 0.59 NTU.

During 2009–2016 APHN monitoring, turbidity at two Obed River sampling locations ranged from 0.3–26.0 NTU with a mean of 3.4 NTU (Table 81) (APHN 2016). Measurements were more variable at Alley Ford (further downstream) than at Adams Bridge. The overall mean and maximum during this period were lower than during 1982–1998 sampling (Spradlin and Rikard 1998). Again, this could be due to differences in the timing of sampling rather than a change in turbidity over time.

Table 81. Turbidity results (NTU) from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
March 2009	0.5	0.8
April 2009	2.0	2.0
June 2009	2.0	7.5
August 2009	2.5	2.0
October 2009	2.5	0.8
April 2012	2.0	–
May 2012	7.6	26.0
July 2012	2.1	–
November 2012	0.8	0.3
May 2013	–	4.8
June 2013	2.1	–
October 2015	1.5, 1.2	0.9
January 2016	3.7	–

Continuous data recorded at Adams Bridge show that turbidity has been highly variable on the Obed River over the past 2 years (Appendix P) (USGS 2016). From October 2013–August 2014, readings remained below 300 FNU. Since October 2014, turbidity readings have fluctuated wildly between very low levels to increasingly frequent spikes above 1,200 FNU (USGS 2016).

Emory River Watershed

Turbidity on the Emory River during 1982–1998 sampling ranged from 0 to 78 NTU (Spradlin and Rikard 1998). Although seasonal trends were less defined, the highest observation occurred in late winter and the lowest during early summer. Mean turbidity during this time period was 4.8 NTU. Rock Creek turbidity ranged from 0.2 NTU to 105 NTU during this sampling period, but with only one measurement above 30 NTU (Spradlin and Rikard 1998). Mean turbidity was 3.0 NTU when including the single high outlying value, and 2.1 NTU with the outlier excluded.

Hutton (2009) presented mean turbidity values for five locations in the Emory River watershed from spring-fall 2007 sampling (Appendix P). Site means ranged from 0.33–0.97 NTU with an overall mean turbidity of 0.68 NTU across all watershed locations.

During more recent APHN monitoring, Emory River turbidity ranged from 0.5–20.6 NTU with a mean of 3.2 NTU (Table 82) (APHN 2016). Similar to previous watersheds, the mean and maximum were lower than during 1982–1998 sampling (Spradlin and Rikard 1998).

Table 82. Turbidity results (µS/cm) from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed River (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	0.5	–	–
April 2009	2.0	1.5	0.5
June 2009	4.0	–	–
August 2009	3.0	–	–
October 2009	2.0	1.0	2.0
May 2012	2.9	20.6	–
November 2012	0.8	0.5	–
October 2015	1.5	1.5	–
February 2016	–	3.3	–

Acid Neutralizing Capacity

Clear Creek Watershed

The first available data for ANC in OBRI are from 2009. During 2009–2016 APHN sampling, ANC at two Clear Creek sampling locations ranged from 4.1–15.9 mg/l as $CaCO_3$ with a mean of 8.7 mg/l (Table 83) (APHN 2016). Values were generally lower in winter and spring and higher in summer and fall. Measurements of ANC at White Creek during the same period ranged from 3.8–15.6 mg/l as $CaCO_3$ with a mean of 8.6 mg/l (APHN 2016).

Table 83. ANC results (mg/l as $CaCO_3$) from Clear and White Creek sampling sites, 2009–2016 (APHN 2016).

Date	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
March 2009	4.5	–	–
April 2009	5.6	5.7	5.3
June 2009	9.7	–	–
August 2009	14.1	–	–
October 2009	9.6	9.1	9.1
February 2012	4.6	4.5	3.8
April 2012	–	8.8	-
May 2012	9.0	7.0	11.1
July 2012	11.0	9.6	–
November 2012	–	12.6	10.4
April 2013	5.9	–	4.7
June 2013	–	10.6	–
October 2015	14.7	13.0, 15.9	15.6
December 2015	–	6.2	–
January 2016	–	4.1	–
February 2016	–	4.6	–
March 2016	–	7.5	–

Daddy's Creek Watershed

ANC measurements were taken by the APHN at Antioch Bridge along Daddy's Creek from 2012–2016. Results ranged from 15.4–31.7 mg/l as $CaCO_3$ with a mean of 25.2 mg/l (Table 84) (APHN 2016). Lower values occurred during winter months while higher values were during late spring and summer.

Table 84. ANC results (mg/l as $CaCO_3$) from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2012–2016 (APHN 2016).

Date	ANC	Date	ANC
February 2012	17.3	June 2013	21.7
April 2012	29.7	October 2015	27.0, 27.5
May 2012	30.0	December 2015	24.2
July 2012	31.7	January 2016	15.4
November 2012	29.2	March 2016	23.0

Obed River Watershed

APHN sampling of ANC at two Obed River locations from 2009–2016 yielded a range of 8.2–70.4 mg/l as $CaCO_3$ with an average of 28.8 mg/l (Table 85) (APHN 2016). Seasonal patterns were similar to previous watersheds, with lower values in late winter and spring and higher values in the summer and fall. ANC was consistently higher at the Adams Bridge site than at Alley Ford (further downstream), likely due to upstream urban influences (e.g., high solute levels in runoff).

Table 85. ANC results (mg/l as $CaCO_3$) from Obed River sampling sites, 2009–2016 (APHN 2016).

Date	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
March 2009	19.0	10.0
April 2009	21.9	12.4
June 2009	33.8	12.3
August 2009	43.5	21.3
October 2009	34.1	22.6
February 2012	17.9	10.3
April 2012	31.7	–
May 2012	26.0	20.3
July 2012	70.4	–
November 2012	52.4	23.9
May 2013	–	8.2
June 2013	39.5	–
October 2015	58.8, 63.3	30.3
December 2015	23.1	–
January 2016	18.0	–
March 2016	24.8	–

Emory River

During 2009–2016 APHN sampling, ANC at two Emory River locations ranged from 7.2–29.5 mg/l as $CaCO_3$ with a mean of 16.4 mg/l (Table 86) (APHN 2016). Seasonal patterns were similar to previous watersheds. ANC was consistently higher below the confluence with the Obed (at Nemo Bridge) than it was above the confluence (Table 86). Two samples taken from Rock Creek during 2009 yielded results of 0 mg/l as $CaCO_3$ (APHN 2016). These values may be related to acidic runoff from coal mine waste in the creek's upper reaches.

Table 86. ANC results (mg/l as $CaCO_3$) from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed River (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
March 2009	7.2	–	–
April 2009	8.6	11.5	0.0
June 2009	15.1	–	–
August 2009	24.9	–	–
October 2009	15.1	21.9	0.0

Table 86 (continued). ANC results (mg/l as $CaCO_3$) from Emory River and Rock Creek sampling sites, 2009–2016 (APHN 2016).

Date	Upstream of Obed River (OBRI_9)	At Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
February 2012	7.5	10.1	–
May 2012	16.4	23.0	–
November 2012	18.3	22.5	–
October 2015	21.0	29.5	–
February 2016	–	9.6	–

<u>Nutrients</u>

Clear Creek Watershed

Nutrient data from the 1982–1998 sampling period are limited to a few measurements of ammonia (NH_3) between 1995 and 1998. During this time, NH_3 levels in Clear Creek ranged from 0 to 0.31 mg/l with a mean of 0.13 mg/l (Spradlin and Rikard 1998). NH_3 measurements from White Creek during the same period (15 samples) ranged from 0 to 0.4 mg/l with a mean of 0.18 mg/l (Spradlin and Rikard 1998).

Arnwine et al. (2005) measured N (nitrite [NO_2] + NO_3) and total P in Clear Creek twice during September 2004. Values for total N were 0.05 mg/l and 0.11 mg/l while P were below 0.004 mg/l (Arnwine et al. 2005).

During 2009 monitoring, five samples were taken at Norris Ford on Clear Creek and two samples each at Lilly Bridge on Clear Creek and from White Creek (EPA 2016). Ammonium (NH_4) and phosphate (PO_4) were not detected in any of these samples (Table 87). The maximum levels of dissolved N detected at both Clear Creek stations were higher than the total N measurements found by Arnwine et al. (2005). Maximum P levels were also higher than levels detected by Arnwine et al. (2005). It is unclear if these differences are due to the timing of sampling or actual changes in nutrient levels within the watershed.

Table 87. Nutrient result ranges (mg/l) from Clear and White Creek sampling sites, 2009 (EPA 2016). ND = not detected.

Constituent	Norris Ford (OBRI_1)	At Lilly Bridge (OBRI_3)	White Creek near mouth (OBRI_2)
Ammonium as NH_4	ND	ND	ND
Nitrate as NO_3	0.09–1.19	0.16–0.17	0.11–0.12
Nitrite as NO_2	ND–0.1	ND–0.08	ND–0.8
Dissolved Nitrogen	0.06–0.45	0.14–0.18	0.12–0.14
Phosphate-phosphorus as PO_4	ND	ND	ND
Phosphorus	ND–0.14	0.12	ND

Daddy's Creek Watershed

Limited nutrient sampling on Daddy's Creek from 1995–1998 yielded a range of NH_3 levels from 0 to 0.24 mg/l (Spradlin and Rikard 1998). The mean NH_3 level during this time (only 18 samples) was 0.11 mg/l.

Arnwine et al. (2005) measured N (NO_2 + NO_3) and total P in Daddy's Creek during August-September 2004. Values for N were 0.09 mg/l and 0.10 mg/l while P levels were below 0.004 mg/l (Arnwine et al. 2005).

During 2009 monitoring, four samples were taken throughout the year at Daddy's Creek (EPA 2016). As with Clear Creek, NH_4 and PO_4 were not detected in any of the samples (Table 88). All N levels and two of the four P readings were above those measured previously by Arnwine et al. (2005).

Table 88. Nutrient result ranges (mg/l) from Daddy's Creek at Antioch Bridge (near Hebbertsburg, OBRI_7), 2009 (EPA 2016). ND = not detected.

Constituent	Range
Ammonium as NH_4	ND
Nitrate as NO_3	0.18–0.74
Nitrite as NO_2	ND–0.10
Dissolved Nitrogen	0.19–0.27
Phosphate-phosphorus as PO_4	ND
Phosphorus	ND–0.11

Obed River Watershed

Nutrient sampling from the Obed River during the 1982–1998 sampling period is limited to 16 measurements of NH_3 between 1995 and 1998. Values ranged from 0 to 0.4 mg/l with a mean of 0.13 mg/l (Spradlin and Rikard 1998).

During 2009 monitoring, five samples were taken throughout the year from two different locations along the Obed River (EPA 2016). As with the previous watersheds, NH_4 and PO_4 were not detected in any of the samples (Table 89). Nutrient levels were generally higher at the upstream Adams Bridge location than at Alley Ford further downstream. This may be due to additional inputs from smaller, higher quality tributaries of the Obed River, such as Clear Creek. Maximum dissolved N levels were higher at Obed River stations than at Clear and Daddy's Creek locations, while P levels were similar (EPA 2016).

Table 89. Nutrient result ranges (mg/l) from Obed River sampling sites, 2009 (EPA 2016). ND = not detected.

Constituent	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
Ammonium as NH_4	ND	ND
Nitrate as NO_3	0.99–2.34	ND–1.01

Table 89 (continued). Nutrient result ranges (mg/l) from Obed River sampling sites, 2009 (EPA 2016). ND = not detected.

Constituent	At Adams Bridge (OBRI_4)	At Alley Ford (OBRI_8)
Nitrite as NO_2	0.05–0.12	ND–0.13
Dissolved Nitrogen	0.39–0.62	0.18–0.46
Phosphate-phosphorus as PO_4	ND	ND
Phosphorus	ND–0.09	ND–0.11

Emory River Watershed

During limited sampling between 1995–1998, NH_3 levels in the Emory River ranged from 0 to 0.37 mg/l (Spradlin and Rikard 1998). Mean NH_3 was 0.13 mg/l. NH_3 levels on Rock Creek during this period ranged from 0 to 0.52 mg/l with a mean (17 samples) of 0.21 mg/l (Spradlin and Rikard 1998).

During 2009 monitoring, five samples were taken on the Emory River upstream of the Obed and two samples each were taken at Nemo Bridge and from Rock Creek (EPA 2016). Again, NH_4 and PO_4 were not detected in any of the samples (Table 90). Maximum NO_2, NO_3, and dissolved N levels were generally lower on the Emory River than on the Obed River. P levels at Nemo Bridge and on Rock Creek were similar to other watersheds, but the maximum level upstream of the Obed River was higher than in other watersheds (EPA 2016).

Table 90. Nutrient result ranges (mg/l) from Emory River and Rock Creek sampling sites, 2009 (EPA 2016). ND = not detected.

Constituent	Upstream of Obed River (OBRI_9)	at Nemo Bridge (OBRI_10)	Rock Creek near mouth (OBRI_11)
Ammonium as NH_4	ND	ND	ND
Nitrate as NO_3	ND–0.38	0.13–0.37	ND–0.61
Nitrite as NO_2	ND–0.08	ND–0.08	ND–0.04
Dissolved Nitrogen	0.05–0.27	0.16–0.32	0.04–0.07
Phosphate-phosphorus as PO_4	ND	ND	ND
Phosphorus	ND–0.19	0.05–0.1	ND–0.04

Threats and Stressor Factors

The NRCA project team identified many potential threats and stressors to OBRI's water quality. These included urban development (particularly storm and waste water treatment), increased water demand, agriculture (e.g., bacteria and nutrient contributors), drought/climate change, oil and gas development, mining (e.g., metal contaminants), and sedimentation.

The historically rural character of portions of the OBRI watersheds have been replaced by urban and suburban growth in recent decades (e.g., retirement communities, golf resorts) (Hughes 2008). Many aspects of upstream urban development can threaten water quality. These developments have increased industrial and municipal water demand, as well as increasing wastewater discharge and interest in stream impoundment for agriculture/residential development (Hughes 2008). The cities of Crossville and Crab Orchard supply drinking water to much of Cumberland County; this water comes from sources in the Obed River headwaters such as Lake Holiday and Stone Lake (Figure 63) (Knight et al. 2014). Increased withdrawal from these sources reduces the amount of water available to streams in the Obed watershed, which can concentrate pollutants and other solutes in the remaining waters. Just over half of the drinking water removed by Crossville is returned to the Obed River as effluent from the Crossville wastewater treatment plant, just 22.5 km (14 mi) upstream of the OBRI boundary (Figure 63) (Knight et al. 2014). Although this effluent has been treated, it may still contain contaminants from human use. Development since the 1970s has led to the construction of over 2,000 impoundments in the Obed River headwaters for purposes ranging from recreation and water supply to irrigation and livestock watering (Forester et al. 1998, Knight et al. 2014). Runoff from recreational areas such as parks and golf courses may contribute sediment, herbicides, fertilizers, and other chemicals to the watershed (Trustees 2008). Road and other construction often contributes high levels of silt to area streams (TDEC 2002, Emmott et al. 2005), leading to increased sedimentation.

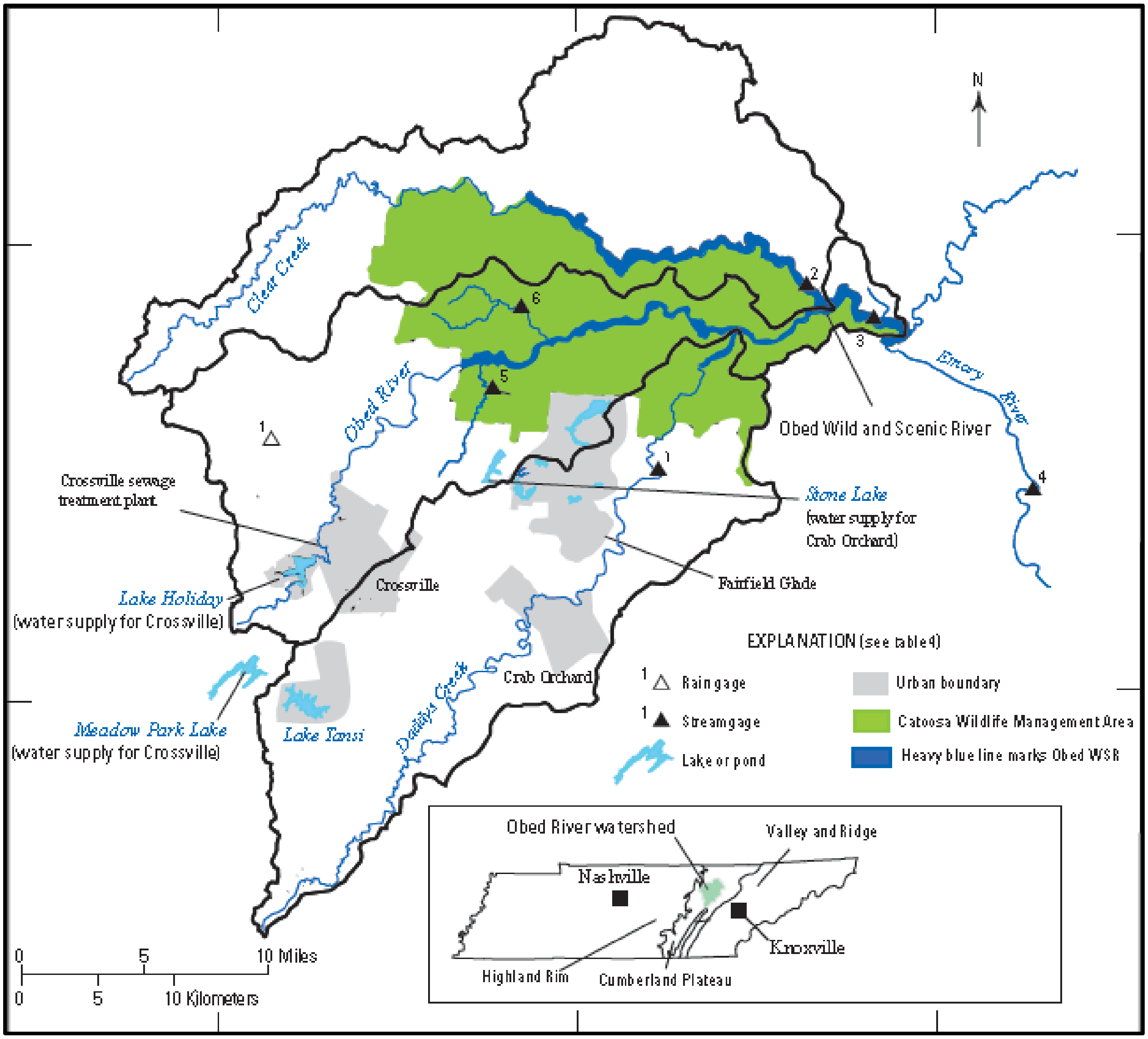


Figure 63. Locations of developments, water supply sources, and the Crossville sewage treatment plant relative to OBRI (reproduced from Knight et al. 2014).

Upstream agricultural activities can withdraw water from the Obed River system and also contribute pollutants into the watersheds. Livestock operations are a major source of nutrients and coliform bacteria in regional waters (Ahlstedt et al. 2001, Emmott et al. 2005). Nutrient loading affects DO and pH levels, potentially triggering wide diurnal fluctuations in these parameters and interfering with the respiration of aquatic organisms (NPS 2015b). The presence of coliform bacteria indicates fecal contamination of a water body, which can cause serious illness in humans (USGS 2011). Agricultural runoff may also contribute to elevated conductivity (Emmott et al. 2005).

There are no longer any active coal mines operating within the Obed River watershed, but the impacts of historic (pre-1970s) mining activity continue to influence regional water quality (Emmott et al. 2005, Knight et al. 2014). Abandoned coal strip mines are present in the headwaters of Daddy's

Creek, various tributaries of Clear Creek, and the Emory River (Emmott et al. 2005). Mining activity contributes sediment, metals, and acids to stream ecosystems (Hutton 2009). Strip mining involves depositing waste materials in spoil piles near the mine, which can leach sediment, toxic chemicals, and acids into nearby streams over time, particularly following rainfall (Hutton 2009). The ANC of some OBRI streams is naturally low, which makes them particularly vulnerable to acid contributions from mining wastes and other sources (Hughes 2008).

Oil and gas development, which is still active in and around OBRI, poses a serious threat to the park's water quality. Eleven oil and gas wells are located within OBRI's legislative boundaries, four of which are still active (NPS 2011, Spradlin, written communication, 29 August 2016). Oil drilling involves the use of fuels and drilling fluids that could influence nearby streams if they leak or spill (Sadiq et al. 2003, Hutton 2009). Leaks or spills of the oil or natural gas itself could also contaminate park waters (Emmott et al. 2005, Hutton 2009). In 2002, an oil well fire and explosion occurred adjacent to the park in the Clear Creek watershed (Emmott et al. 2005, Trustees 2008). The associated oil spill contaminated approximately 0.3 km (0.2 mi) of White Creek and at least 3.2 km (2 mi) of Clear Creek in the area of Barnett Bridge (Trustees 2008). Water quality, sediment quality, and aquatic communities (e.g., algae, benthic invertebrates, fisheries) were all impacted by the contamination (Trustees 2008). A portion of Clear Creek is still classified as "impaired" by the TDEC as a result of the spill (TDEC 2014b).

Global climate change is projected to increase temperatures across the southeastern U.S. over the next century (Carter et al. 2014). Increasing air temperatures contribute to increased water temperatures, which influences a wide variety of water chemistry parameters, particularly DO (Delpla et al. 2009). Warmer temperatures will also likely accelerate the loss of surface water to the atmosphere through evapotranspiration (Bates et al. 2008), which could influence the concentrations of solutes (e.g., minerals, nutrients, pollutants) in the remaining water (Delpla et al. 2009). In addition to temperature changes, climate change is projected to cause precipitation events to become less frequent but more intense, with longer dry periods between rain events (Bates et al. 2008). This could contribute to low flow conditions in streams and rivers, particularly during summer, which are often linked to decreased DO levels and increased solute concentrations (Bates et al. 2008, Delpla et al. 2009). Drought conditions can also affect water quality sampling efforts. Hutton (2009) had originally identified 51 sites within OBRI for aquatic invertebrate and water quality sampling, but due to a long-term regional drought, only 21 sites had enough water for sampling.

Data Needs/Gaps

With the exception of ANC, historical (pre-2000) and more recent water quality data are available for the measures selected for this assessment. Sampling methods and locations have varied somewhat over time, making statistical comparisons of data challenging. Continued collection of data using the APHN monitoring protocol will allow for comparisons over time in order to identify any changes or trends in water quality parameters. Additional study of the treated wastewater effluent returned to the Obed watershed by the Crossville treatment plant will help managers better understand any potential threats this input may pose.

Overall Condition

Water Temperature

The project team assigned this measure a *Significance Level* of 3 (Table 91). Water temperatures throughout OBRI's streams vary by season, along with air temperatures. During 2009–2016 APHN sampling, all four OBRI watersheds (Clear and Daddy's Creeks, Obed and Emory Rivers) showed similar temperature ranges, from about 2–28 °C (35.6–82.4 °F) (APHN 2016). Temperature measurements during this recent monitoring and from continuous data collection at three sites (USGS 2016) were similar to measurements from previous NPS monitoring (1982–1998) for all four watersheds. Recent APHN monitoring results were also within the selected reference condition (based on Clear Creek conditions) of 0–30 °C (32–86 °F) and within the Tennessee state standard of <30.5 °C (86.9 °F) (TDEC 2013). Therefore, this measure for all four watersheds is assigned a *Condition Level* of 0 indicating no current concern.

Table 91. A summary of Condition Levels for each measure by watershed and Weighted Condition Scores (WCS) for each watershed.

Measure	Significance Level	Condition Levels			
		Clear Creek	Daddy's Creek	Obed River	Emory River
Temperature	3	0	0	0	0
pH	3	1	1	1	1
Dissolved oxygen	3	2	2	3	1
Conductivity	3	0	1	3	0
Turbidity	3	1	1	2	0
ANC	3	1	0	0	2
Nutrients	3	3	2	3	3
WCS	**–**	**0.38**	**0.33**	**0.57**	**0.33**

pH

The pH measure was assigned a *Significance Level* of 3 (Table 91). The reference condition, based on previous Clear Creek conditions (Spradlin and Rikard 1998), is a range of 4.8–7.7.

Clear Creek appears to have a natural pH that is slightly acidic. The range of pH values recorded during 2009–2016 APHN sampling was within the reference condition range from previous sampling. The mean during recent sampling was slightly lower than during previous sampling, but it is unclear if this is due to slight differences in the timing of sampling (pH can fluctuate seasonally) or an actual change in pH over time. Continuous data measurements at Lilly Bridge from the summer of 2016 showed higher than usual pH values and wide fluctuations (USGS 2016), but the provisional nature of this data makes its reliability somewhat uncertain. For Clear Creek, pH is assigned a *Condition Level* of 1 for low concern. However, future sampling results should be monitored closely to determine if changes are occurring, as suggested by recent continuous data.

While Daddy's Creek also appears to have a slightly acidic natural pH, the range of values from recent APHN sampling was less acidic than Clear Creek and well within the reference condition.

There is no evidence of any pH changes over time based on APHN monitoring, but continuous data taken near Hebbertsburg suggests an increasing trend with wide fluctuations, particularly during the summer months (USGS 2016). Although this data is provisional, the potential changes it suggests are enough to create concern; therefore, a *Condition Level* of 1 is assigned for Daddy's Creek.

The range of pH values for the Obed River is higher (i.e., less acidic) than those for Clear and Daddy's Creeks (Spradlin and Rikard 1998, APHN 2016), which is to be expected for a larger water body. Although the higher pH values from the river are outside the reference conditions from Clear Creek, they are within Tennessee state standards (6.0–9.0) (TDEC 2013). However, the wide fluctuations in pH suggested by the continuous data from Adams Bridge, particularly in the summer of 2016, are a cause for concern (USGS 2016). As a result, this measure is assigned a *Condition Level* of 1 for the Obed River.

The pH range for the Emory River was slightly lower than the range for the Obed and, therefore, recent measurements (APHN 2016) were closer to the Clear Creek reference condition. Two measurements during 2009–2016 sampling fell just below the Tennessee state standard for "larger rivers" of 6.5 (TDEC 2013), but this is not a serious concern at this time. This measure is assigned a *Condition Level* of 1 for the Emory River.

Dissolved Oxygen

The project team also assigned a *Significance Level* of 3 (Table 91) for this measure. The reference condition for DO, based on Clear Creek conditions (Spradlin and Rikard 1998), is >6.0 mg/l.

During 2009–2016 APHN sampling, all DO measurements from Clear and White Creeks were above 6.0 mg/l. However, as recently as 2007, Hutton (2009) reported a mean sampling season DO below 6.0 mg/l on White Creek and a mean of 6.1 mg/l for Norris Ford on Clear Creek. Continuous sampling at Lilly Bridge showed frequent measurements below 6.0 mg/l during the summer of 2016 with drastic fluctuations (USGS 2016), which can be stressful for aquatic life. This contributes to a moderate concern for the Clear Creek watershed (*Condition Level* = 2).

Recent APHN monitoring results on Daddy's Creek also showed all DO measurements above 6.0 mg/l, with a minimum of 7.1 mg/l. However, continuous monitoring of DO on Daddy's Creek in 2005 showed that levels dropped below 6.0 mg/l at certain times of day when routine sampling is not likely conducted (Arnwine et al. 2005). More recent continuous data collected near Hebbertsburg also showed occasional decreases below 6.0 mg/l with wide fluctuations (USGS 2016), making this measure also a moderate concern (*Condition Level* = 2) for Daddy's Creek.

During 2009–2016 APHN monitoring, only one DO measurement from the Obed River fell below the reference condition of 6.0 mg/l. This reading of 5.8 mg/l came during July, when air and water temperatures are higher and the oxygen-holding capacity of water is lower. Continuous data from Adams Bridge suggests that DO levels regularly dropped below 6.0 mg/l during the summers of 2015 and 2016, and occasionally fell below this standard at other times of year (USGS 2016). Even though these are provisional data, they create a cause for high concern (*Condition Level* = 3) on the Obed River.

All DO readings from the Emory River and Rock Creek during recent APHN sampling were above the reference condition of 6.0 mg/l. However, the mean from sampling on Rock Creek during 2007 was below the reference condition and the state standard at 4.22 mg/l (Hutton 2009). This suggests that DO levels on some smaller tributaries within the Emory watershed may be a concern, leading to a *Condition Level* of 1.

Conductivity

The conductivity measure was assigned a *Significance Level* of 3 (Table 91) by the project team. The reference condition, based on Clear Creek, is <150 µS/cm.

SpC results from 2009–2016 monitoring on Clear Creek were well within the reference condition, with a maximum value of 65 µS/cm (APHN 2016). Measurements on White Creek were even lower, with a maximum of 50 µS/cm. Recent continuous data from Lilly Bridge also shows values below 100 µS/cm (USGS 2016). As a result, SpC is currently of no concern for Clear Creek (*Condition Level* = 01).

During recent APHN monitoring, SpC on Daddy's Creek exceeded the reference condition just once, with a measurement of 169 µS/cm (APHN 2016). Sampling site means in the Daddy's Creek watershed during 2007 were also within the reference condition with the exception of Yellow Creek, a smaller tributary outside of OBRI boundaries (Cook and Hutton 2009). Continuous data from near Hebbertsburg are also within the reference condition range with one extreme exception (USGS 2016). Given the provisional nature of this data, it is impossible to know if the high reading is due to an actual temporary spike or if it is an error. Therefore, SpC is of low concern for Daddy's Creek (*Condition Level* = 1).

During 2009–2016 sampling on the Obed River, three SpC measurements from the Adams Bridge location exceeded the 150 µS/cm reference condition (APHN 2016). The means for several sites along the Obed River also exceeded this reference condition during 2007 sampling (Cook and Hutton 2009). Recent continuous data from Adams Bridge suggests that SpC is frequently above 150 µS/cm, sometimes for extended periods of time, and occasionally nears or exceeds 400 µS/cm (USGS 2016). As a result, SpC is considered of high concern for the Obed River (*Condition Level* = 3).

All recent APHN measurements from the Emory River sample sites fell within the reference condition, with a maximum of 94 µS/cm (APHN 2016). A *Condition Level* of 0, indicating no concern, is assigned for this measure.

Turbidity

Turbidity was also assigned a *Significance Level* of 3 (Table 91) by the project team. The reference condition for this measure is <40 NTU.

During recent monitoring (Cook and Hutton 2009, APHN 2016), Clear and White Creek turbidity levels have fallen well within the reference condition, never exceeding 6.5 NTU. Continuous data collection at Lilly Bridge has captured occasional extreme spikes in turbidity, particularly during the summer and fall of 2015 (USGS 2016). Although these measurements are in FNU and are therefore not comparable to the reference condition and previous measurements, which are in NTU, this creates some cause for concern. This measure is assigned a *Condition Level* of 1 for Clear Creek.

Turbidity was also low on Daddy's Creek during recent sampling, with a maximum of 13.4 NTU (APHN 2016). However, this peak was the only measurement >4 NTU. Similar to Clear Creek, continuous data collection near Hebbertsburg recorded several extreme spikes in turbidity, occasionally exceeding 800 FNU (USGS 2016). Therefore, turbidity is also of low concern for Daddy's Creek (*Condition Level* = 1).

Instantaneous measurements from Obed River were also low, with a maximum turbidity of 26.0 NTU at Alley Ford, but with only this one measurement above 8.0 NTU (APHN 2016). However, continuous data from Adams Bridge show numerous spikes since the fall of 2014, sometimes exceeding 1,200 FNU (USGS 2016). As a result, turbidity is of moderate concern (*Condition Level* = 2) for the Obed River.

Emory River turbidity was generally low, with a maximum of 20.6 NTU, but no other measurements above 5.0 NTU (APHN 2016). This measure is assigned a *Condition Level* of 0 for the Emory River.

Acid Neutralizing Capacity

The project team assigned this measure a *Significance Level* of 3 (Table 91). The reference condition for ANC, based on data from Clear Creek, is >4.5 mg/L $CaCO_3$. However, Clear Creek appears to have a naturally low ANC and may not represent a natural range for larger water bodies like the Emory River.

Since results from Clear Creek were used as a guide to identify the reference conditions for this assessment, all but one measurement from 2009–2016 sampling met the reference condition (APHN 2016). However, ANC readings from the Clear Creek watershed were much lower than the other park watersheds. Although this appears to be a natural condition, it means that Clear Creek will be less able to buffer acidic inputs from atmospheric deposition and other anthropogenic sources. Therefore, this measure is of slight concern and is assigned a *Condition Level* of 1.

The range of ANC values from Daddy's Creek was well above the reference condition, with a minimum measurement of 15.4 mg/L $CaCO_3$ (APHN 2016). As a result, this measure is assigned a *Condition Level* of 0 for Daddy's Creek.

The Obed River sampling results also met the reference condition and yielded the highest single ANC reading of any watershed at 70.4 mg/L $CaCO_3$ (APHN 2016). This measure is assigned a *Condition Level* of 0, indicating no concern, for the Obed River as well.

The Emory River sampling locations showed the second lowest ANC results, behind only Clear Creek. While all measurements from the river itself met the identified reference condition, values from Rock Creek did not; this tributary is known to be impacted by acid mine waste runoff. Other tributaries in the watershed may also experience acid mine drainage impacts. As a result, this measure is of moderate concern for the watershed (*Condition Level* = 2).

Nutrients

A *Significance Level* of 3 (Table 91) was assigned to the nutrients measure by the project team. The reference conditions, based on data from Clear Creek (Arnwine et al. 2005), are <0.12 mg/l for total N and <0.005 mg/l for total P.

Maximum nutrient levels from Clear Creek sampling locations in 2009 were above the selected reference conditions, particularly at Norris Ford (OBRI_1) (EPA 2016). Several measurements were also above the proposed TDEC standards for the ecoregion (≤ 0.23 mg/l for N, ≤ 0.02 mg/l for P). While it is unclear whether differences between the reference condition (based on previous Clear Creek measurements) and 2009 results are due to the timing of sampling or actual changes in nutrient levels within the watershed, this raises a significant concern (*Condition Level* = 3).

All Daddy's Creek dissolved N measurements from 2009 were above the identified reference condition levels (EPA 2016). The maximum P level was also above the reference condition. Therefore, nutrients are of moderate concern in this watershed (*Condition Level* = 2).

During 2009 sampling on the Obed River, all dissolved N measurements were above the reference condition; levels were substantially higher at the upstream Alley Ford location (EPA 2016). Maximum P levels were above reference condition as well. These high levels may be partly due to additional nutrient contributions from upstream developments, including treated effluent from the Crossville wastewater treatment plant. As a result, nutrients are of high concern for the Obed River watershed (*Condition Level* = 3).

On the Emory River, 2009 dissolved N samples from Nemo Bridge (downstream of the Obed confluence) were all above the selected reference condition but were lower than levels from the Obed (EPA 2016). Above the Obed confluence, only some samples were above the reference condition. Rock Creek nitrogen measurements were within the reference condition. The majority of P measurements were also above the reference condition, with the highest phosphorus level across all 2009 sampling (0.19 mg/l) recorded on the Emory above the Obed confluence (EPA 2016). This measure is assigned a *Condition Level* of 3 for the Emory watershed.

Watershed Summaries

Clear Creek

Based on the measures selected for this NRCA, the Clear Creek watershed is considered of *Moderate Concern* (*WCS* = 0.38) (Table 91, Figure 64). The water temperature and conductivity measures are currently of no concern. Turbidity, pH, and ANC are of low concern. DO is of moderate concern, while nutrients are currently of significant concern.

Daddy's Creek

Water quality in the Daddy's Creek watershed is also in *Good Condition* (*WCS* = 0.33) (Figure 64). However, this score is on the border of the moderate concern range, suggesting that any deterioration in conditions could increase the concern for this watershed. The water temperature and ANC measures are currently of no concern. DO, pH, conductivity, and turbidity are of low concern.

Similar to Clear Creek, nutrients are of most concern, but are currently only at a moderate concern level.

<u>*Obed River*</u>

Water quality in the Obed River watershed is of *Moderate Concern* (*WCS* = 0.57) at this time (Figure 64). Only the water temperature and ANC measures are of no concern. pH is the only measure of low concern, while turbidity is of moderate concern. DO, conductivity, and nutrients are of high concern, which may be related to runoff (e.g., additional nutrient contributions) from upstream developed areas. There is concern that several measures (e.g., nutrients, pH, conductivity) may be declining due to upstream anthropogenic influences. Additional data are needed to more clearly identify trends.

<u>*Emory River*</u>

Based on the selected measures, the *WCS* for the Emory River watershed is 0.33. This score falls at the very top of the *Good Condition* category; however, concerns over nutrients (particularly from tributaries such as the Obed) are growing, and smaller tributaries in this watershed (e.g., Rock Creek) are heavily impacted by acid mine drainage. As a result, SMUMN GSS analysts feel justified in elevating this watershed to *Moderate Concern* (Figure 64).

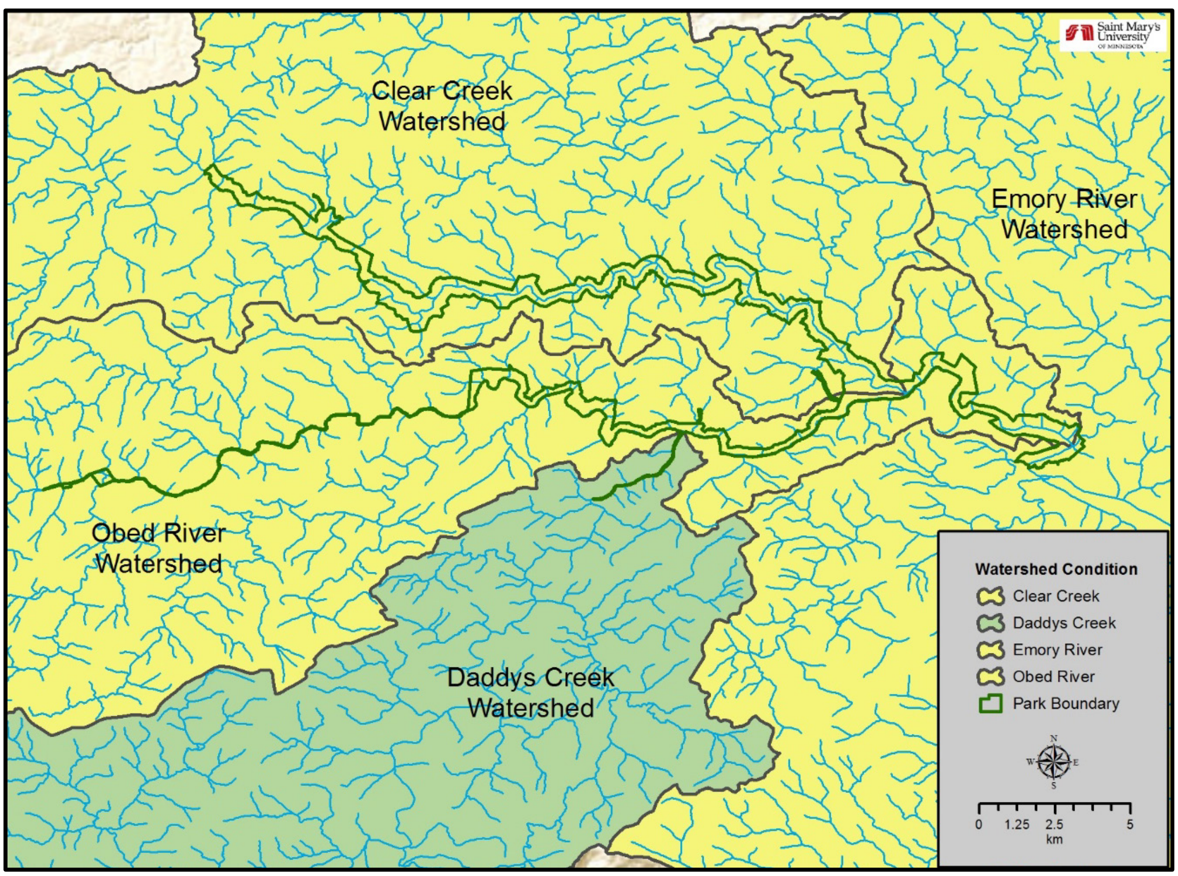
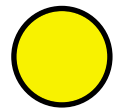


Figure 64. Watershed conditions based on the NRCA scoring process. Green = good condition, yellow = moderate concern.

Weighted Condition Score

An overall *WCS* for OBRI was calculated by averaging the individual scores for the Clear Creek, Daddy's Creek, and Obed River watersheds. Since the Emory River watershed comprises only a small portion of OBRI and is downstream of the other three watersheds, it was not included in the calculation. The overall *WCS* for OBRI water quality is 0.43, which indicates moderate concern. Due to variability in trends between watersheds and measures (some are stable, others are declining or unknown), an overall, park-wide trend could not be assigned. However, there is substantial concern that water quality conditions may be declining due to increased upstream development.

Water Quality		
Watershed	**WCS**	**Overall WCS = 0.43**
Clear Creek	0.38	
Daddy's Creek	0.33	
Obed River	0.57	

4.8.6. Sources of Expertise

- Jim Hughes, APHN Hydrologist

4.8.7. Literature Cited

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4.9. Water Quantity

4.9.1. Description

The quantity of water in OBRI's rivers and streams influences many of the ecological, scenic, and recreational values and functions that contributed to the area's Wild and Scenic River designation (Knight et al. 2014). Water quantity is a significant resource throughout the APHN, leading to the selection of flow rate and water level fluctuations as measures within the network's surface water dynamics Vital Sign (Emmott et al. 2005). The Obed and surrounding river systems on the Cumberland Plateau are characterized by thin soils atop low permeability bedrock geology that promotes rapid surface runoff with relatively little groundwater storage. These geohydrologic conditions cause rapid rise in streamflow rates in response to rainfall events which are reflected in intense, scouring floods that are critical to sustain native aquatic and riparian communities (Emmott et al. 2005). Water quantity and hydrologic cycles are driven by precipitation and influence many aspects of terrestrial and aquatic ecosystems. In riverine systems these include not only stream flow but also pollutant concentrations and oxygen carrying capacity (Emmott et al. 2005). The Southern Appalachian Mountains, where OBRI is located, are considered to have the highest annual precipitation in the eastern U.S., mostly falling as winter and early spring rain. Flooding may occur during prolonged wet periods in the winter and spring, although high flows can also occur after severe summer thunderstorms (Emmott et al. 2005). Low flow periods are normal during the warmer summer and early fall months, sometimes reducing upper portions of the creek systems to isolated pools with little or no flow (Emmott et al. 2005). Water availability and water rights issues during these low precipitation months are significant issues at OBRI and surrounding areas of the Cumberland Plateau (Hughes, written communication, September 2016).

OBRI's ecosystems have adapted to this fluctuating flow regime and there is growing concern that human alterations to the regime would negatively impact multiple park resources (Emmott et al. 2005, Knight et al. 2014). Several expanding communities upstream of OBRI withdraw water from the system and return treated wastewater to the Obed and its tributaries (Knight et al. 2014). These communities, as well as private landowners, have also created impoundments in the watershed for urban, recreational, and agricultural uses. Any changes in the amount or timing of stream flow could alter channel morphology and habitats within and along streams (Emmott et al. 2005).

4.9.2. Measures

- Annual peak discharge
- Annual minimum discharge
- Annual number of significant runoff events
- Annual changes in precipitation amount/patterns
- Changes in water demand/effluent volume

4.9.3. Reference Conditions/Values

The reference conditions for discharge and runoff events measures will be based on historic flow and gage height data from USGS gages. Two gages in the OBRI area have historic flow records for over 40 years: The Obed River near Lancing (USGS 03529800), approximately 2.2 km (1.4 mi) upstream of the Emory confluence, and the Emory River at Oakdale (USGS 03540500), which is around 15 river km (9.3 river mi) downstream of OBRI (Figure 65). The gage on Daddy's Creek near Hebbertsburg (USGS 03539600) has some historic records (1958–1967) to provide insight regarding a reference condition. The gage on Clear Creek at Lilly Bridge (USGS 03539778), which most closely approximates minimally-disturbed reference conditions, has only collected data since 1997, which may not be a long enough period of record to provide a representative reference condition.

The reference condition for annual precipitation will be based on data from the Crossville Experimental Station (USC00402202) in the Obed River watershed upstream of OBRI (Figure 65). For water demand/effluent volume, the reference will be no net reduction in discharge (e.g., water demand does not exceed effluent return volume).

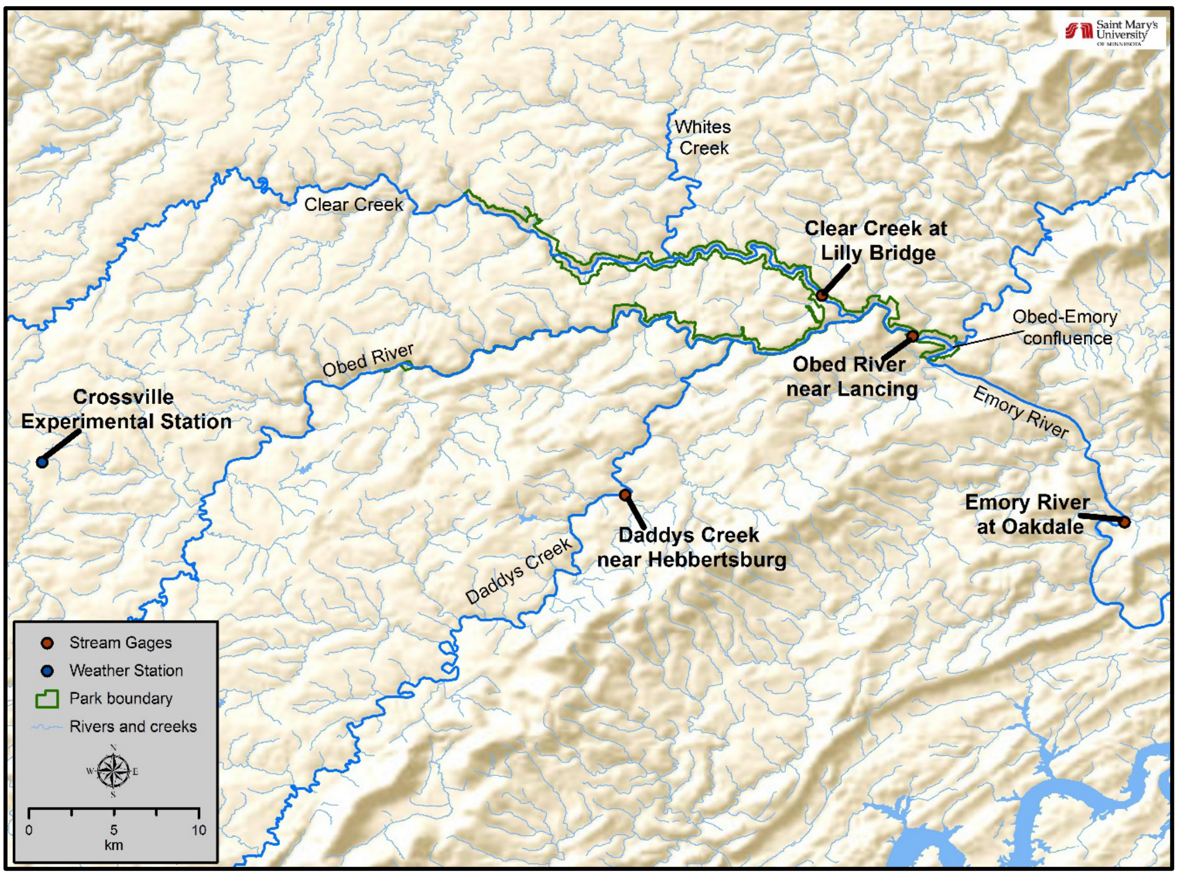

Figure 65. Locations of stream gages and Crossville Experimental Station in relation to OBRI.

4.9.4. Data and Methods

Knight et al. (2014) reported the findings of hydrological studies on the Obed River watershed conducted jointly the USGS and NPS from 1999–2005. These studies included analyses of long-term streamflow and precipitation records and documentation of human alteration and influence within the watershed (e.g., impoundments, water withdrawals, effluent discharge). Flow data were examined from six USGS stream gages and precipitation analysis was based on data from the Crossville Experimental Station (Knight et al. 2014).

For the purposes of this NRCA, four gages in or near OBRI with longer-term data have been selected for analysis: Clear Creek at Lilly Bridge, Daddy's Creek near Hebbertsburg, Obed River near Lancing, and the Emory River at Oakdale (Figure 65). Discharge data from one additional gage on the Obed River at Adams Bridge (USGS 03538830; just upstream of the OBRI boundary) will be presented here, but will not be used for condition assessment since the gage only began measurements in January 2010. Daily discharge and peak streamflow data for these gages were downloaded through the USGS NWIS (USGS 2016). The period of record for the four selected gages varies from over 85 years for the Emory River at Oakdale to just 18 years for Clear Creek at Lilly Bridge. Annual discharge measures will be based on the water year (October-September) as opposed to the calendar year. Discharge data are presented in cubic meters per second (cms). Gage height observation data were also downloaded from the NWIS (USGS 2016) to analyze the annual number of significant runoff events by water year. For the purposes of this assessment, a "significant event" will be any time the gage height exceeds a watershed-specific value (outlined in Section 4.9.5).

Precipitation data for the Crossville Experimental Station were downloaded through the National Oceanic and Atmospheric Administration (NOAA) Climate Data Online website (NOAA 2016a). Data are available from 1912 through 2016; however, any years with missing monthly data will be excluded from an assessment of change over time. Thirty-year precipitation normals (annual and monthly) for the station were also obtained (NCDC 2002, NOAA 2016b).

4.9.5. Current Condition and Trend

Annual Peak Discharge

Clear Creek

Annual peak discharge at the Clear Creek at Lilly Bridge gage over the available period of record (1998–2015) ranged from 121.2 cms (2008) to 509.7 cms (2003) (4,280–18,000 cubic feet per second [cfs]) (USGS 2016). A 5-year moving average shows variation over time but with no overall increasing or declining trend (Figure 66). The timing of peak discharge was highly variable, occurring any time between October and early May (USGS 2016).

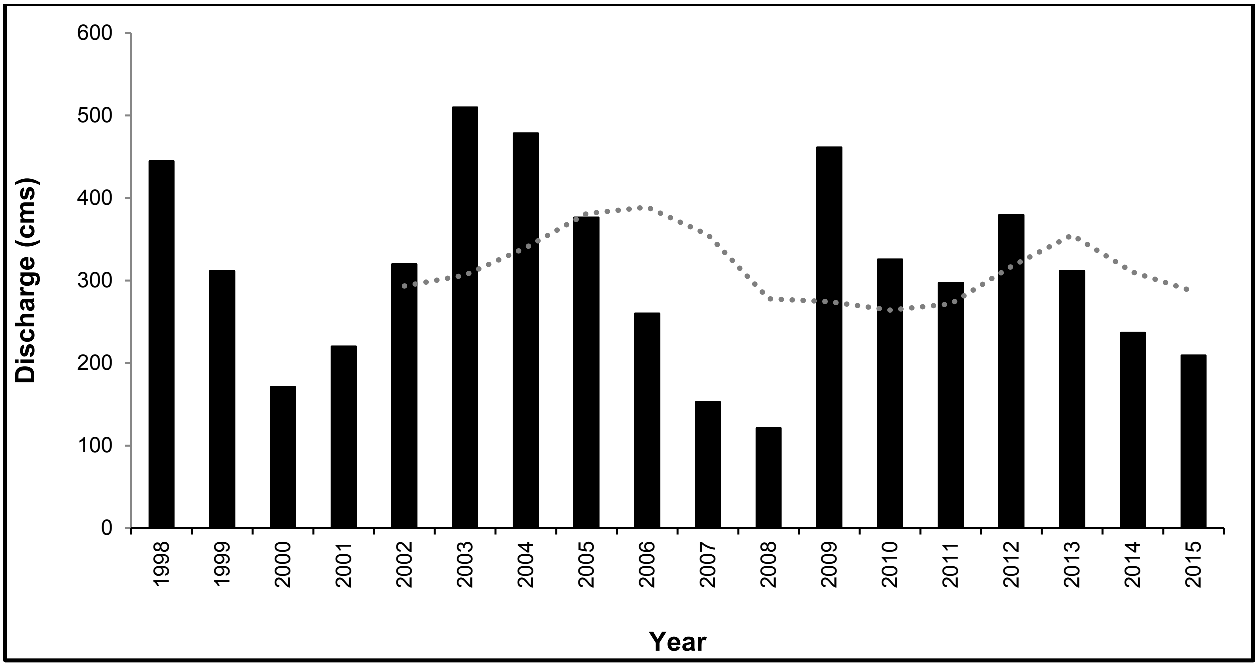

Figure 66. Annual peak discharge for the Clear Creek at Lilly Bridge gage (USGS 03539778) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years.

Daddy's Creek

Peak discharge at the Daddy's Creek near Hebbertsburg gage for the period of record (1958–1967, 2000–2015) ranged from 44.5 cms (1960) to 317.1 cms (2004) (1,572–11,198 cfs) (USGS 2016). Five-year moving averages for 2000–2015 are generally higher than averages from the historic period (1958–1967) but are variable and do not show a consistent trend (Figure 67). The timing of peak discharge was also highly variable at this gage, occurring during all months except June, August, and October (USGS 2016).

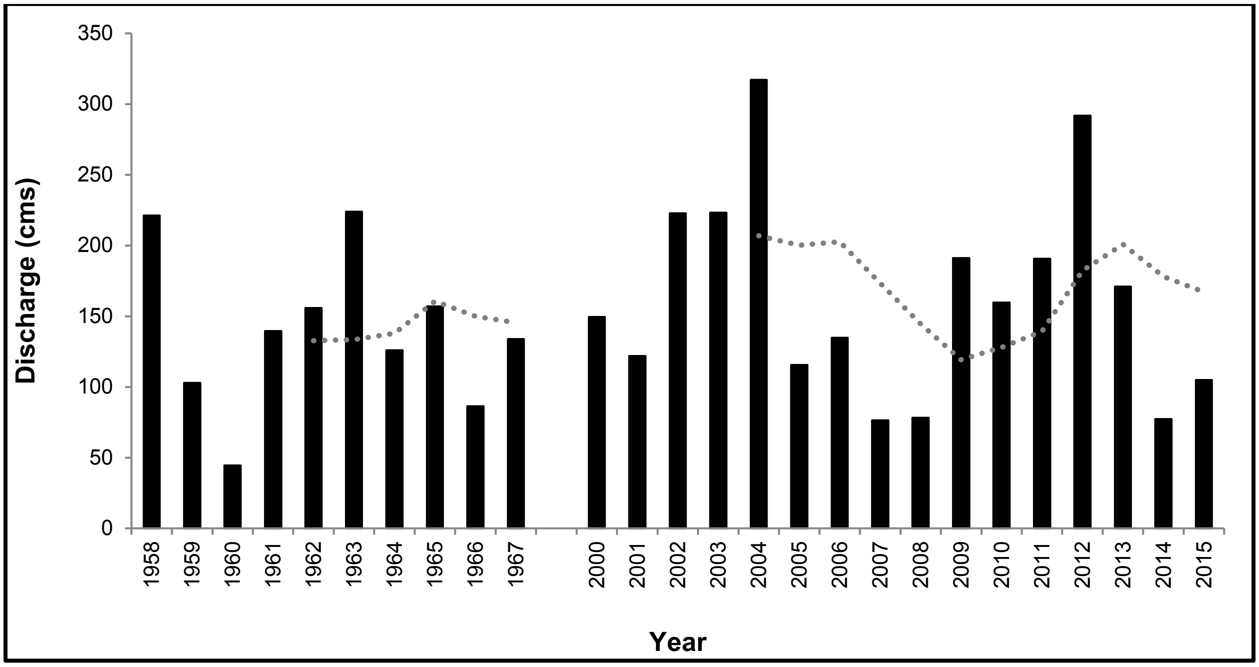

Figure 67. Annual peak discharge for the Daddy's Creek near Hebbertsburg gage (USGS 03539600) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years, and that there is a gap in data from 1968–1999.

Obed River

The period of record for discharge data from the Obed River near Lancing gage is not continuous. Measurements are available for 1929, 1958–1968, 1973–1987, and 1999–2015. During these years, annual peak discharge has ranged from 246.1 cms (1981) to 2,973.3 cms (1929, 1973) (8,691–105,001 cfs) (USGS 2016). Five-year moving averages for the periods of record show variation with no consistent trends (Figure 68). The timing of peak discharge is also variable, occurring during all months of the year except June-August and October (USGS 2016).

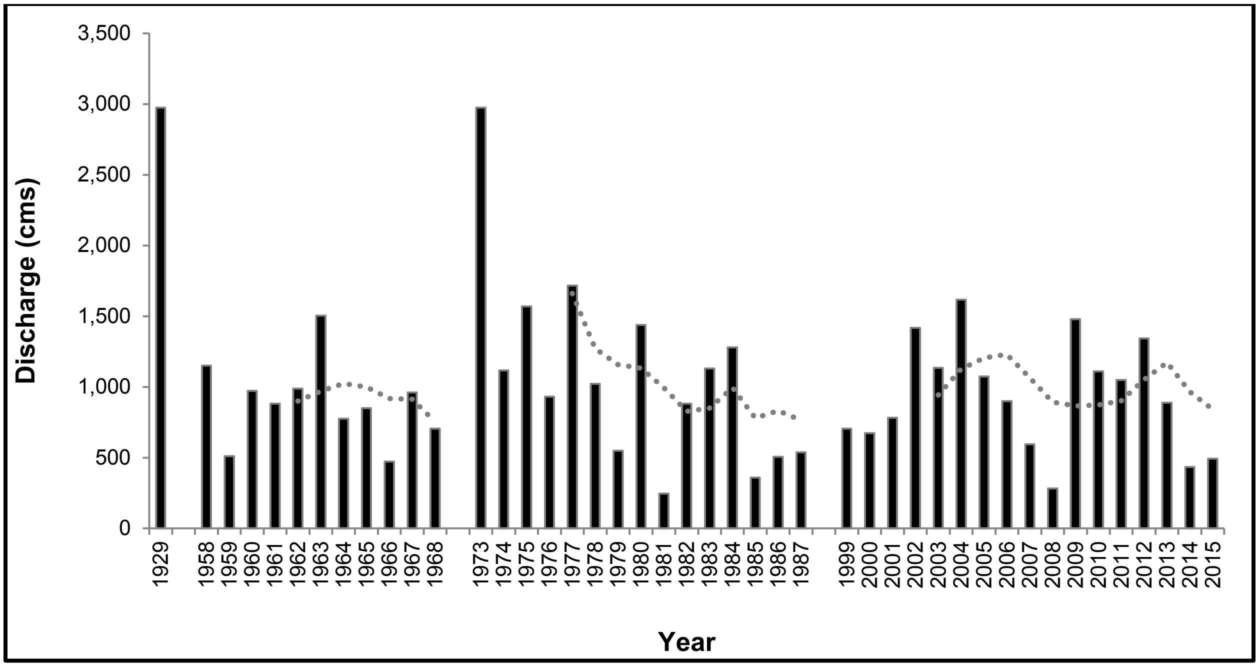

Figure 68. Annual peak discharge for the Obed River near Lancing gage (USGS 03529800) (USGS 2016). The dotted lines represent 5-year moving averages. Note that the years represent water years (October-September) rather than calendar years.

Peak discharge at the newer Adams Bridge gage has ranged from 103 cms in 2014 to 164 cms in 2013 (3,640–5,800 cfs) (USGS 2016). Peak discharge in all water years (2011–2015) was above 150 cms (5,300 cfs), with the exception of 2014. The timing of peaks was variable, having occurred between late November and early July during the 5 years for which data are available (USGS 2016).

Emory River

Annual peak discharge for the Emory River at Oakdale gage over the available period of record (1928–2015) ranged from 359.6 cms (1931) to 5,521.8 cms (1921) (12,699–195,000 cfs) (USGS 2016). During the last 30 years alone (1986–2015), peak discharge has ranged from 413.4 cms (2008) to 4,813.9 cms (1991) (14,599–170,001 cfs) (USGS 2016). Since approximately 2000, annual peak discharge appears to be less variable than during the historic period of record (Figure 69). Moving averages for the past decade have been within the range of historical variation. The timing of peak discharge at this Emory River gage has been the most variable of all OBRI watersheds, with peaks occurring in all months of the year except August (USGS 2016).

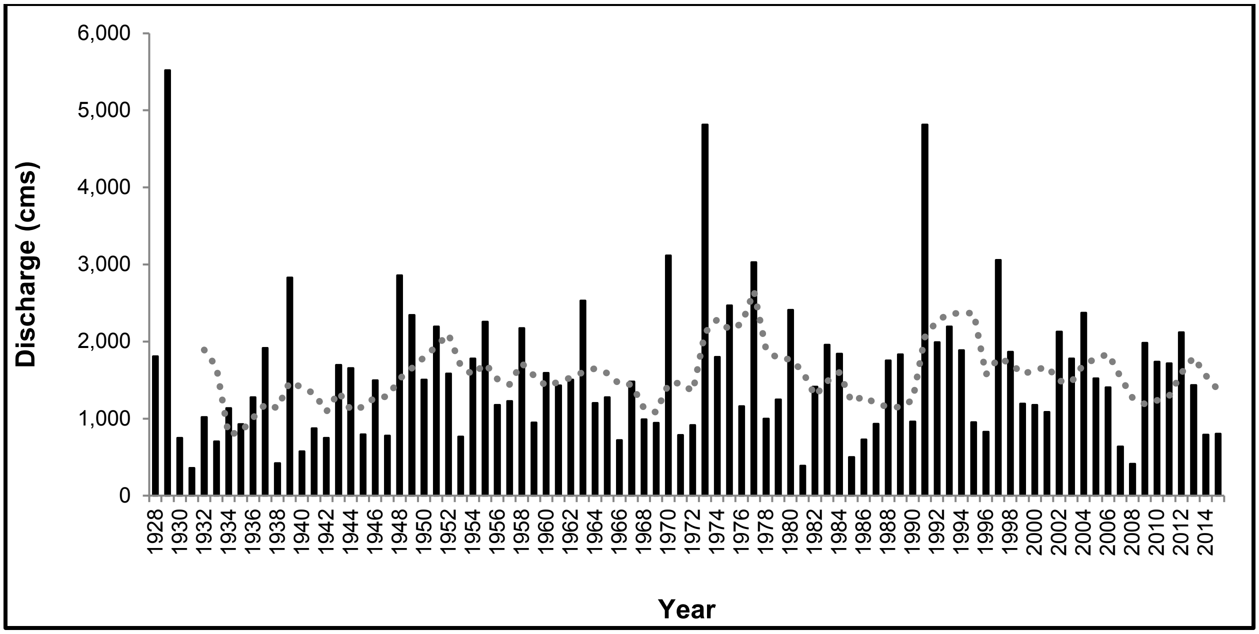

Figure 69. Annual peak discharge for the Emory River at Oakdale gage (USGS 03540500) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years.

<u>Annual Minimum Discharge</u>

Clear Creek

Annual minimum discharge for the Clear Creek at Lilly Bridge gage over the available period of record ranged from 0.005 cms (2000, 2009) to 0.331 cms (2004) (0.2–11.7 cfs) (USGS 2016). As with peak discharge in the watershed, 5-year moving averages for minimum discharge show variation with no clear trend (Figure 70). However, minimum discharges during the most recent three years (2013–2015) have been higher than minimum discharge during 13 of the previous 15 years. Minimum discharge typically occurred between late August and early November (USGS 2016).

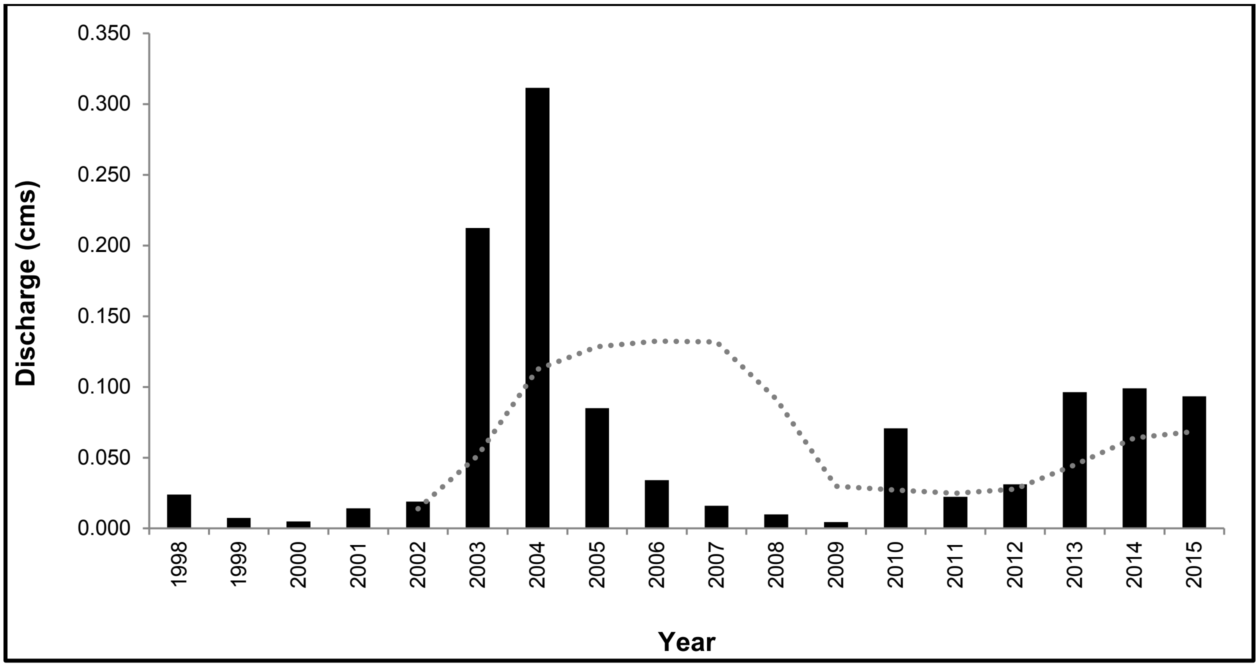

Figure 70. Annual minimum discharge for the Clear Creek at Lilly Bridge gage (USGS 03539778) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years.

Daddy's Creek

Minimum discharge at the Daddy's Creek near Hebbertsburg gage for the period of record ranged from 0.005 cms (2002) to 0.368 cms (2004) (0.2–13 cfs) (USGS 2016). Data suggest that minimum discharge has been higher and more variable during recent years (2000–2015) than during the historic period (1958–1967) (Figure 71). Minimum discharge generally occurred between mid-July and early October (USGS 2016).

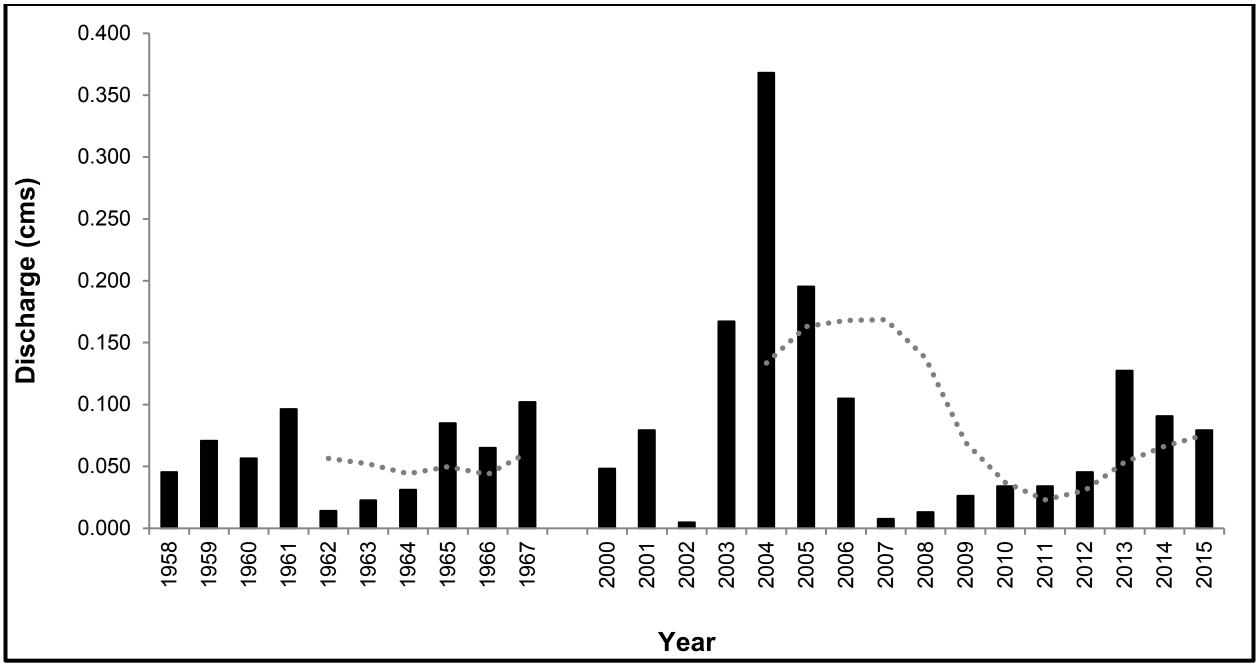

Figure 71. Annual minimum discharge for the Daddy's Creek near Hebbertsburg gage (USGS 03539600) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years, and that there is a gap in data from 1968–1999.

Obed River

Annual minimum discharge during the discontinuous period of record for the Obed River near Lancing gage has ranged from 0.01 cms (1964) to 0.93 cms (2004) (0.4–33 cfs) (USGS 2016). While 5-year moving averages have been variable during all periods of record, they have been higher and most variable during the most recent period of record (2000–2015) (Figure 72). Annual minimum discharges occurred between August and early November (USGS 2016).

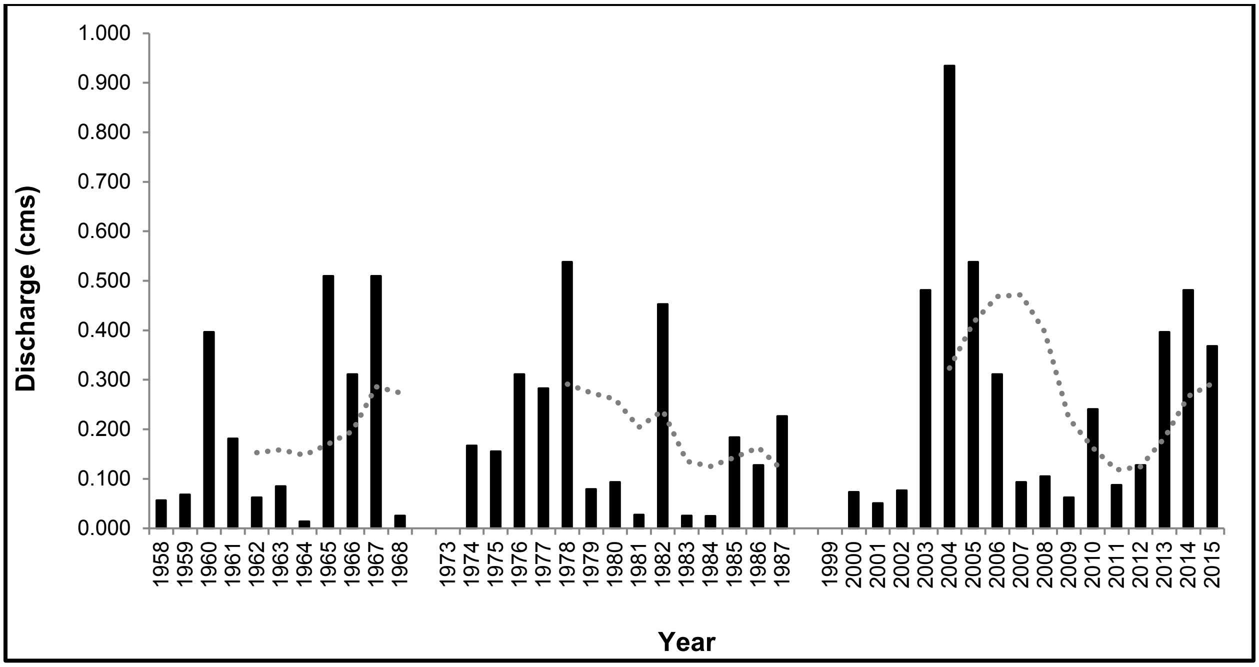

Figure 72. Annual minimum discharge for the Obed River near Lancing gage (USGS 03529800) (USGS 2016). The dotted lines represent 5-year moving averages. Note that the years represent water years (October-September) rather than calendar years.

At the Adams Bridge gage, minimum discharge during the 2010–2015 period of record has ranged from 0.01 cms in 2011 to 0.20 cms in 2013 (0.5–6.9 cfs) (USGS 2016). All minimum discharges, with the exception of 2013, were below 0.09 cms (3.0 cfs). Over the limited period of record, minimum discharge has occurred between late June and early October (USGS 2016).

Emory River

Minimum discharge for the Emory River at Oakdale gage has ranged from 0 cms (1944, 1953–54) to 1.73 cms (2003) (0–61 cfs) (USGS 2016). As with previous watersheds, 5-year moving averages for the Emory River show that minimum discharge has increased and become more variable over time, particularly since the mid-1960s (Figure 73). Over the period of record (1929–2015), minimum discharge occurred between July and November but most often in September or October (USGS 2016).

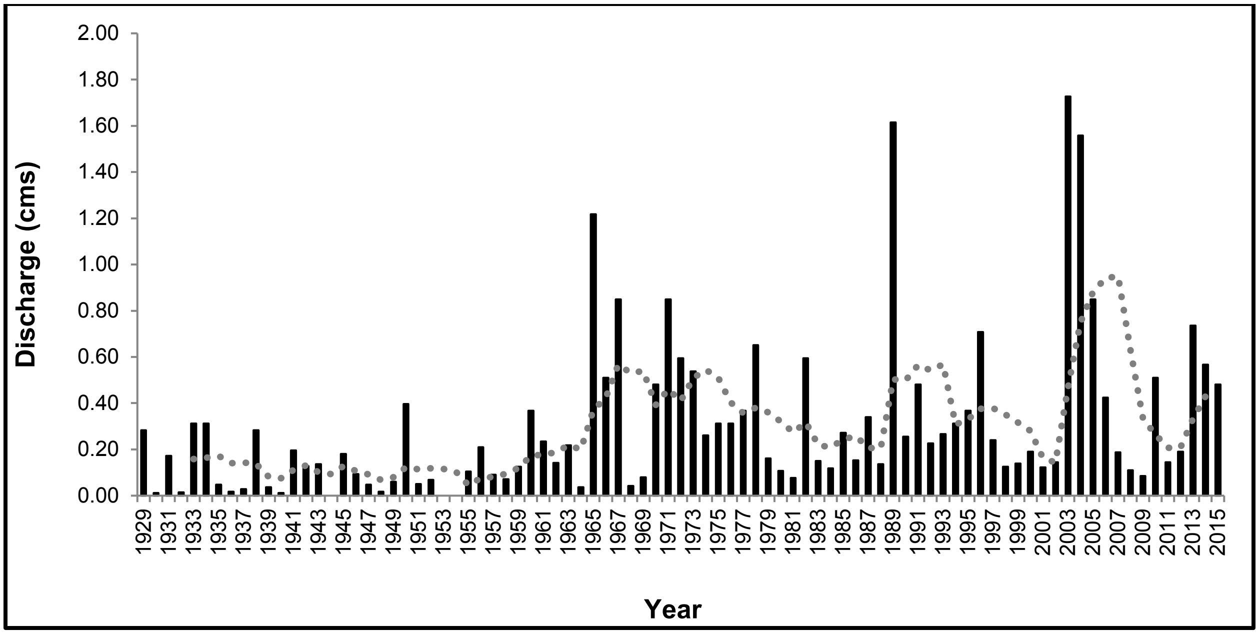

Figure 73. Annual minimum discharge for the Emory River at Oakdale gage (USGS 03540500) (USGS 2016). The dotted line represents a 5-year moving average. Note that the years represent water years (October-September) rather than calendar years.

<u>Annual Number of Significant Runoff Events</u>

Clear Creek

Based on available observations of gage height for Clear Creek at Lilly Bridge, a stage height above 3.05 m (10 ft) will represent a significant runoff event. Since 2008, the annual number of significant events has ranged from zero (2008) to eight (2011, 2013) with a mean of 4.5 events (USGS 2016) (Appendix R). The majority of significant runoff events typically occur during the first 7–8 months of the water year in this region. In the first half of the 2016 water year (October 2015-March 2016), there have already been four significant runoff events (USGS 2016, provisional data). No clear increasing or decreasing trend in the annual number of events is apparent in the available data (Figure 74).

Daddy's Creek

Available data from the Daddy's Creek suggest that a stage height above 1.83 m (6 ft) would represent a significant runoff event. The annual number of significant events during the period of record has ranged from one (2008) to eight (2011) with a mean of 5.4 events (USGS 2016) (Appendix R). Through the first half of the 2016 water year, there have been six significant runoff events (USGS 2016, provisional data). As with Clear Creek, there is no clear increasing or decreasing trend apparent in the data (Figure 74).

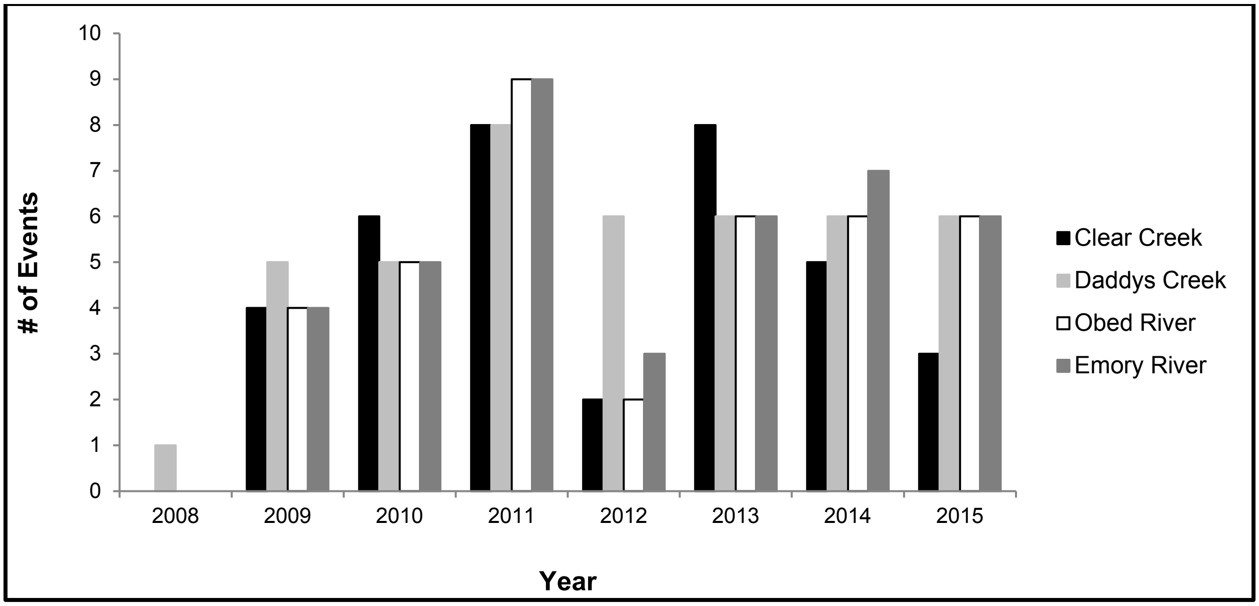

Figure 74. Annual number of significant runoff events in the four OBRI watersheds, 2008–2015 (USGS 2016).

Obed River

Based on available observations from the gage near Lancing, a stage height above 3.05 m (10 ft) will represent a significant runoff event. Since 2008, the annual number of significant events has ranged from zero (2008) to nine (2011) with a mean of 4.75 events (USGS 2016) (Appendix R). Through the first half of the 2016 water year (October 2015-March 2016), there have been five significant runoff events (USGS 2016, provisional data). There are no discernible trends in the data, although the annual number of events in the three most recent years (2013–2015) is higher than in four of the previous five years (Figure 74). Due to the limited period of record, it is unclear if this represents an actual change or is simply natural variation.

Emory River

Available data from the gage at Oakdale suggest that a stage height above 4.57 m (15 ft) would represent a significant runoff event. The annual number of significant events during the period of record has ranged from zero (2008) to nine (2011) with a mean of 5.0 events (USGS 2016) (Appendix R). In the first half of the 2016 water year, there have already been six significant runoff events (USGS 2016, provisional data). Like the Obed River, there are no discernible trends in the data, but the annual number of events in the three most recent years (2013–2015) is higher than in four of the previous five years (Figure 74).

<u>Annual Changes in Precipitation Amount/Patterns</u>

Annual precipitation at the Crossville Experimental Station has been highly variable over the available period of record. Yearly totals have ranged from 98.9 cm (38.9 in) in 2007 to 192.7 cm (75.9 in) in 1973 with an overall mean for the entire period of record (1914–2015) of 145.7 cm (57.4 in) (Figure 75) (NOAA 2016a). The high variability is apparent even in 5-year moving averages, which have ranged from 125.0 cm (49.2 in, for 1932–1936) to 170.4 cm (67.1 in, for 1972–1976).

These moving averages suggest a slight increasing trend since the 1940s (Figure 75). Knight et al. (2014) noted that several national and regional studies documented a substantial increase in precipitation across the southeastern U.S. beginning around 1970; this is consistent with observations at the Crossville Experimental Station.

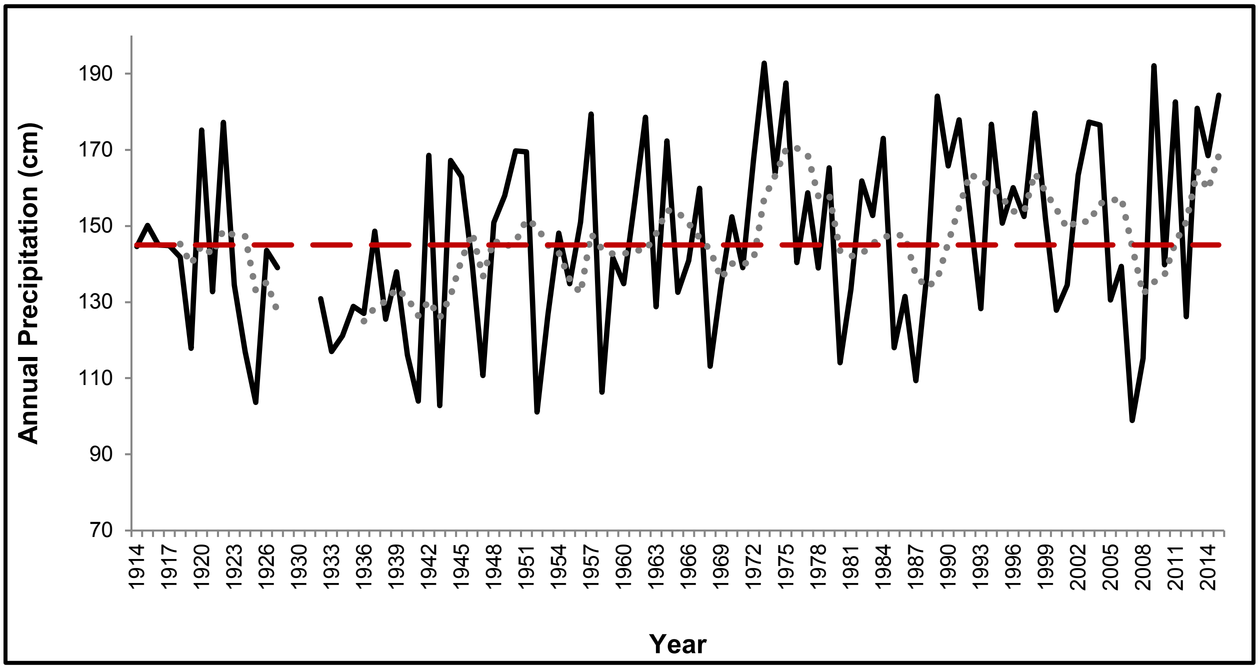

Figure 75. Annual precipitation (cm) at the Crossville Experimental Station for the historic period of record (NOAA 2016a). The dotted line represents a five-year moving average and the red dashed line is the overall annual mean for the entire period of record.

Changes in precipitation patterns can be explored by comparing 30-year climate normals from1971–2000 (NCDC 2002) and 1981–2010 (NOAA 2016b). Monthly precipitation normals from the Crossville Experimental Station for these two time periods are relatively similar but with slight differences (Figure 76). From the earlier to the more recent period, monthly precipitation decreased for March, May-June, and October-January. Monthly precipitation increased for February, April, and July-September, although most increases were slight (Figure 76).

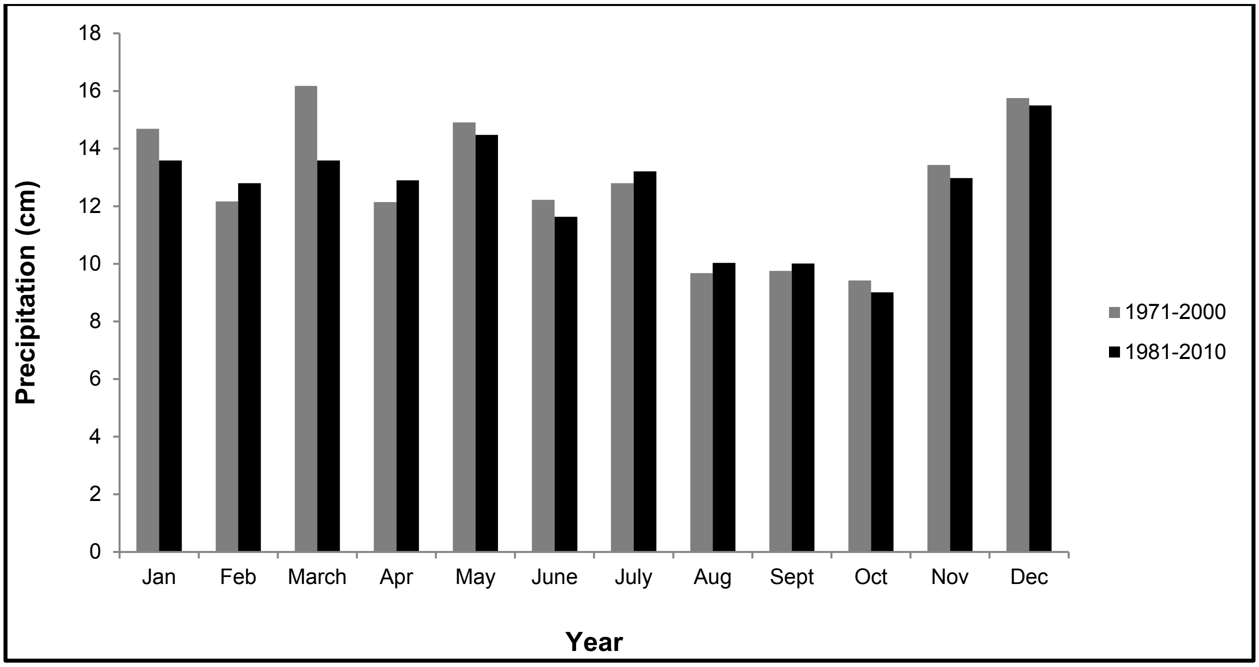

Figure 76. Monthly precipitation normals for the Crossville Experimental Station, 1971–2000 (NCDC 2002) and 1981–2010 (NOAA 2016b).

When grouped by season, summer and fall precipitation normals show very little change between 1971–2000 and 1981–2010 (Figure 77). Small decreases occurred in winter and spring precipitation. However, the season with the most precipitation (winter) and least precipitation (fall) have not changed (Figure 77).

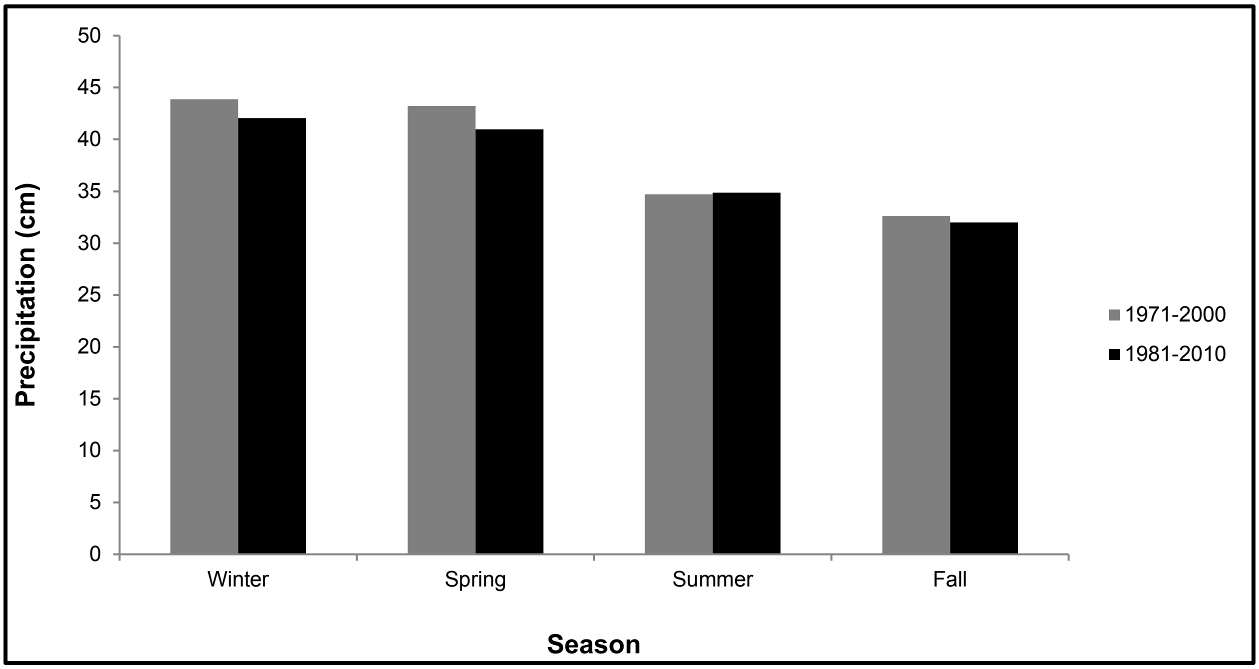

Figure 77. Seasonal precipitation normals for the Crossville Experimental Station, 1971–2000 (NCDC 2002) and 1981–2010 (NOAA 2016b). Winter = Dec, Jan, Feb; Spring = Mar, Ap., May; Summer = June, July, Aug; Fall = Sept, Oct, Nov.

In spring 2007, a weather station began collecting precipitation data at Fairfield Glade, in the Daddy's Creek watershed and closer to OBRI. Several years later, in 2011, a station became operational in Crab Orchard, also in the Daddy's Creek watershed. While the periods of record for these newer stations are not long enough to analyze any changes or trends, annual totals are included below to provide a baseline for future assessments (Figure 78, Figure 79).

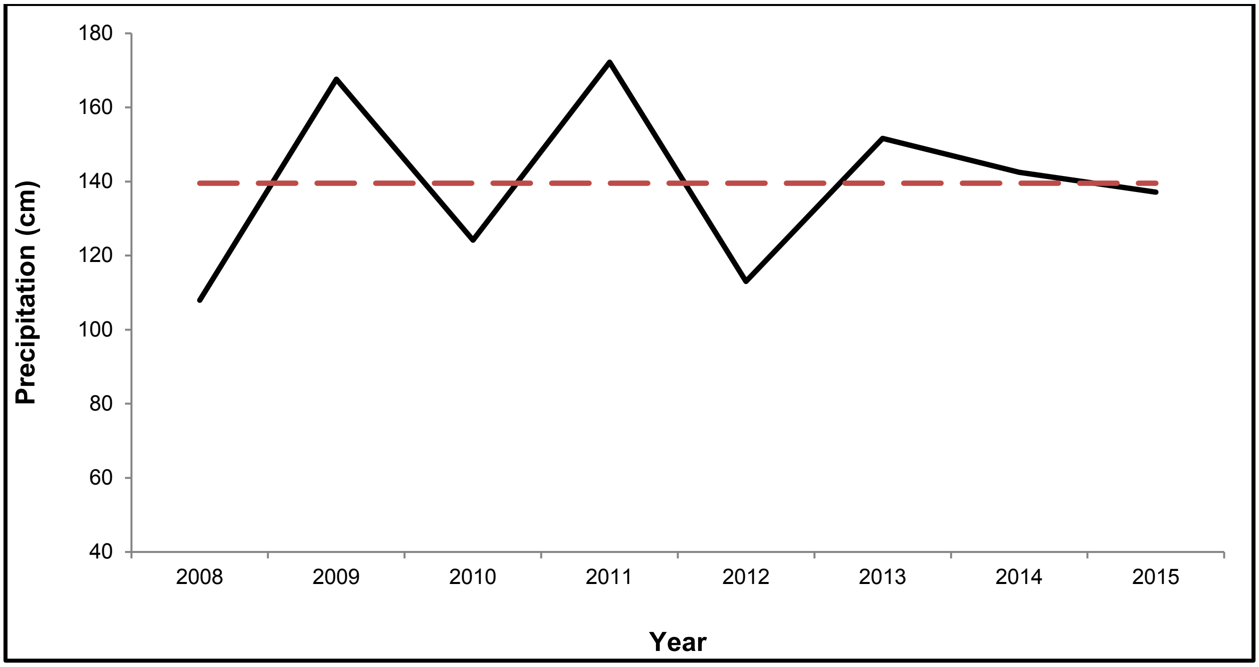

Figure 78. Annual precipitation (cm) at the Fairfield Glade 0.1 NNW weather station (US1TNCM0004) for the available period of record (NOAA 2016a). The red dashed line is the overall annual mean for the entire period of record.

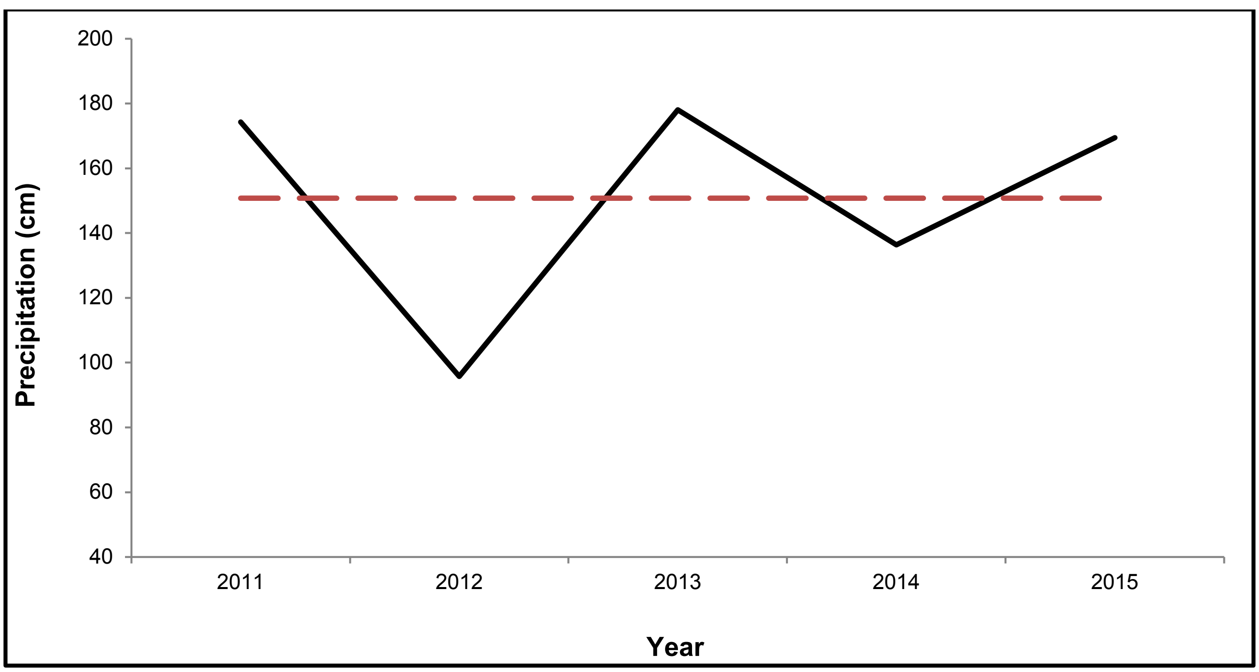

Figure 79. Annual precipitation (cm) at the Crab Orchard weather station (USC00402140) for the available period of record (NOAA 2016a). The red dashed line is the overall annual mean for the entire period of record.

Changes in Water Demand/Effluent Volume

Water is withdrawn from the Obed River system to supply public drinking water for the cities of Crossville and Crab Orchard (Knight et al. 2014). Crossville draws water from Lake Holiday on the Obed River while Crab Orchard draws water from Stone Lake on Otter Creek, a tributary of the Obed River (see Figure 63) (Knight et al. 2014). The City of Crossville also withdraws water from the Caney Fork watershed. The combined capacity of these systems (e.g., possible maximum withdrawals) as of 2010 was around 8.0 million gallons per day (Mgal/d). Knight et al. (2014) compiled available average daily water withdrawal data for these two municipalities. Daily withdrawals by Crab Orchard have increased since the system began operations, nearly doubling between 1995 and 2010 (Table 92). Crossville's withdrawals from the Obed watershed decreased over time, likely due to increased withdrawals from the Caney Fork watershed (Table 92). The total water demand for Crossville (Obed River + Caney Fork watershed withdrawals) has increased from 3.0 Mgal/d in 1988 to 4.2 Mgal/d in 2010. Based on drinking water production estimates from the City of Crossville (2014), approximately 1.22 Mgal/d were withdrawn from the Obed River watershed in 2013 and 2.68 Mgal/d from the Caney Fork watershed in 2013 for a total water demand of 3.9 Mgal/d. This is a slight decrease from 2010 total demand, but with a slight increase in withdrawals from the Obed River watershed. As of 2014, the Crab Orchard Utility District (2014) was treating an estimated 1.5 Mgal/d, similar to the withdrawal levels for 2010.

Table 92. Average daily water withdrawals (Mgal/d) by public water systems upstream of OBRI (modified from Knight et al. [2014]).

Watershed	Municipality	1988[A]	1995[B]	2000[C]	2005[D]	2010[C]
Obed River watershed	Crossville	2.55	1.91	1.84	1.30	1.17
	Crab Orchard	–[E]	0.89	1.41	1.55	1.6
Caney Fork watershed	Crossville	0.46	1.22	1.09	2.59	3.07

[A] Hutson and Morris (1992).

[B] Hutson (1999).

[C] Webbers (2003).

[D] (TDEC 2011).

[E] Withdrawal system was not yet operational.

Approximately half of the water withdrawn by the City of Crossville is returned to the Obed River as effluent from the Crossville wastewater treatment plant (Knight et al. 2014). The plant is located approximately 22.5 km (14 mi) upstream of OBRI. At times, this effluent comprises a significant portion of flow in the Obed River below Crossville, particularly during typical low-flow periods (July-October) (Knight et al. 2014). During these times, treated effluent may account for 10–40% of streamflow at the Obed River near Lancing stream gage (Figure 80) (Knight et al. 2014).

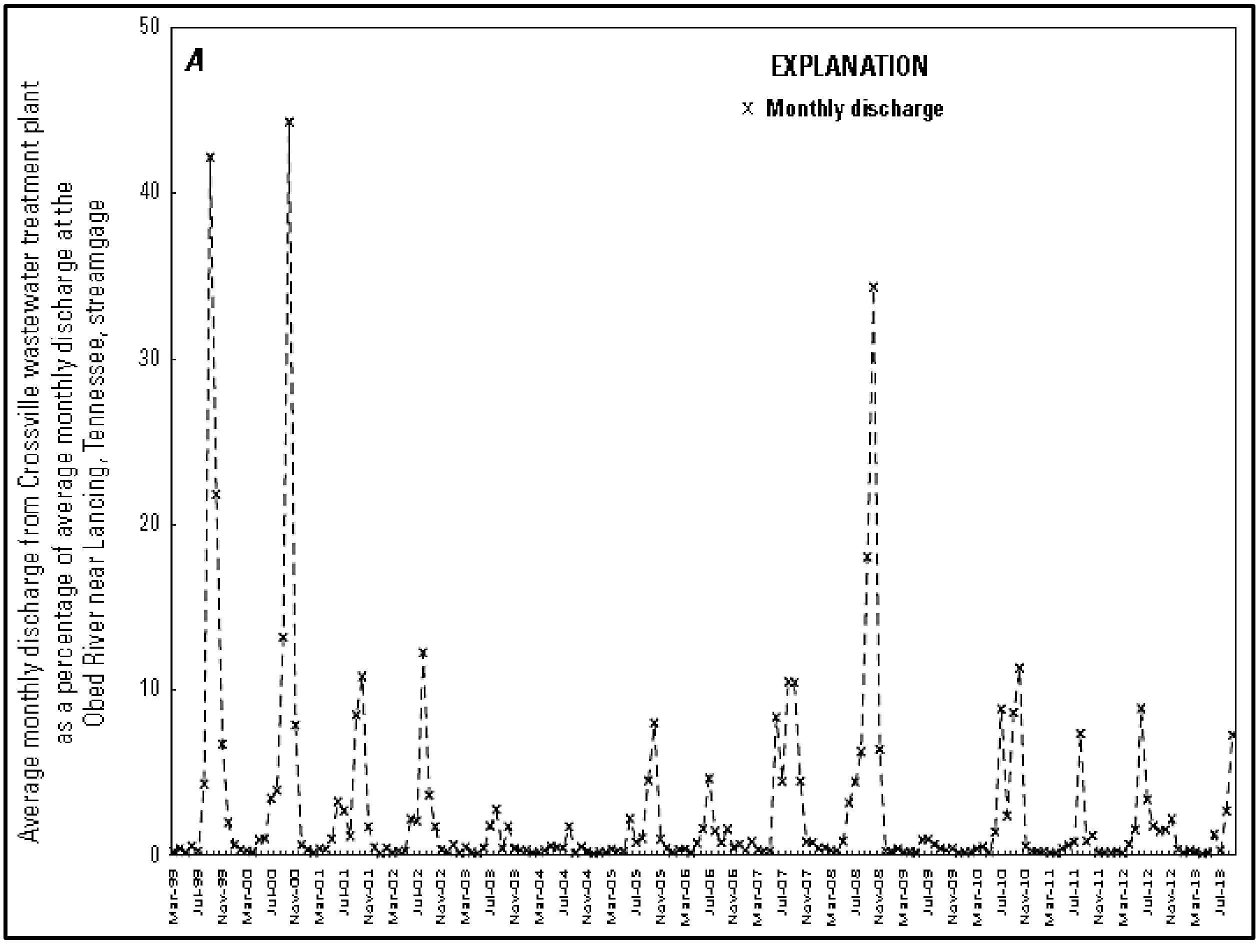

Figure 80. The percent of average monthly discharge at the Obed River near Lancing gage contributed by effluent from the Crossville wastewater treatment plant, March 1999-September 2013 (reproduced from Knight et al. [2014]).

Annual average discharge from the Crossville wastewater treatment plant has varied over time from less than 1.9 Mgal/d (3.0 ft^3/sec) to over 2.6 Mgal/d (4.0 ft^3/sec) (Figure 81). This variation can result in a difference in total annual discharge of over 250 million gallons. Unfortunately, annual effluent discharge data cannot be directly compared to annual withdrawals by Crossville, as effluent discharge is tracked by water year (October-September) and withdrawals are tracked by calendar year. However, available data suggest that Crossville may be returning as much (or more) water to the Obed River as they are withdrawing (Table 92, Figure 81). This is possible because water withdrawn by Crossville from the Caney Fork watershed is also discharged into the Obed River. While the total amount of water may not be significantly impacted by Crossville withdrawals at this time, it is unknown if the natural timing of high and low flows is being impacted.

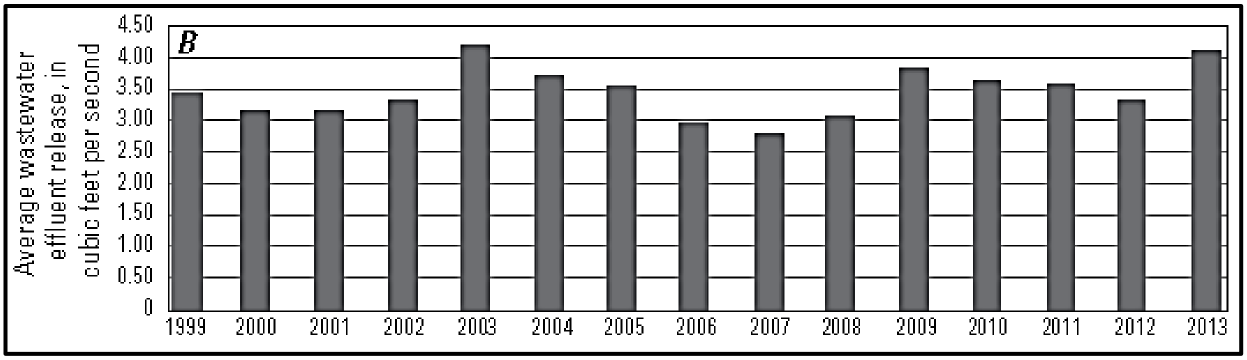

Figure 81. Average wastewater effluent release from the Crossville wastewater treatment plant by water year, 1999–2013 (reproduced from Knight et al. [2014]).

Threats and Stressor Factors

Threats to OBRI's water quantity are similar to those for water quality: urban growth and development, drought/climate change, and resource extraction (e.g., oil and gas development, mining). Cumberland County has been experiencing a period of population growth since the 1970s, which has resulted in increased construction of impoundments in the Obed River watershed for purposes ranging from public drinking water supply to water recreation and irrigation of golf courses (Emmott et al. 2005, Knight et al. 2014). These impoundments can alter the quantity and timing of streamflow, posing a serious threat to downstream ecosystems. Impoundments tend to reduce natural variability by retaining water during natural high-flow conditions and releasing water (often through unintentional seepage) during periods of low flow (Forester et al. 1998, Knight et al. 2014). Between 1975 and 1997, over 2,000 impoundments were constructed in the Obed River watershed (Knight et al. 2014). By 2002, a total of 2,454 impoundments existed in the Obed, Clear Creek, and Daddy's Creek watersheds, covering a cumulative surface area of 14.1 km^2 (5.5 mi^2) (Table 93) (Knight et al. 2014). Nearly 80% of these impoundments are small (<4,047 m^2 [1 ac]) and for private use. The largest impoundment is Lake Tansi near Crossville with a designed area of 1.7 km^2 (0.66 mi^2) (Knight et al. 2014). As of 2007, aerial photos and digital elevation model (DEM) data showed that approximately 13% (179 km^2 [69 mi^2]) of the Obed River watershed drained into impoundments (Knight et al. 2014).

Table 93. Number and surface area (km^2) of impoundments in the Obed, Clear Creek, and Daddy's Creek watersheds in 1975 and 2002 (modified from Knight et al. 2014). All areas are in km^2.

Watershed (Drainage area)	Year	# of impoundments	Surface area	Drainage area controlled
Obed River (445)	1975	215	1.2	–
	2002	929	5.9	73.3
Clear Creek (448)	1975	133	0.4	–
	2002	695	1.9	22.4
Daddy's Creek (453)	1975	40	0.5	–
	2002	830	6.3	82.9
Total (1,347)	1975	388	2.1	–
	2002	2,454	14.1	178.5

The water supply needs of Cumberland County, including Crossville and Crab Orchard, are expected to grow, exceeding 10 Mgal/d by 2020 (USACE 1998, Knight et al. 2014). This will likely increase demand for withdrawals from the Obed River. Much of the water withdrawn is returned to the Obed River as treated effluent, but these effluent discharges appear to be altering the natural variability and low-flow periods of the Obed River system (Knight et al. 2014). The natural systems of OBRI have adapted to and survived these variable conditions and low flow periods during late summer/early fall, and may be impacted by the flow stabilization from effluent discharge.

Oil and gas development activities, particularly resource extraction, can be very water-intensive (Mielke et al. 2010). In oil extraction, water may be used to flood an oil reservoir, displacing the oil and increasing its flow to the surface (Mielke et al. 2010). In the shale gas industry, water is used for hydraulic fracturing (i.e., "fracking"), a process which can require millions of gallons of water for each well (Mielke et al. 2010). Any water used by these industries will likely reduce the water available for the region's rivers and streams.

Global climate change is projected to increase temperatures across the southeast over the next century (Carter et al. 2014). Warmer temperatures will likely accelerate the loss of surface water to the atmosphere through evapotranspiration (Bates et al. 2008). In addition to temperature changes, climate change is projected to cause precipitation events to become less frequent but more intense, with longer dry periods between rain events (Bates et al. 2008). These two factors combined may increase water demand for urban and agricultural uses.

Data Needs/Gaps

Sufficient long-term gage data exist to analyze trends in discharge for the Obed and Emory Rivers in or near OBRI. Enough data are available for Daddy's Creek to make some historic comparisons, but continued data collection will allow managers and researchers to better understand any trends. Additional data are also needed for Clear Creek to identify any changes in discharge that may be occurring.

The impacts of effluent releases on the Obed River's variability and low discharge periods have not been fully analyzed (Knight et al. 2014). Closer tracking of the timing and amounts of effluent discharges and their proportion of Obed River flow will help managers better understand any threat this may pose to the river system.

Overall Condition

Annual Peak Discharge

The project team assigned this measure a *Significance Level* of 3 (Table 94). Data from gages in all four OBRI watersheds show that annual peak discharge is highly variable between years (USGS 2016). Five-year moving averages from the gages have not shown any clear increasing or decreasing trends. Therefore, this measure is currently of low concern (*Condition Level* = 1) for all four watersheds.

Table 94. A summary of Condition Levels for each measure by watershed and Weighted Condition Scores (WCS) for each watershed.

Measure	Significance Levels	Condition Levels			
		Clear Creek	Daddy's Creek	Obed River	Emory River
Annual peak discharge	3	1	1	1	1
Annual minimum discharge	3	2	2	2	3
Number of significant runoff events	3	0	0	1	1
Changes in precipitation amount/patterns	3	1	1	1	1
Changes in water demand/ effluent volume	3	0	0	2	2
WCS	–	**0.27**	**0.27**	**0.47**	**0.53**

Annual Minimum Discharge

This measure was also assigned a *Significance Level* of 3 (Table 94). The Clear Creek gage has the shortest period of record (1998–2015) of the four gages utilized for this assessment (USGS 2016). As a result, it is difficult to identify any long-term trends in minimum discharge for this watershed. The available data suggest that annual minimum discharge on Clear Creek is variable. However, minimum discharges during the most recent three years have been higher than minimum discharge during 13 of the previous 15 years (Figure 70). This may indicate a cause for concern, and the measure is therefore assigned a *Condition Level* of 2.

Gage data for Daddy's Creek suggest that minimum discharge has been higher and more variable during recent years (2000–2015) than during the historic period of record (1958–1967) (Figure 71). This is also cause for moderate concern (*Condition Level* = 2).

Similar to Daddy's Creek, 5-year moving averages for the Obed River gage suggest that minimum discharges have been higher and more variable during the most recent period of record (2000–2015)

(Figure 72). As a result, this measure is of moderate concern (*Condition Level* = 2) for the Obed watershed as well.

Due to the long, continuous period of record for the Emory River gage, changes in annual minimum discharge over time are even more apparent for this watershed than for the previous three. Prior to the 1960s, 5-year moving averages for minimum discharge were all below 0.2 cms (7.1 cfs) (USGS 2016). Since that time, moving averages have fluctuated widely from just over 0.2 cms (7.1 cfs) to nearly 1.0 cms (35.3 cfs) (Figure 73). Annual minimum discharge has exceeded 1.0 cms (35.3 cfs) in four individual years since the mid-1960s (USGS 2016). In a river system that has adapted to periodic low flows, this change is cause for concern (*Condition Level* = 3).

Annual Number of Significant Runoff Events

A *Significance Level* of 3 (Table 94) was assigned to this measure by the project team. The annual number of significant runoff events on Clear and Daddy's Creeks have been variable over the period of record (2008–2015), ranging from zero or one to eight (USGS 2016). No trends are apparent in the data from these watersheds and there is no indication of cause for concern. Therefore, this measure is assigned a *Condition Level* of 0 for Clear and Daddy's Creeks.

The annual number of significant events has also been variable on the Obed and Emory Rivers, ranging from zero to nine (USGS 2016). While there are no clear trends in these data either, the annual number of events in the three most recent years (2013–2015) is higher than in four of the previous five years (2008–2012) (Figure 74). The number of significant runoff events in each of these watersheds during the first half of the 2016 water year has already surpassed the mean for the 2008–2015 period of record (USGS 2016, provisional data). Because of the limited period of record, it is unclear if this is indicative of an actual change or is simply natural variation. However, it is still a cause for some, albeit low, concern (*Condition Level* = 1).

Annual Changes in Precipitation Amount/Patterns

The project team assigned this measure a *Significance Level* of 3 (Table 94) as well. Like peak discharge, annual precipitation totals in the OBRI area are highly variable (Figure 75). Long-term data from the Crossville Experimental Station (NOAA 2016a) suggest a slight increase in annual precipitation over the past 60–70 years. A comparison of monthly precipitation normals for 1971–2000 and 1981–2010 show that winter and spring precipitation were slightly lower during the more recent 30-year period than during the previous period (Figure 77). However, at this time, these slight changes are of low concern (*Condition Level* = 1) for all four watersheds.

Changes in Water Demand/Effluent Volume

This measure was also assigned a *Significance Level* of 3 (Table 94) by the project team. The amount of water withdrawn from the Obed River watershed by the City of Crossville has declined in recent decades, as they have drawn more water from the Caney Fork watershed (Knight et al. 2014). However, water withdrawals by Crab Orchard have increased, and the water needs of Cumberland County as a whole are expected to continue growing (Knight et al. 2014).

Approximately half of the water withdrawn by Crossville is returned to the Obed River watershed as effluent from the wastewater treatment plant (Knight et al. 2014). While the total amount of water returned to the Obed River as effluent appears to come close to the total amount withdrawn from the watershed by Crossville (as of 2010), the timing of the returns may not match the natural flow regime of the river. Effluent discharge comprises up to 40% of the Obed's flow at Lancing at some times and may be causing higher minimum discharges than are natural on the river (Knight et al. 2014).

Due to concerns over increasing demands and alteration of flow timing, this measure is assigned a *Condition Level* of 2 for the Obed and Emory River watersheds, indicating moderate concern. Since the Clear and Daddy's Creek watersheds are not currently experiencing withdrawals for public water supply or wastewater effluent discharge, this measure is of no concern (*Condition Level* = 0) for those watersheds.

Watershed Summaries

Clear Creek

Based on the measures selected for this NRCA, water quantity in the Clear Creek watershed is in *good condition* (*WCS* = 0.27) (Figure 82). Annual peak discharge is of low concern and annual minimum discharge is of moderate concern. The change in precipitation amount/patterns measure is of low concern, as changes in the region have only been slight over time, and there is currently no concern regarding the number of significant runoff events. The change in water demand/effluent volume measure is also of no concern, as mentioned previously.

Daddy's Creek

Water quantity in the Daddy's Creek watershed is also in *good condition*, with a *WCS* of 0.27 (Figure 82). The measures were assigned the same *Condition Levels* as Clear Creek based on similar reasoning.

Obed River

Water quantity in the Obed River watershed is of *moderate concern* (*WCS* = 0.47) (Figure 82). Annual peak discharge and annual minimum discharge measures are in similar condition as the previous watersheds, at low and moderate concern, respectively. Change in precipitation amount/patterns is also of low concern, as with previous watersheds. However, the number of significant runoff events was assigned a low concern and the change in water demand/effluent volume was assigned moderate concern for the Obed watershed, both higher condition levels than for Clear and Daddy's Creeks.

Emory River

Water quantity is also considered of *moderate concern* for the Emory River watershed with a *WCS* of 0.53 (Figure 82). The same *Condition Levels* were assigned as for the Obed River, with the exception of annual minimum discharge, which is considered of high concern for the Emory River watershed.

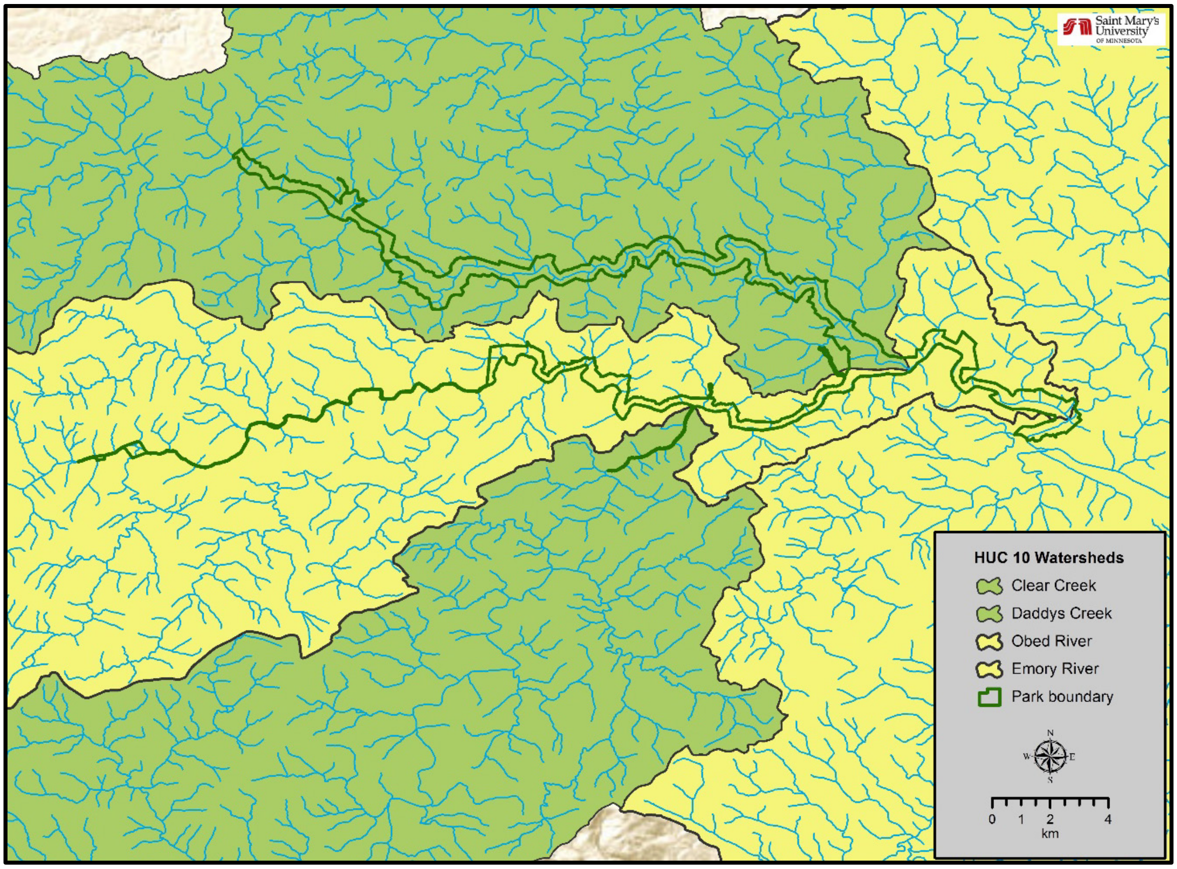

Figure 82. Water quantity condition designations by watershed. Green = good condition, yellow = moderate concern.

Weighted Condition Score

An overall *WCS* for OBRI was calculated by averaging the individual scores for the Clear Creek, Daddy's Creek, and Obed River watersheds. Since the Emory River watershed comprises only a small portion of OBRI and is downstream of the other three watersheds, it was not included in the calculation. The overall *WCS* for OBRI water quantity is 0.34, indicating moderate concern. An overall trend has not been assigned; while the Clear and Daddy's Creek watersheds appear stable or unchanging, some parameters in the Obed River watershed (e.g., annual minimum discharge) may be declining.

Water Quantity		
Watershed	**WCS**	**Overall WCS = 0.34**
Clear Creek	0.27	
Daddy's Creek	0.27	
Obed River	0.47	

4.9.6. Sources of Expertise

- Jim Hughes, APHN Hydrologist

4.9.7. Literature Cited

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4.10. Dark Night Skies

4.10.1. Description

A lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS NSNSD 2015a). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006, NPS NSNSD 2015a). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS NSNSD 2015a). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

OBRI is located along the northern boundary of the CWMA in Morgen and Cumberland Counties in Tennessee. Many small communities are within a close proximity to the park (Figure 83). Wartburg and Crossville, the county seats of Morgan and Cumberland Counties, are within a ten-minute drive of the park (Hudson 2014). Larger communities such as Oak Ridge and Knoxville are within an hour's drive from the park (Hudson 2014). Straight-line distance to Oak Ridge is 24.1 km (15 m) and 48.3 km (30 m) to suburban Knoxville (Hudson 2014). Nashville is approximately a two-hour drive from the park, with a straight-line distance of approximately 170 km (106 m).

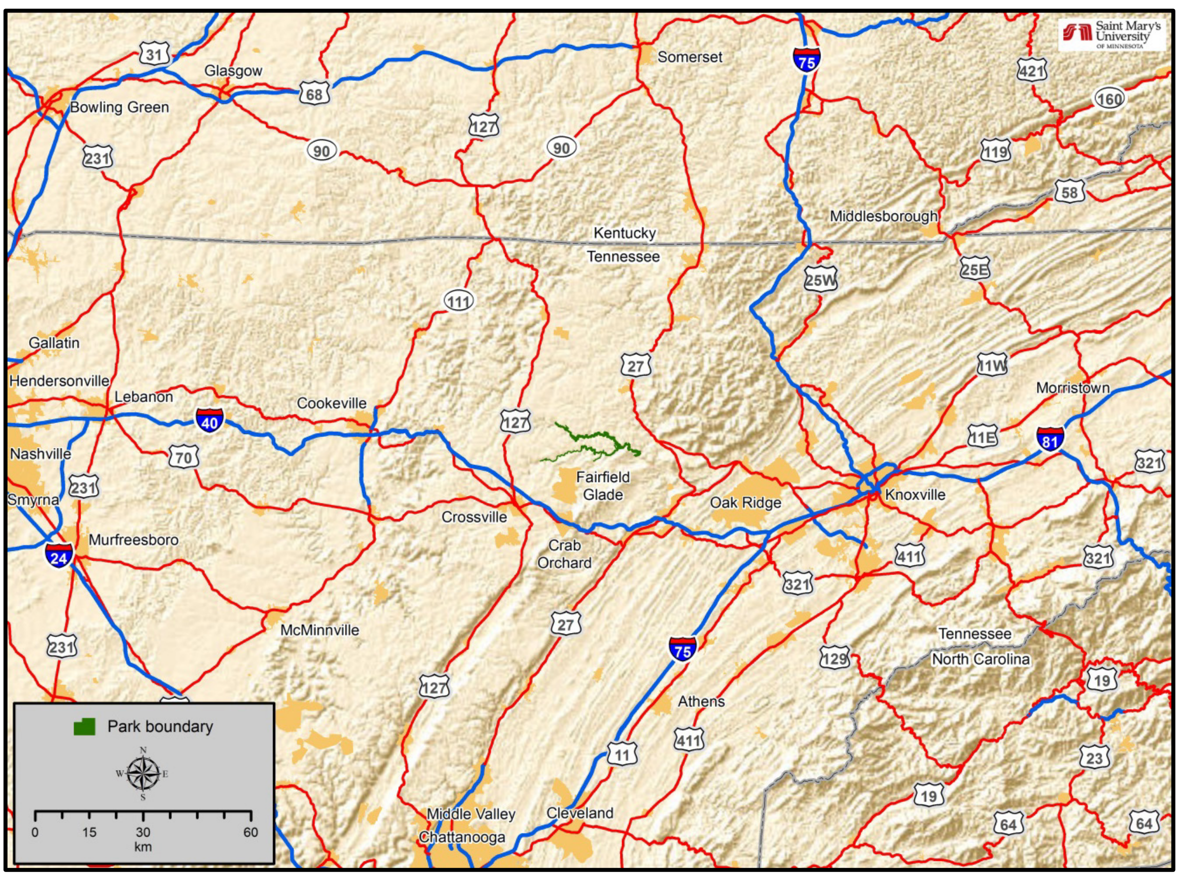


Figure 83. Location of the park and nearby sources of anthropogenic light.

The resource of a dark night sky is important to the NPS for a variety of reasons. First, the preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals (NPS NSNSD 2015a). The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved. Second, the "scenery" of national park areas does not just include the daytime hours (NPS NSNSD 2015a). Due to its close proximity to these urban areas, local astronomy clubs frequently use the park for star parties and other astronomy gatherings (Hudson 2014). Star gazing is an attraction that brings visitors to the park, and the park is open around the clock to accommodate this activity (Hudson 2014). Third, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes (NPS NSNSD 2015a). As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Fourth, the recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or "sleeping under the stars" (NPS NSNSD 2015a). And lastly, night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology (NPS NSNSD 2015a).

4.10.2. Measures

The dark night sky at OBRI was assessed using the suite of measures that the NPS Natural Sounds and Night Sky Division (NSNSD) uses to define the dark night conditions in a park unit. While the NPS NSNSD has not conducted a field visit to OBRI as of this writing, the park has conducted data collection for one of these measures as part of its application for designation as an International Dark Sky Park (Hudson 2014). Selection of the standard NSNSD measures ensures that this assessment aligns with NSNSD standards and incorporates the data the park is collecting in a manner that can be used as a baseline for a potential future visit by the NSNSD or with continued data collection by park personnel. The suite of measures that the NSNSD typically uses to define the condition of dark night skies include:

- Sky luminance over the hemisphere in high resolution (thousands of measurements comprise a data set), reported in photometric luminance units (V magnitudes per square arc second [mag/arcsec^2] or milli-candela per square meter [mcd/m^2]) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude (mags) is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter. It is similar to the "CIE photopic" broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990);
- Integrated measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance;
- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal)

illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance;

- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux;
- Visual observations by a human observer, such as Bortle Class and Zenith limiting magnitude (ZLM);
- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter (SQM), in mag/arcsec^2.

In the absence of this data, the NPS NSNSD recommends the use of the anthropogenic light ratio (ALR) as a measure of the quality of the photic environment and lightscape within a park (Moore et al. 2013). The ALR measures the average anthropogenic sky luminance as a ration of natural conditions (Moore et al. 2013). This measure is easily modeled and provides a robust and descriptive metric (Moore et al. 2013).

4.10.3. Reference Conditions/Values

Park staff identified the absence of anthropogenic light as the preferred reference condition. This condition can be defined as the absence of artificial light in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

> *No portion of the sky background brightness exceeds natural levels by more than 200 percent, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 10 percent. The ratio of anthropogenic hemispheric illuminance to natural hemispheric illuminance from the entire night sky does not exceed 20 percent. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated the naturally dark zone* (Dan Duriscoe, NPS NSNSD Team Lead/Physical Scientist, personal communication, 2011).

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (NPS 2006, p. 7) as follows in section 4.10:

> *"The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light."*

Implementing this directive in OBRI requires that facilities within the park meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park:

- Produce zero light trespass beyond the boundary of their intended use;
- Be of an intensity that meets the minimum requirement for the task, but does not excessively exceed that requirement;
- Be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow;

- Be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

4.10.4. Data and Methods

The NPS NSNSD has developed a GIS model derived from data from the 2001 World Atlas of Night Sky Brightness (Cinzano et al. 2001), which depicts *zenith* sky brightness (the brightness of the sky directly above the observer) (Moore et al. 2013). A neighborhood analysis is then applied to the World Atlas to determine the anthropogenic sky brightness over the *entire* sky. Anthropogenic light up to 200 km (124 m) from parks can have an impact on a parks night sky quality. Finally, the modeled anthropogenic light over the entire sky is presented as a ratio (ALR) over the natural sky brightness (Duriscoe In preparation).

OBRI is in the process of submitting a proposal for International Dark Sky Park designation. Data was collected by park personnel on two separate nights in November 2013 (Hudson 2014). A Unihedron SQM was used to collect brightness of the sky at zenith at 20 locations long the park's river corridors. Four readings were taken at each site, the first reading was discarded and the following three readings were recorded and used to calculate the average (Hudson 2014). The sample points are a representative subset of locations in the park where there is an unobstructed view of the sky (Hudson 2014). The sample points consisted of five types of natural and anthropogenic openings; locations where the river and river canyon are both wide, overlooks on top of the cliff, parking lots, bridges and fields (Hudson 2014).

Sample points were most concentrated in the downstream section of the park (downstream of Barnett Bridge on Clear Creek and downstream of Obed Junction on the Obed River), especially in the vicinity of Lilly Bridge (Figure 84) (Hudson 2014). This particular area is where both visitor use and natural and anthropogenic clearings in the forest canopy are most abundant (Hudson 2014). Overall the downstream section had a maximum distance of approximately 2.5 mi between sampling points (Hudson 2014). The upstream section of the park had fewer sample sites due to the lack of open spaces in the canopy where measurements could be taken (Hudson 2014). With the notable exception of Adams Bridge (approximately 0.8 km [0.5 m] upstream of the park boundary), no major bridges offering an unobstructed view of the sky intersect the upper reaches of park streams, and furthermore no developed areas are present (Hudson 2014). The streams in this section of the park also tend to be narrow, often with complete canopy cover provided by the riparian forest (Hudson 2014).

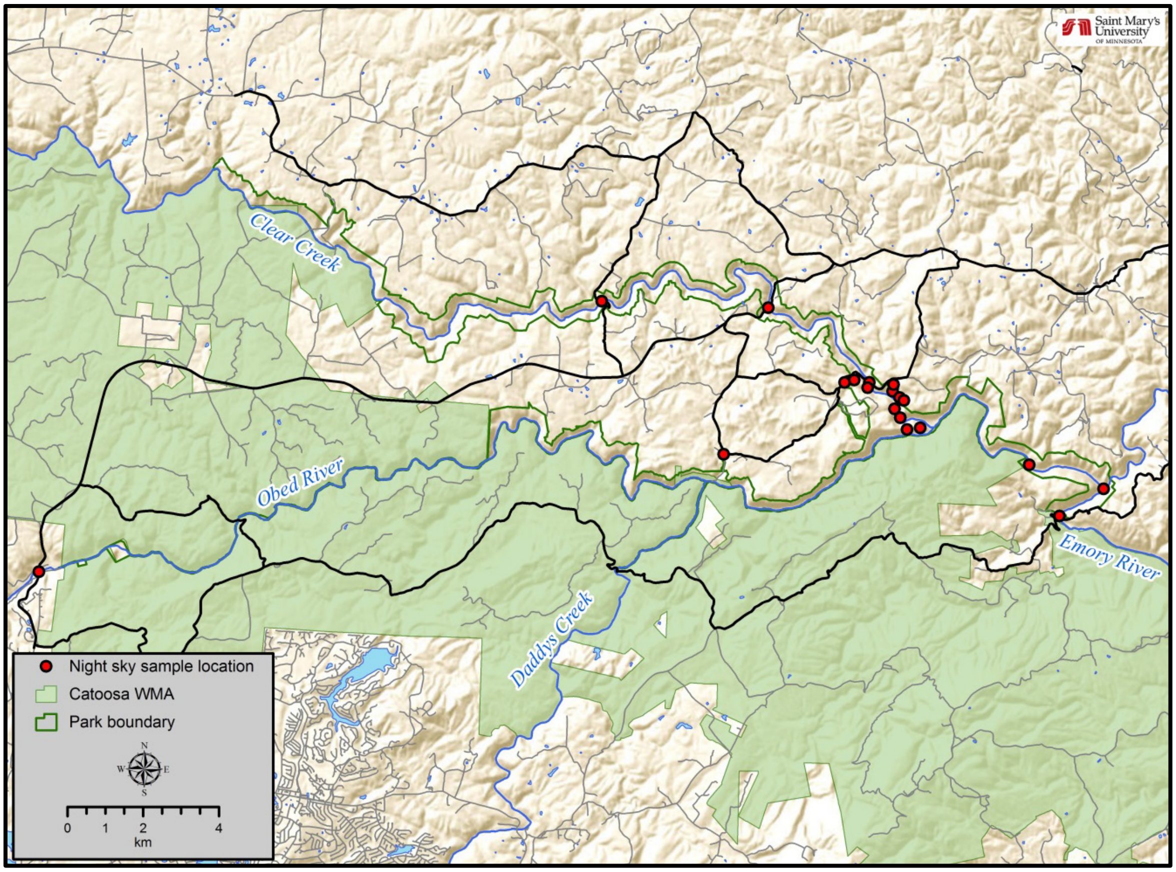


Figure 84. Unihedron Sky Quality Meter sampling locations in the park.

4.10.5. Current Condition and Trend

Background for NPS Night Sky Division's Suite of Measures

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a "detector" or a measuring device, or entering the observer's pupil. This type of measure is called illuminance (Ryer 1997).

Illuminance is measured in lux (metric) or foot-candles (English), and is usually defined as luminous flux per unit area of a flat surface (1 lux = 1 lumen/m^2). However, different surface geometries may be employed, such as a cylindrical surface or a hemispheric surface. Integrated illuminance of a hemisphere (summed flux per unit area from all angles above the horizon) is a useful, unbiased metric for determining the brightness of the entire night sky. Horizontal and vertical illuminance are also used; horizontal illuminance weights areas near the Zenith much greater than areas near the horizon, while vertical illuminance preferentially weights areas near the horizon, and an azimuth of orientation must be specified (Ryer 1997).

Direct vertical illuminance from a nearby anthropogenic source will vary considerably with the location of the observer, since this value varies as the inverse of the square of the distance from light source to observer (Ryer 1997). Therefore, measures of light trespass are usually made in sensitive areas (such as public campgrounds).

Anthropogenic light which results in an upward component will be visible to an observer as "sky glow". This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason, bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and is more directional. When the air is full of larger particles, this process gives clouds their white appearance and produces a whitish glow around bright objects (e.g., the sun and moon). The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

Light propagated at an angle near the horizon will be effectively scattered and the sky glow produced will be highly visible to an observer located in the direction of propagation. Predictions of the apparent light dome produced by a sky glow model demonstrate this (Luginbuhl et al. 2009). Light reflected off surfaces (e.g., a concrete road or parking area) becomes visible light pollution when it is scattered by the atmosphere above it, even if the light fixture has a "full cutoff" design and is not visible as glare or light trespass to a distant observer. For this reason, the intensity and color of outdoor lights must be carefully considered, especially if light-colored surfaces are present near the light source.

Light domes from many cities, as they appear from a location within Joshua Tree National Park, are shown in Figure 85 and Figure 86, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the NSNSD.

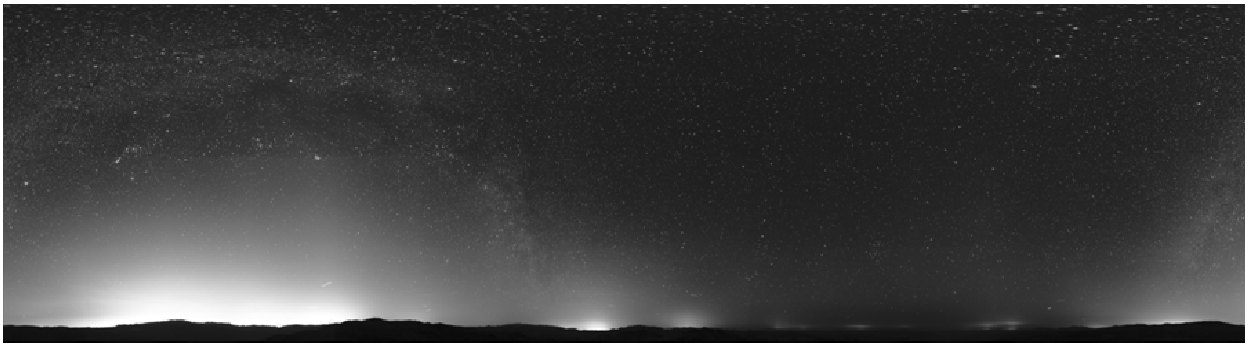


Figure 85. Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS NSNSD).

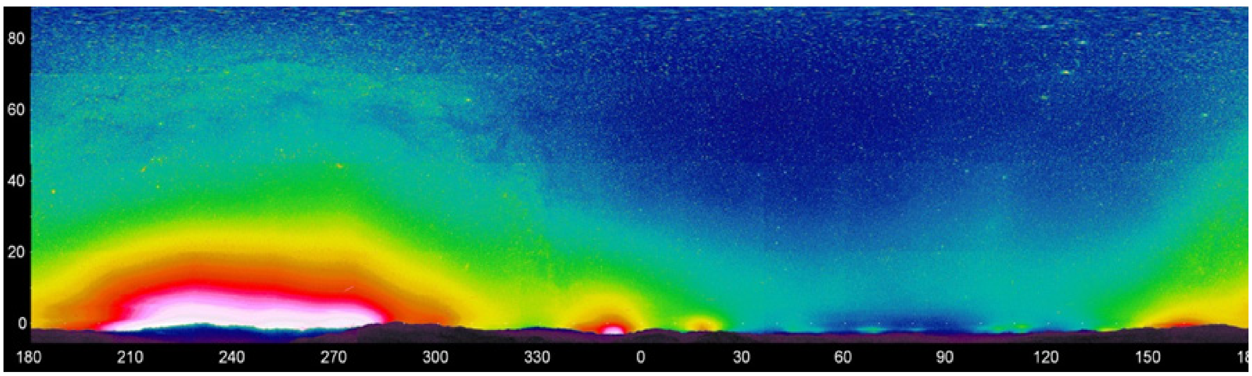


Figure 86. False color representation of Figure 85 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS NSNSD).

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NSNSD utilizes a digital camera with a large, dynamic range, monochromatic charge-coupled device (CCD) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data and the image scale in arc seconds per pixel is accurately known. Sky luminance is reported in astronomical units of mag/arcsec^2, and in engineering units of mcd/m^2. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

Figure 85 and Figure 86 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date, time, and the relative brightness of the natural airglow (the so-called “permanent aurora” which varies in intensity over time) (Roach and Gordon 1973). The NSNSD has constructed such a model, and uses it in analysis of data sets to remove the natural components. This results in a more accurate measure of anthropogenic sky glow (Figure 87). Figure 86 represents “total sky brightness” while Figure 87 displays “anthropogenic sky glow” or “net light pollution.” This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

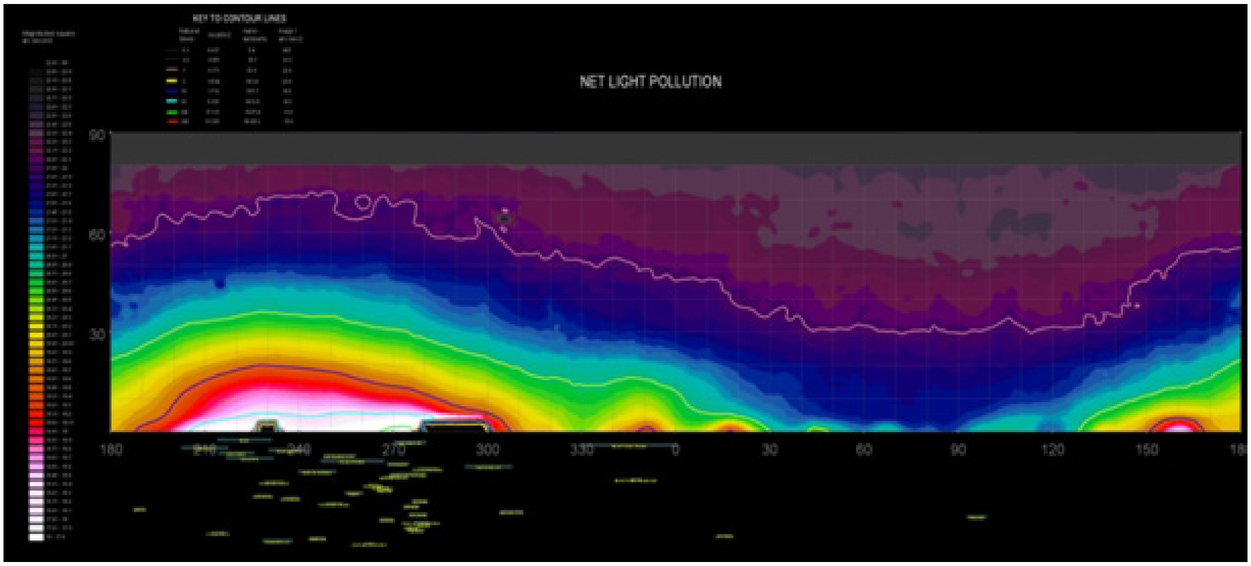


Figure 87. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 85 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS Night Sky Division).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition - a ratio of anthropogenic to natural light, the ALR identified previously (Moore et al. 2013). Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2010). This so-called “light pollution ratio” is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSNSD data, the atmospheric conditions determined from each individual data set. The ALR is derived from ground-based measurements when available, or from a GIS model (calibrated to ground-based measurements in the park) when field based data are measures are not available (Moore et al. 2013).

A quick and moderately accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron SQM. The Unihedron SQM is a single-channeled hand-held photometric device. A single number in mag/arcsec^2 is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because the meter is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NSNSD produces values from each data set as both a synthesized value derived from the high-resolution images and by hand held measures with a Unihedron SQM. The performance of the SQM has been tested and reviewed by Cinzano (2001). While fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, a value of about 21.85 would be considered “pristine”, providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken (Moore et al. 2013).

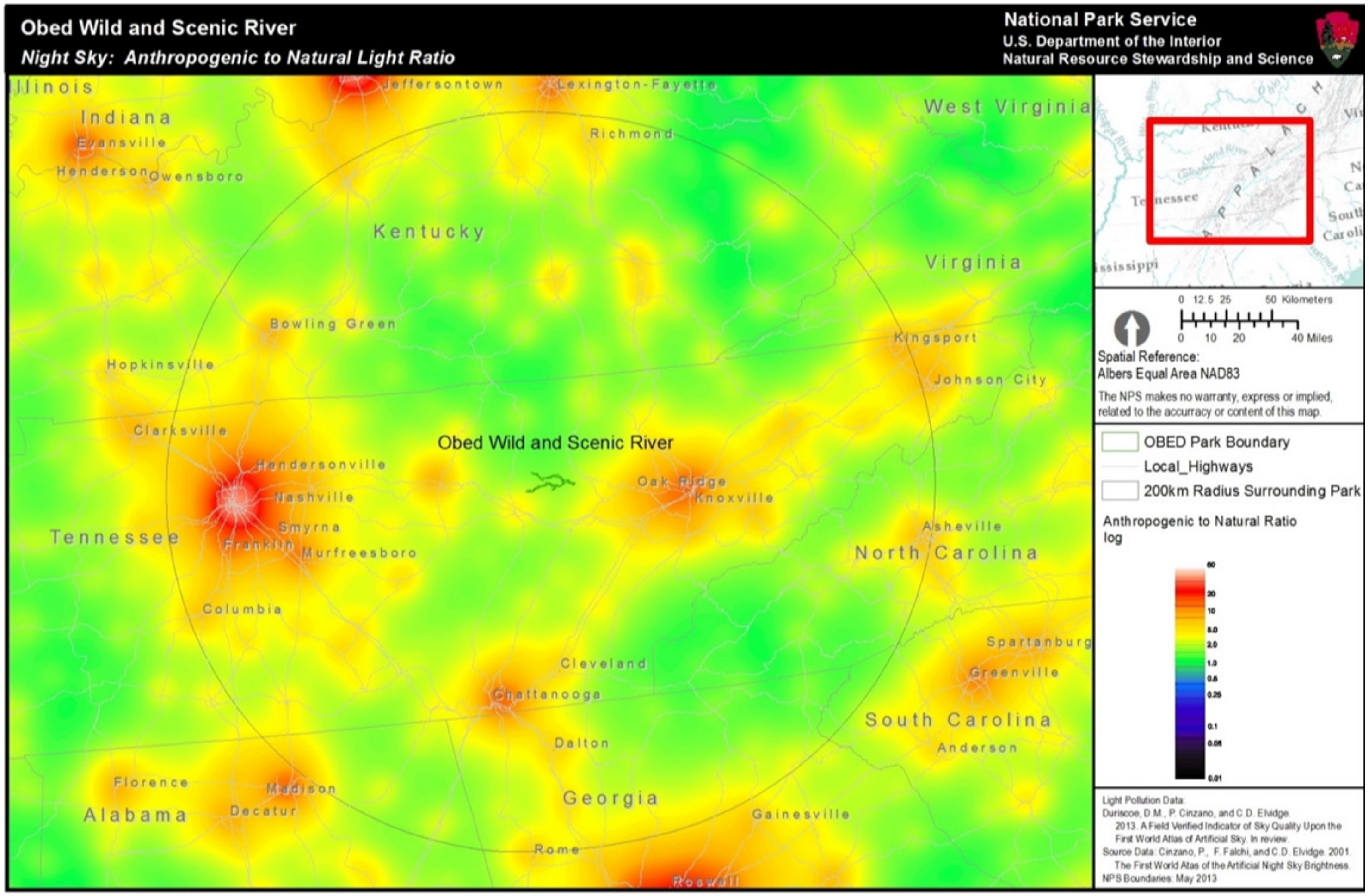
Visual observations are important in defining sky quality, especially in defining the aesthetic character of night sky features. A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2001). Observations of several features of the night sky and anthropogenic sky glow are synthesized into a 1–9 integer interval scale, where class 1 represents a “pristine sky” filled with easily observable features and class 9 represents an “inner city sky” where anthropogenic sky glow obliterates all the features except a few bright stars. Bortle Class 1 and 2 skies possess virtually no observable anthropogenic sky glow (Bortle 2001).

Another visual method for assessing sky quality is the ZLM, which is the apparent brightness or magnitude of the faintest star observable to the unaided human eye, which usually occurs near the Zenith. This method involves many factors, the most important of which is variability from observer to observer. A ZLM of 7.0–7.2 is usually considered “pristine” or representing what should be observed under natural conditions; observation of ZLM is one of the factors included in the Bortle Dark Sky Scale. The ZLM is often referenced in literature on the quality of the night sky, and is the basis for the international “Globe at Night” citizen-scientist program (see http://www.globeatnight.org/index.html). The NSNSD has experimented with the use of this observation in predicting sky quality, and has found that it is a much coarser measure and prone to much greater error than accurate photometric measures over the entire sky. For these reasons, it is not included in the reference conditions section.

NPS Night Sky Division Suite of Measures

The NSNSD has not made a field visit to OBRI, however data is available for two of the measures normally used to define the condition of the night sky is available. They consist of the GIS modeled ALR and the SQM data collected for the application for designation as an International Dark Sky Park.

The results of the ALR model for the area surrounding OBRI is shown in Figure 88. A condition level can be assigned to the modeled ALR data, based on a threshold applied spatially to the park (Moore et al. 2013). This threshold is dependent on whether the park is considered to be urban or non-urban (Moore et al. 2013). The distinction between urban (Level II) and non-urban (Level I) parks is based on the relative proximity of the park (and its borders) to an “Urban Area” as defined by the 2010 U.S. Census (Moore et al. 2013). For parks managed as wilderness, the designated condition is based on ALR level that exists in more than 90% of the wilderness area (Moore et al. 2013). Due to its “Wild and Scenic River” designation, OBRI falls into this third category.



NPS Natural Sounds & Night Skies Division and NPS Inventory and Monitoring Program MAS Group 20151201

Figure 88. Output of the NPS NSNSD GIS model for the anthropogenic to natural light ratio (ALR) for OBRI. Graphic of the model output was provided by the NPS NSNSD.

In interpreting the results of the model, for both urban and non-urban parks, the condition (green, amber, red) corresponds to the ALR level that represents the median condition (in at least half the parks area) for the parks' landscape (Moore et al. 2013). This median condition reflects the probable night sky quality that park visitors will experience at any location within the park (Moore et al. 2013). It is also probable that the majority of wildlife and habitats within the park exist under this quality of night sky (Moore et al. 2013). The NPS NSNSD recommendations for ALR condition are given in Table 95. The median ALR value for OBRI is 1.95, which puts the park at the upper limit of moderate condition category for areas managed as wilderness (Moore et al. 2013, NPS 2015).

Table 95. NPS NSNSD recommendations for condition levels for modeled ALR values (Moore et al. 2013).

Area	Good Condition (Green)	Moderate Condition (Amber)	Poor Condition (Red)
Non-urban (Level 1) parks	< 0.33	0.33–2.00	> 2.00
Urban (Level 2) parks	< 2.00	2.00–18.00	> 18.00
Areas Managed as Wilderness	< 0.33	0.33–2.00	> 2.00

The park has collected SQM readings using protocols similar to the NPS NSNSD that can be used to assess the measure of the luminance of the sky within 50° of the Zenith. This data was collected at 20 representative observation points within the park on the nights of 3 November and 30 November 2013 (Hudson 2014). Sky conditions were clear with a new moon (moonless) (Hudson 2014). The night of 3 November did have higher relative humidity and potentially more haze from air pollution that is believed to have resulted in slightly lower SQM readings for that night (Hudson 2014). Park personnel also noted that the skies did appear darker and the stars more brilliant on the night of 30 November (Hudson 2014).

Data collected using the Unihedron SQM on the nights of 3 November and 30 November 2015 are given in Table 96. The SQM values for the two field visits ranged from 21.04–21.29 mag/arcsec^2 (Table 96) (Hudson 2014). The NPS NSNSD (2015b), considers SQM values of 21.3 and greater to be within the range of natural skies, 19.5–21.3 could be considered significantly degraded, while values less than 19.5 are considered severely degraded. The SQM values collected during the two field visits in November 2013 are all below 21.3, or just below the borderline for natural sky conditions. The lowest readings were observed at Adams Bridge (location 17). This was to be expected, as this site is closer in proximity to populated areas than the rest of the park (Hudson 2014). The differences in sky conditions between the two field visits is thought had an impact of the observed readings as evidenced by the differences in the recorded values in the two visits to Lilly Bridge (Hudson 2014). SQM readings were taken at Lilly Bridge on the night of 3 November were lower (21.13, 21.12, and 21.11) under the higher humidity and haze conditions than were recorded on the clearer night of 30 November (21.25, 21.22, and 21.22) (Hudson 2014). Overall the SQM values recorded during each field visit suggest that some degradation of the night sky has taken place.

Table 96. Sky Quality Meter readings collected during 2013 field visits (Hudson 2014).

Sample Point	Date	Time	SQM Readings (mag/arcsec^2)			
			Reading 1	Reading 2	Reading 3	Average
1. Emory River at Fork Hole	11/3/2013	2015	21.15	21.15	21.18	21.16
2. Obed River at Alley Ford	11/3/2013	2110	21.12	21.14	21.13	21.13
3. Emory River at Nemo	11/3/2013	2330	21.10	21.11	21.11	21.11
4. Inner Circle Overlook	11/4/2013	0020	21.10	21.11	21.14	21.12
5. Camel Rock Overlook	11/4/2013	0035	21.10	21.11	21.10	21.11
6. Great Roof Overlook	11/4/2013	0100	21.09	21.08	21.07	21.08
7. Clear Cut Near Trail	11/4/2013	0110	21.09	21.08	21.07	21.08
8. Back Overlook Parking Lot	11/4/2013	0145	21.11	21.11	21.08	21.10
9. Y12 Overlook	11/4/2013	0225	21.07	21.07	21.07	21.07
10. Point Trail Overlook	11/4/2013	0245	21.08	21.07	21.08	21.08
11. Arch Overlook	11/4/2013	0250	21.09	21.09	21.06	21.08
12. End of Point Trail	11/4/2013	0300	21.07	21.07	21.09	21.08
13. Doc Howard Parking Lot	11/30/2013	0040	21.20	21.19	21.19	21.19
14. Lilly Bridge	11/30/2013	0046	21.22	21.25	21.21	21.23
15. Front Overlook Parking Lot	11/30/2013	0051	21.22	21.25	21.20	21.22
16. Obed Junction Field	11/30/2013	0102	21.22	21.25	21.22	21.23
17. Adams Bridge	11/30/2013	0125	21.07	21.05	21.04	21.05
18. Barnett Bridge	11/30/2013	0150	21.25	21.23	21.23	21.24
19. Jett Bridge	11/30/2013	0215	21.29	21.27	21.27	21.28
20. Lilly Overlook Platform	11/30/2013	0240	21.25	21.22	21.22	21.23

Threats and Stressor Factors

Due to its designation as a Wild and Scenic River, there are no artificial lights within the park (Hudson 2014). Light trespass within the park is entirely from anthropogenic sources that are beyond the control of the park. Light trespass from nearby cities, developments, and lack of planning information for local lighting within nearby communities and developments are considered the most concerning threat to night sky quality of a park. Contributing to these typical light sources are air transparency (haze, smoke) conditions, which are often degraded in the area due to local weather patterns and proximity to the mountains which trap and concentrate air contaminants from coal fired power plants and vehicle emissions (Emmott et al. 2005, Emmott and Porter 2008).

Data Needs/Gaps

As part of the application for designation as an International Dark Sky Park, the park has committed to annually measure the darkness/brightness of the night skies using the SQM sampling discussed above (Hudson 2014). It is recommended that this data be supplemented by field visits by the NPS NSNSD. The night sky condition data collected by the NPS NSNSD provides a more comprehensive suite of measures that are more conducive to developing desired conditions or making management decisions. These visits should occur on a more periodic basis, approximately once every five years, in order to assess and track external light source impacts within the park.

The park has used the initial dark sky inventory conducted in 2013 as a basis for interpretive and educational programming that highlights the importance of dark skies and their relative scarcity in the eastern U.S. (Hudson 2014). During 2014–2015, OBRI staff offered four interpretive programs to the general public that focused on the importance of dark skies (Hudson 2014). Two of these programs were focused exclusively on dark sky issues (Hudson 2014). All four programs included an emphasis on naked-eye astronomy, the critical importance of dark skies to many of the wildlife species found within the park, and on the importance of dark night skies to human happiness and well-being (Hudson 2014). OBRI staff are committed to the continuation and expansion of these existing programs and to making dark sky programming a central theme of its interpretive outreach (Hudson 2014). The park also intends to include information about the park's ongoing dark sky monitoring effort as a part of these programs and any subsequent monitoring conducted NPS NSNSD (either from field visits or GIS modeling) should also be incorporated in this programming as it becomes available.

The park is also incorporating dark night sky issues as one of its central themes on its social media sites. The park is actively using social media to post dark night sky related events and promote dark night sky issues (Hudson 2014). The park also produced a movie in 2014 that highlights the park's dark night skies and the importance of protecting them (Hudson 2014).

The park is also working to raise the awareness of visitors and the surrounding community on the importance of dark night skies and will strive to be an environmental leader on dark sky issues (Hudson 2014). The park is working with Tennessee Citizens for Wilderness Planning and the Knoxville Observers in an effort to help educate civic and business leaders in the communities of Wartburg, Crossville, Oak Ridge and Knoxville on the importance of dark sky issues and potential solutions such as alternate lighting (Hudson 2014).

Overall Condition

NPS NSNSD's Suite of Measures

During scoping meetings, the OBRI NRCA team assigned the NPS NSNSD suite of measures a *Significance Level* of 3. While NPS NSNSD has not conducted a field visit to OBRI, data are available for two of these measures from alternate sources. The ALR data modeled by the NPS NSNSD can be used as a surrogate for the Average Natural Sky Luminance data collected during their field visits (Moore et al. 2013). The modeled ALR data for OBRI was 1.95, which places it at the upper end of the NPS NSNSD moderate condition. This measure was assigned a *Condition Level* of 2, or moderate concern for the NRCA condition assessment.

The SQM observations collected in 2013 were all within the range the NPS NSNSD considers being significantly degraded (19.5–21.3). The lowest value recorded was 21.04 and most were near the 21.3 value. As the majority of the results recorded are just outside the lower limit for natural skies and sky conditions appear to have influenced the readings on the night of 3 November 2012, a

Condition Level of 1, or low concern was assigned. However, if subsequent data continues to exhibit SQM values in the significantly degraded range (19.5–21.3), this assignment should be re-addressed.

The remaining measures are considered to be data gaps at this time; therefore, a *Condition Level* has not been assigned.

Weighted Condition Score

A *Weighted Condition Score* of 0.5 was calculated for the dark night skies component, indicating moderate concern. Normally when more than half of the measures are unassigned a *Condition Level*, the overall scoring is not calculated. Since the ALR is recommended by the NPS NSNSD for use when the more comprehensive suite of data is not available, the overall score was calculated. A stable trend was assigned due to a number of factors. The population growth of Knoxville (3.1%), Oak Ridge (-0.1%) and Crossville (4.6%) has been slow to moderate over the period 1 April 2010 to 1 July 2014 (USCB 2015). Secondly, there is no anthropogenic light sources within the park due to its "Wild and Scenic River" designation (NPS 1995). This may change with the addition of future night sky assessments of OBRI or if external light sources increase with additional urban sprawl and other human development in the area.

Dark Night Skies			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.5**
Average Natural Sky Luminance	3	2	
Average Anthropogenic Light Dome	3	N/A	
Horizontal Illuminance	3	N/A	
Maximum Vertical Illuminance	3	N/A	
Sky Quality Meter/Bortle Class	3	1	

4.10.6. Sources of Expertise

- Matt Hudson, OBRI Chief Ranger/Deputy Superintendent
- Dan Duriscoe, NPS NSNSD Team Lead/Physical Scientist
- Jeremy White, NPS NSNSD Physical Science Technician

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4.11. Soundscape and Acoustic Environment

4.11.1. Description

Acoustic resources are physical sound sources, including both natural sounds (wind, water, wildlife, vegetation) and cultural and historic sounds (battle reenactments, tribal ceremonies, quiet reverence) (NPS 2014). The acoustic environment is the combination of all the acoustic resources within a given area, natural sounds and human-caused sounds (NPS 2014). The acoustic environment includes sound vibrations made by geological processes, biological activity, and even sounds that are inaudible to most humans, such as bat echolocation calls (NPS 2014). Soundscape is the component of the acoustic environment that can be perceived by humans (NPS 2014). The character and quality of the soundscape influence human perceptions of an area, providing a sense of place that differentiates from other places (NPS 2014; Photo 19). Noise refers to sound which is unwanted either because of its effects on humans and wildlife, or its interference with the perception or detection of other sounds (NPS 2014). The natural soundscape is an inherent component of the scenery, the natural and historic objects, and the wildlife protected by the Organic Act of 1916 (NPS 2014). NPS Management Policies (§4.9) require the NPS to preserve the park's natural soundscape, to restore the degraded natural conditions wherever possible, and to prevent or minimize noise (NPS 2014).

Photo 19. A quiet and serene landscape during the fall in OBRI (NPS Photo).

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (Ackerman 2012). Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

Noise not only affects visitor experience, it can also alter the behavior of wildlife. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Anderssen et al. 1993, NPS 1994, NPS 2016b). Repeated noise can cause chronic stress to animals, possibly affecting their energy use, reproductive success, and long-term survival (Radle 2007). Even low levels of noise can interfere with ecological processes in surprising and complex ways (Shannon et al. 2015).

4.11.2. Measures

Sound measures may be classified in terms of amplitude, frequency, or duration, as described below. Additional details are provided in Chapter 4.11.4.

- Sound pressure levels (in decibels [dB], a logarithmic unit) - the most common measure of sound amplitude, and especially A-weighted sound levels (in A-weighted decibels [dBA])
- Frequency - a measure of the repetition rate of a sound wave component (in Hertz [Hz] or less commonly, cycles per second [cps]); it may be perceived as pitch by an auditory system
- Duration of sounds - examples include Time Above Ambient (TAA), Time Above 35 dBA (or other level), Noise Free Interval (NFI), Time Audible (TAud), in hours, minutes, or seconds, and Percent Time Audible (%TAud), in percent.

4.11.3. Reference Conditions/Values

Reference conditions should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself. NPS policy states that the natural ambient sound level is the baseline (reference condition) and standard against which current conditions in a soundscape are to be measured and evaluated (NPS 2006). The NPS defines natural ambient sound level as the environment of sound that would exist in the absence of human-caused noise (NPS 2006). Also, according to the EPA, outdoor background conversations should not exceed 55 dB in order to protect public health and welfare, and to maintain the integrity of interpretive programs at the park (EPA 1974).

4.11.4. Data and Methods

<u>Sound Science</u>

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency (pitch) and volume (amplitude), or sound level. Noise, essentially the negative evaluation of sound, is defined as extraneous or undesired sound (NPS 2014).

Frequency, measured in Hz, describes the cps of a sound wave (NPS 2014). Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and are most sensitive to frequencies between 1,000 Hz and 6,000 Hz (NPS 2014). High frequency sounds are more readily absorbed by the atmosphere or scattered by obstructions than low frequency sounds. Low frequency sounds diffract more effectively around obstructions. Therefore, low frequency sounds travel farther.

In addition to the pitch of a sound, humans also perceive the amplitude (or level) of a sound (NPS 2014). This metric is described in dB. The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy (NPS 2014). This also means that small variations in sound pressure level can have significant effects on the acoustic environment (NPS 2014). Sound pressure level is commonly summarized in terms of dBA (NPS 2014). Table 97 provides examples of dBA levels measured in national parks.

Table 97. Examples of sound levels measured in national parks (NPS 2014) and comparable sound levels in common developed settings.

Park Sound Sources	Common Sound Sources	dBA
Volcano crater (Haleakala National Park)	Human breathing at 3m	10
Leaves rustling (Canyonlands NP)	Whispering	20
Crickets at 5m (Zion NP)	Residential area at night	40
Conversation at 5m (Whitman Mission National Historic Site)	Busy restaurant	60
Snowcoach at 30m (Yellowstone National Park)	Curbside of busy street	80
Thunder (Arches National Park)	Jackhammer at 2m	100
Military jet at 100m AGL (Yukon-Charley Rivers National Preserve)	Train horn at 1m	120

The natural acoustic environment is vital to the function and character of a national park. Natural sounds include those sounds upon which ecological processes and interactions depend. Examples of natural sounds in parks include (NPS 2014):

- Sounds produced by birds, frogs or insects to define territories or attract mates;
- Sounds produced by bats to navigate or locate prey;
- Sounds produced by physical processes such as wind in trees, flowing water, or thunder.

Although natural sounds often dominate the acoustic environment of a park, human-caused noise has the potential to mask these sounds. Noise impacts the acoustic environment much like smog impacts the visual environment; obscuring the listening horizon for both wildlife and visitors.

4.11.5. Current Condition and Trend

Unlike other components within this NRCA, the specified measures for this component are discussed in conjunction with each other below. Measure-specific subheadings are not used in this component assessment.

Because it is difficult to collect acoustic data across all landscapes, the NPS developed a novel geospatial sound model that predicts natural and existing sound levels within 270 m (886 ft) resolution (see Figure 89). The model is based on acoustic data collected at 244 sites and 109 spatial explanatory layers (such as location, landcover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports) (Mennitt et al. 2013).

The model shows that predicted median existing daytime sound levels (L_{50}) within OBRI are moderate, ranging from 35.3 to 39.6 dBA. In addition to predicting these two ambient sound levels, the model also calculates the difference between the two metrics which provides a measure of impact to the natural acoustic environment from anthropogenic sources. The resulting metric (L_{50} dBA impact) indicates how much anthropogenic noise raises the existing sound pressure levels in a given location (Figure 90). Predicted impacts due to anthropogenic sources are low in OBRI, and range from 0 to 2.1 dBA. No on-the-ground data have been collected in OBRI, and the modeled sound levels are currently the only source of acoustic data that exist for the park.

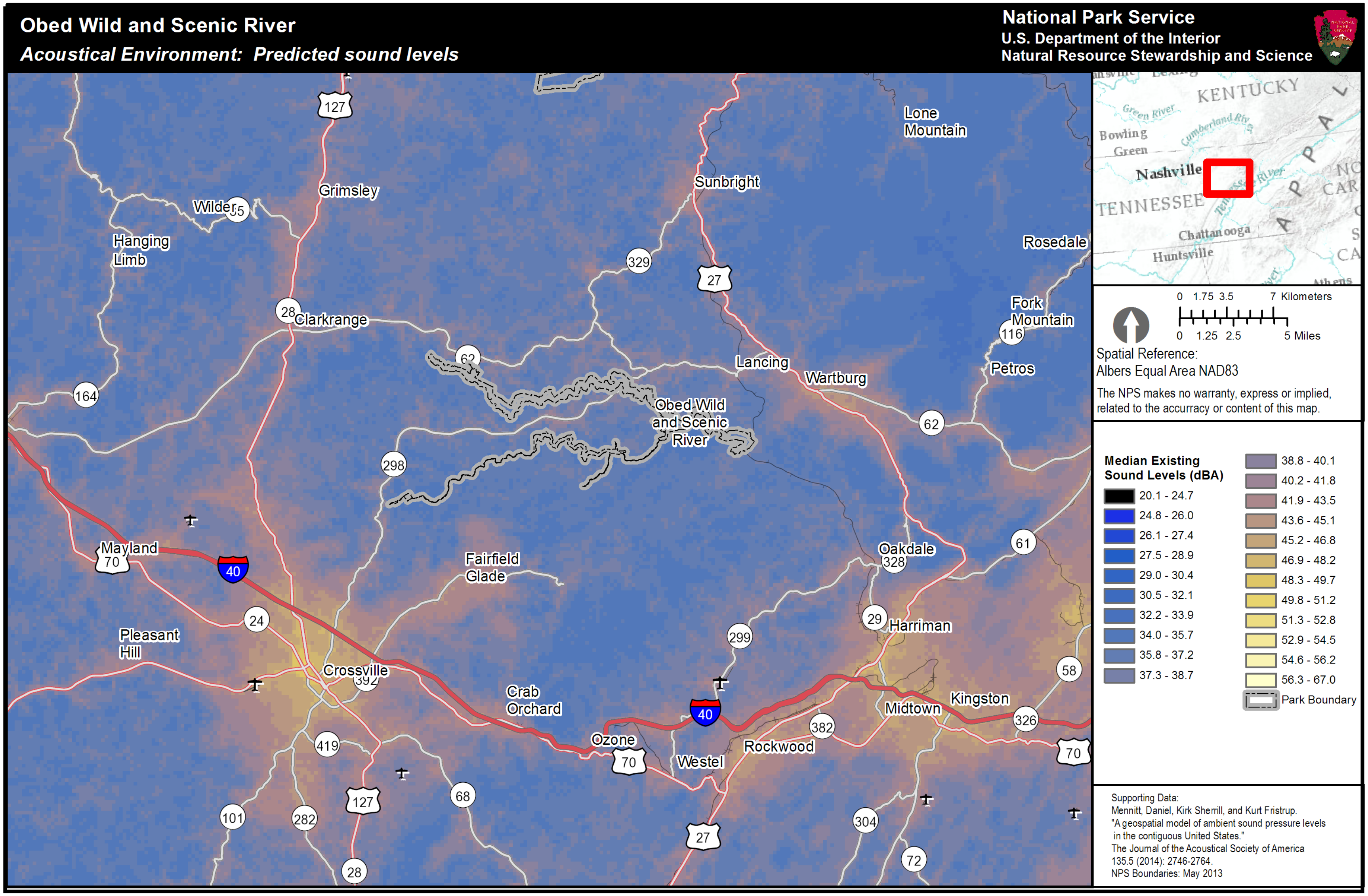

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Figure 89. Map displaying predicted median existing sound levels (L_{50}) in dBA (figure provided by NPS NSNSD).

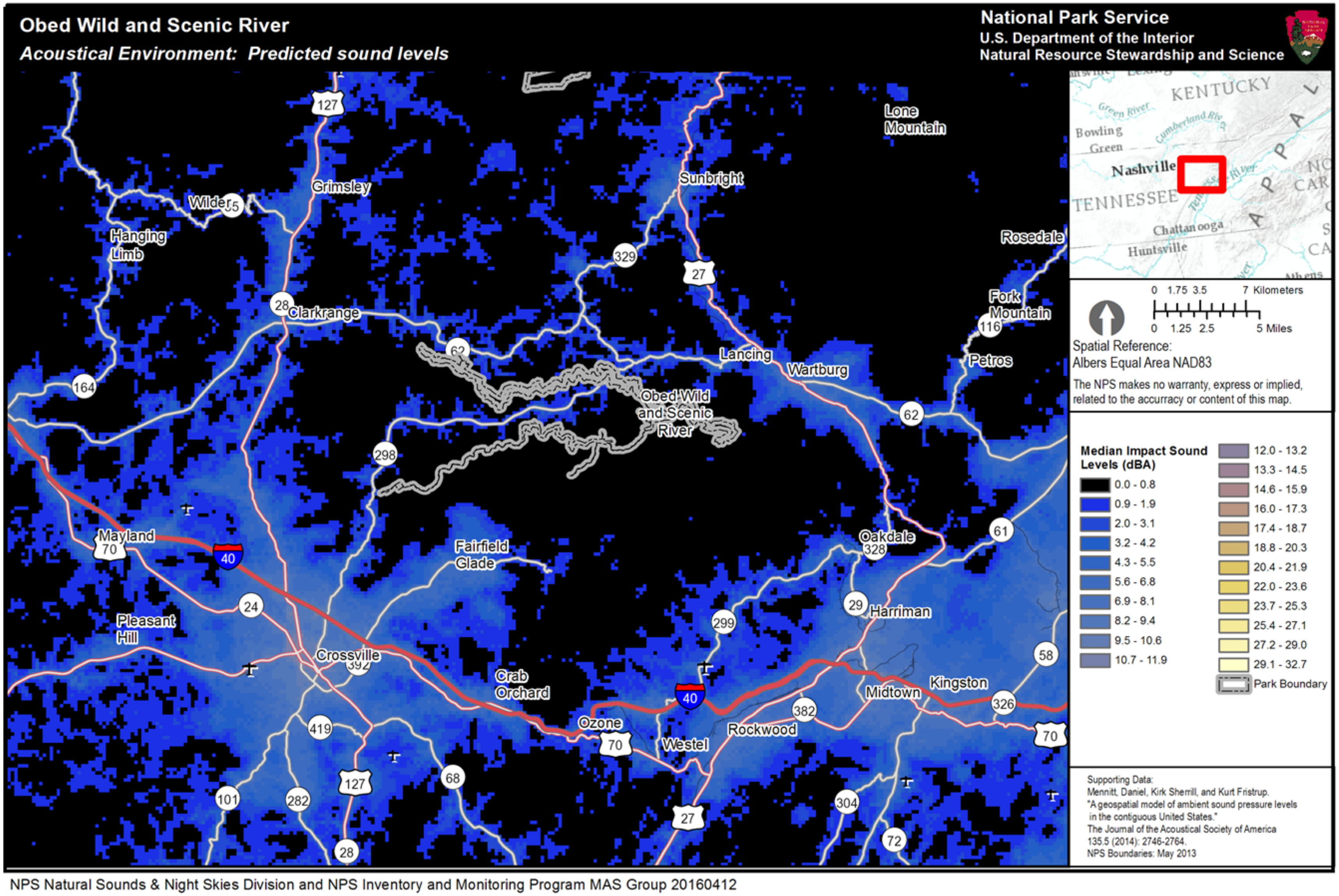

Figure 90. Map displaying modeled L_{50} dBA impact levels in OBRI.

Threats and Stressor Factors

Multiple factors can go into increasing anthropogenic sound inside a park. These can be anything from park maintenance equipment to noisy visitors (NPS 2016b). In a sound study completed in Muir Woods National Monument, it was discovered that anthropogenic noise from loud talking, disruptive behaviors, and other related sounds created the most distraction and interruption to the quality of a visitor's park experience (NPS 2016b). Most visitors to OBRI expect to hear certain sounds associated with the overall park experience; these can be anything from birds chirping, water flowing, or wind rustling leaves or rushing through a gorge (NPS 2006). On average, OBRI receives approximately 187,000 visitors a year (NPS 2016a) and in 2015, around 3,000 people utilized the 11-site Rock Creek campground along with an additional 500 people who camped in the backcountry of the park (NPS 2016a). Due to the number of visitors, the campground can produce additional anthropogenic noises (i.e., loud talking, automobiles, running generators) that contribute to the disruption of the overall natural soundscape. There is also anthropogenic noise that originates from power tools such as lawn mowers, chainsaws, and other landscape tools. A power lawn mower can produce a noise level ranging from 80 to 95 dBA (EPA 1974). This is above the level known to disrupt interpretive programs (EPA 1974).

Vehicle noise is also a concern especially with public roads nearby and passing through the park. Barber et al. (2009) stated that park transportation corridors have sound levels more than four orders of magnitude higher than natural conditions. This type of noise from transportation networks are increasing at a faster rate than population size (Barber et al. 2009). According to the U.S. Federal Highway Administration (FHA) (2008), "between 1970 and 2007, the U.S. population increased by approximately one-third (USCB 2007), but traffic on U.S. roads nearly tripled, to almost 5 trillion vehicle km (3 trillion mi) per year." Several roads (including Tennessee State Routes 298 and 62) traverse through OBRI, with river crossings occurring at Jett Bridge, Barnett Bridge, and Adams Bridge (just outside of OBRI's boundaries) (Figure 91).

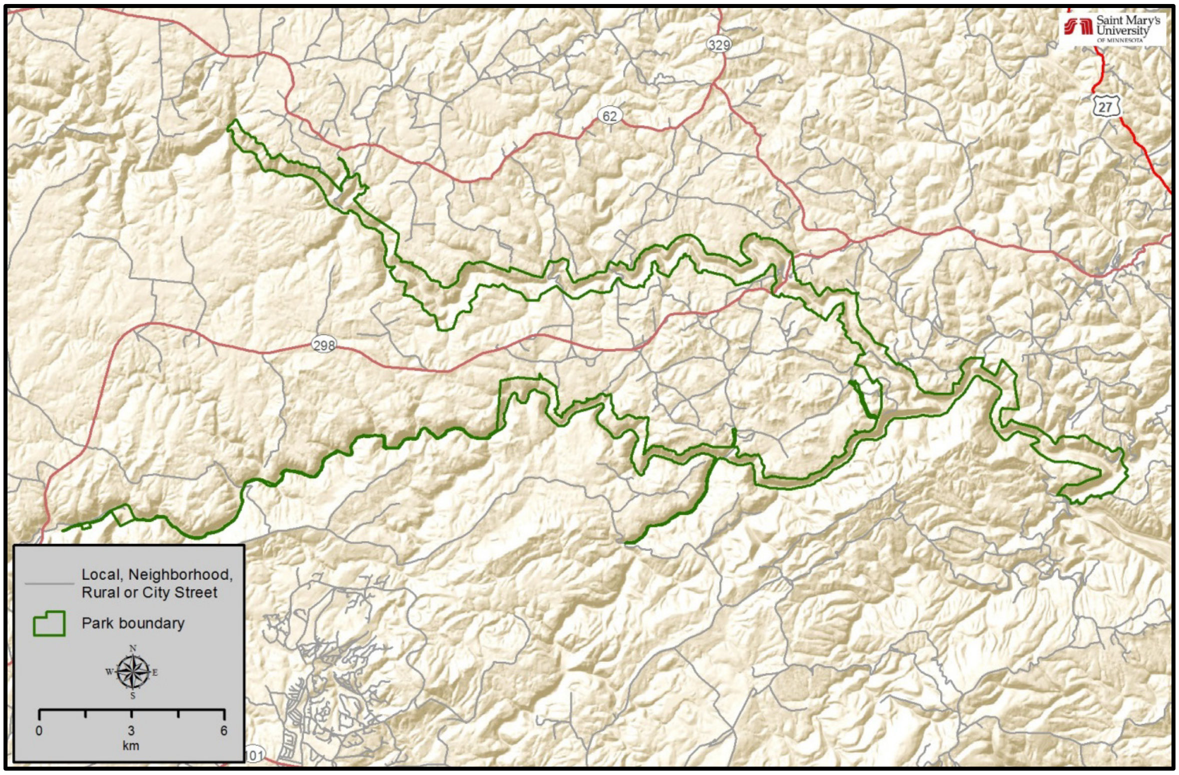

Figure 91. Local and major roads that pass through and nearby OBRI's boundaries. Gray roads indicate rural roads, while roads in a shade of red indicate a major road or highway.

Data Needs/Gaps

At this time, there are no soundscape data for OBRI. Implementing an annual monitoring program of sound levels and sound recordings is essential for the management of the park's soundscape.

Overall Condition

Sound Pressure Levels

The *Significance Level* for this measure was assigned a 3 by the project team. A quiet and serene soundscape is important to park visitors. Studies have shown that people specifically visit parks to get away from everyday noise (NPS 2016b). Loud and unexpected bursts of sound can cause disruption inside parks (NPS 2016b). While modeling appears to indicate moderate noise impacts within the park, a lack of on-the-ground data makes it difficult to accurately understand current condition. Due to the lack of soundscape monitoring inside OBRI at this time, a *Condition Level* cannot be assigned.

Frequency

The *Significance Level* for this measure was also assigned a 3 by the project team. High pitched sounds can cause disruption to wildlife and even bother park visitors (NPS 2016b). Implementing soundscape monitoring inside OBRI can provide information as to where in particular high frequency sounds are disrupting resources in the park. With no monitoring in place, a *Condition Level* cannot be assigned at this time.

Duration of Sounds

A *Significance Level* of 3 was assigned for this measure by the project team. Sound durations can be used to calculate the percent of time human-caused sound is audible and noise-free intervals. Wildlife have had to adapt to the increased occurrence of anthropogenic-sourced sounds (i.e., shorter noise-free intervals) (NPS 2016b). Measurements of sound duration can provide managers with insight into the stress levels human-caused sounds may be causing park wildlife and visitors. Due to the lack of data, a *Condition Level* cannot be assigned at this time.

Weighted Condition Score

The soundscape and acoustic environment was not assigned a *Weighted Condition Score* at this time. To fully understand if the outdoor background noise inside the park is affecting the overall park integrity, soundscape monitoring needs to occur inside OBRI.

Soundscape			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Sound Pressure Levels	3	N/A	
Frequency	3	N/A	
Duration of Sound	3	N/A	

4.11.6. Sources of Expertise

- Randy Stanley, NPS NSNSD Coordinator, Natural Resources Division
- Emma Brown, Acoustical Resource Specialist, NPS NSNSD

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5. Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1. Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform park staff and other concerned parties of the status or overall condition of a key resource component in the park. Data gaps exist for all the resource components assessed in this NRCA. Only landscape dynamics, birds, cobble bars/river scour prairies, and water quality had adequate information available to assign a condition level to all of the identified measures. The remaining components had varying degrees of data needs, ranging from one to all of the identified measures. Table 98 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 98. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Landscape dynamics	➢ No monitoring program in place for oil and gas operations after the initial installation inspection; data on status of the existing oil and gas well are incomplete ➢ Need for more research by the scientific community to better understand the pattern, rates, and ecological effects of urban and exurban sprawl
Native forests/other plant communities	➢ No known monitoring program for invasive pests (HWA and EAB) inside the park ➢ No data available regarding harvesting of plants, legal or illegal, at OBRI ➢ Information on the distribution and total area covered by non-native plants could provide insight into how they may affect the surrounding environment
Mammals	➢ No monitoring in place to keep track of legal harvesting of mammals ➢ No regular monitoring of mammal populations, which could particularly help determine the extent and abundance of black bears
Birds	➢ Annual monitoring needed, such as an expansion of Stedman and Stedman's (2005, 2007) point count efforts ➢ Update of NPS Certified Species List; additional research to document species currently classified as "unconfirmed"
Fish communities	➢ Repeat fish survey to determine if any changes have occurred in species diversity, abundance, or density over the past decade ➢ Collect additional data on age class distribution in order to assess recruitment among OBRI's various fish populations
Cobble bars/river scour prairies	➢ Further research on rare plant populations and threats ➢ Continued monitoring of hydrologic regime and water quality ➢ Revisit EOs without viability information (E or H ranks) to confirm their continued existence and determine current status

Table 98 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Freshwater invertebrates	➢ Quarterly monitoring of water levels, water chemistry, discharge, and macroinvertebrates in all four watersheds associated with the park ➢ Establishment of permanent fixed station sites in order to establish a baseline for long-term freshwater mussel monitoring ➢ Continued mussel surveys to identify trends in mussel abundance, recruitment, and number of species that are surviving in the various stream reaches ➢ Research into the impacts non-native Asian clams may have on native mussel fauna
Water quality	➢ Continued collection of data using the APHN monitoring protocol to allow for comparisons over time in order to identify any changes or trends in water quality parameters ➢ Additional study of the treated wastewater effluent returned to the Obed watershed by the Crossville treatment plant to better understand any potential threats this input may pose
Water quantity	➢ Additional data needed for Clear and Daddy's Creeks to identify any changes in discharge that may be occurring ➢ Closer tracking of the timing and amounts of effluent discharges and their proportion of Obed River flow to help managers better understand any threat this may pose to the river system
Dark night skies	➢ Regular field visits by the NPS NSNSD
Acoustical environment	➢ No data available; annual monitoring of sound levels and sound recordings needed.

Several of the park's data gaps involve the need for new or continued monitoring in order to accumulate data to assess and evaluate the condition and trends over time for some of the resources included in this analysis. This is evident from the high number of measures that could not be assigned a current condition due to either recent data gaps or a lack of regular monitoring over time. Native plant communities would benefit from research on the impacts of various threats, including exotic pests, invasive plant species, and harvesting (legal and illegal). Other components, such as birds, mammals, and freshwater invertebrates, would benefit from more consistent sampling efforts (in terms of timing, sampling sites, and methodology).

5.2. Component Condition Designations

Table 99 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Tables 100 and 101 following Table 99). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 99) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information. Condition could not be determined for two of the 11 components: mammals and acoustic environment. Trends could not be assigned for eight components, due primarily to a lack of either recent park-specific data or consistent monitoring. In some cases, overall trend could not be determined for components because trends varied between measures or across the park (e.g., Daddy's vs. Clear Creek watersheds).

For featured components with available data and fewer information gaps, assigned conditions varied. Only one of the components assessed by this review was considered to be in good condition: fish communities. Five components were of moderate concern (native forests/other plant communities, birds, cobble bars/river scour prairies, water quality, water quantity, and dark night skies), and two components (landscape dynamics and freshwater invertebrates) were considered to be of significant concern. The primary concerns regarding landscape dynamics are with oil and gas wells near the park and potential risks associated with private inholdings within the park boundaries, as the NPS has no influence over land uses on these properties. There have also been increases in total population and housing development in areas upstream of the park, particularly in the Obed River and Daddy's Creek watersheds (USCB 2012, 2016). The highest concerns for freshwater invertebrates are with apparent declines in overall mussel abundance and listed mussel species abundance (purple bean) (Ahlstedt et al. 2001, Dinkins and Faust 2015).

Table 99. Summary of current condition and condition trend for featured NRCA components.

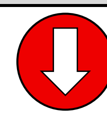
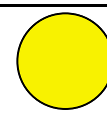
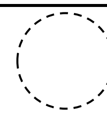
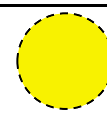
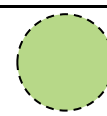
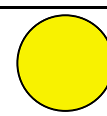
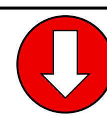
Component	Resource	WCS	Condition
Biological Composition *(Landscape and Ecosystem Processes)*	Landscape dynamics	0.71	
Biological Composition *(Ecological Communities)*	Native forests/other plant communities	0.48	
	Mammals	N/A	
	Birds	0.38	
Biological Composition *(Freshwater Biota)*	Fish communities	0.21	
	Cobble bars/river scour prairies	0.47	
	Freshwater invertebrates	0.75	

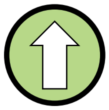
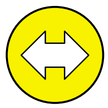
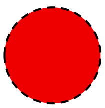
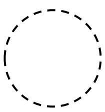
Table 99 (continued). Summary of current condition and condition trend for featured NRCA components.

Component	Resource	WCS	Condition
Environmental Quality	Water quality	0.43	
	Water quantity	0.34	
	Dark night skies	0.40	
Physical Characteristics *(Geologic and Hydrologic)*	Acoustic environment	N/A	

Table 100. Description of symbology used for individual component assessments.

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

Table 101. Examples of how the symbols should be interpreted.

Symbol Example	Verbal Description
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

5.3. Park-wide Condition Observations

5.3.1. Landscape and Ecosystem Processes

The landscape dynamics within and around a park have a direct effect on the condition of its natural resources and the public's perception of those resources (Gross et al. 2009). Much of the land surrounding and upstream of the park is still rural and minimally developed, but several communities have grown in recent decades (e.g., Crossville, Crab Orchard, Fairfield Glade). Increasing upstream development threatens OBRI's water quality and quantity, which would, in turn, put entire aquatic communities at risk. Development can also fragment natural landscapes and increase the likelihood of the introduction and spread of exotic species (Emmott and Murdock 2008, Gross et al. 2009). Oil and gas development is an additional threat to the landscape; with four active wells currently within OBRI's legislative boundaries and 140 wells (active and inactive) within 0.8 km (0.5 mi) of the park (NPS 2011, TDEC 2016).

5.3.2. Ecological Communities

The native forests and other vegetation communities of OBRI are vital resources for the park, providing habitat for wildlife and performing critical ecological functions. The mixed mesophytic forest type found at the park is among the oldest and most complex deciduous forests in the eastern U.S. (Braun 1950). However, there are serious concerns over the threats posed by exotic plants and pests, particularly HWA and EAB. Native plant communities are currently of moderate concern, with additional data needed on the impacts of various threats and stressors.

5.5.3. Freshwater Biota

Some freshwater biota, such as aquatic invertebrate species, are used as indicators of water quality, since they are often sensitive to changes in water quality parameters (Ahlstedt et al. 2001, Cook and Hutton 2009). Fish and invertebrate communities can also provide insight into overall aquatic ecosystem health. Two federally endangered aquatic species are known to occur in OBRI waters: the purple bean (a freshwater mussel) and the spotfin chub (NPS 2015a). The park's fish communities are considered to be in good condition, but confidence in this determination is low, given that data are lacking for density and age class distribution, and some available data for other measures are over 10 years old. Freshwater invertebrates, especially mussels, are of significant concern. The immobility and filter feeding of adult mussels makes them particularly vulnerable to sedimentation, increased turbidity, and water contamination (e.g., oil and chemical spills) (Williams et al. 1993, Ahlstedt and Bakaletz 2006). Cobble bars/river scour prairies are of moderate concern, primarily due to the encroachment of woody species.

5.3.4. Other Biotics

Other biotic components included in the NRCA were mammals and birds. Due to data gaps in two of the three measures (harvest numbers and bear abundance), condition could not be assigned for mammals. Birds were considered to be in moderate condition; however, confidence in this condition assignment is low, and a trend could not be assigned due to lack of park-specific data within the last 10 years.

5.3.5. Environmental Quality

Environmental quality is important in maintaining healthy, functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be affected substantially by air and water quality conditions. Visitor experience may be diminished by the impacts poor environmental quality has on the lands, waters, and viewscapes of the park. Water quality is of moderate concern at OBRI, largely due to elevated nutrient levels and widely fluctuating DO levels. Excess nutrients are contributed by runoff and wastewater effluent releases from upstream communities, and are a particular concern on the Obed River upstream of the Daddy's Creek confluence (Knight et al. 2014, NPS 2015b). Anthropogenic influences on the Obed River have also contributed to increases in SpC and turbidity.

Water *quality* issues can be exacerbated by limited water *quantity*, both of which are of moderate concern at OBRI. When the quantity of surface water decreases, harmful substances become more concentrated in the water. OBRI's ecosystems have adapted to a highly variable hydrological/flow regime, with low flow periods common during the summer and early fall months, and occasional floods and high flows after heavy precipitation events (Emmott et al. 2005). Anthropogenic changes upstream of the park (e.g., impoundments, water withdrawals, effluent discharge) have influenced this regime, generally "evening-out" the variability (i.e., lower peak discharges, higher minimum discharges) (Knight et al. 2014, USGS 2016). Any changes in the amount or timing of stream flow could alter channel morphology and habitats within and along streams (Emmott et al. 2005).

At this time, dark night skies data is limited to Unihedron SQM readings from November 2013, which were taken as part of the "International Dark Sky Park" application process (Hudson 2014). Despite this limited data, dark night skies have been assigned moderate concern, based on NPS NSNSD recommended condition levels for modeled ALR values (Moore et al. 2013). Since there are no artificial lights on park property, due to its Wild and Scenic River designation, all light pollution/trespass comes from sources outside the park and beyond NPS control (Hudson 2014).

5.3.6. Physical Characteristics

Only one physical resource was selected as a component for this NRCA: the acoustic/soundscape environment. The character and quality of the soundscape influence human perceptions of an area, providing a sense of place that differentiates from other places (NPS 2014). Because no acoustic data are available for OBRI, a condition could not be determined for this resource. However, it is likely that traffic noise disrupts the natural soundscape where roads pass through the park.

5.3.7. Park-wide Threats and Stressors

Several threats and stressors influence the condition of multiple resources within OBRI. These include oil and gas development in the area, upstream development, exotic plants and pests, and climate change. Mineral extraction has long been a part of the economy in the region around OBRI (BLM 2008, NPS 2015b). In 2005, Morgan County (where the majority of the park is located) was second in the state in production for both oil and gas (BLM 2008). The impacts from oil and gas drilling activities can have wide-ranging effects on several of the park's natural resources, from air and water quality (which influence aquatic communities) to soundscape and dark night skies. In 2002, an oil well fire and explosion occurred adjacent to the park in the Clear Creek watershed (Emmott et al. 2005, Trustees 2008). The associated oil spill contaminated approximately 0.3 km (0.2 mi) of White Creek and at least 3.2 km (2 mi) of Clear Creek in the area of Barnett Bridge (Trustees 2008). As of 2014, a portion of Clear Creek was still classified as "impaired" by the TDEC as a result of the spill (TDEC 2014).

Increased water use at upstream developments, along with wastewater effluent discharge and polluted runoff, threaten the natural flow regime and water quality of the park's watersheds. The water supply needs of Cumberland County are expected to grow, exceeding 10 Mgal/d by 2020, which will likely increase demand for withdrawals from the Obed River (USACE 1998, Knight et al. 2014). Approximately half of the water withdrawn by the City of Crossville (from both the Obed River and Caney Fork watersheds) is returned to the Obed watershed as effluent from the Crossville wastewater treatment plant (Knight et al. 2014). These releases may be impacting the natural timing of high and low flows on the Obed River. In addition, although the effluent has been treated, it may still contain contaminants from human use.

Invasive plants are considered a major threat to the ecological health of the park, due to their ability to outcompete and eventually replace native species (Emmott et al. 2005, Nordman 2010). One of the species that poses a severe threat at OBRI is the aquatic plant hydrilla, which can quickly develop extensive growths that threaten the park's unique aquatic macroinvertebrate and fish communities (Jacono et al. 2015). Other severe threat species included the Autumn olive, Chinese lespedeza, Japanese honeysuckle, Japanese stiltgrass, princess tree, and multiflora rose (Wofford et al. 2008, TN-IPC 2009). Exotic pests and diseases, such as HWA and EAB, have the potential to alter forest composition and structure, which could impact wildlife habitats (APHIS 2009, Protect TN Forests 2013).

Global climate change is projected to increase temperatures across the southeast over the next century (Carter et al. 2014), and will likely cause precipitation events to become less frequent but more intense, with longer dry periods between rain events (Bates et al. 2008). These changes could impact OBRI's ecological systems by disrupting soil-water relationships, plant-soil processes, and nutrient cycling (Emmott et al. 2005). Changes in climate could also make the area less suitable for certain plant species and more suitable for others, including exotic species, which could drastically alter plant community composition (Fisichelli 2015).

5.3.8. Overall Conclusions

OBRI was established primarily to protect a diverse river system, which provides habitat for a variety of rare and unique species (e.g., mussels, fish, endemic plants). The park also includes spectacular geological features and valuable native forests, offering habitat for terrestrial wildlife. This assessment serves as a review and summary of available data and literature for featured natural resources within the park. For resources where condition could be assessed, the majority warranted moderate concern, with two components of significant concern (landscape dynamics and freshwater invertebrates). Additional or more consistent monitoring is needed to identify any trends in condition for most of these resources. Through the understanding of the condition of these resources and data needs, park resource managers can prioritize management and research objectives to better focus conservation strategies in order to maintain the health and integrity of park ecosystems.

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Appendix A. Change in area for the generalized cover types based on the 2001, 2006, and 2010 NLCD (Homer et al. 2007, Fry et al. 2011, Homer et al. 2015). All values are in hectares.

	2001		2006		2011	
Cover Category	**Total Area**	**Percent of AOA**	**Total Area**	**Percent of AOA**	**Total Area**	**Percent of AOA**
Converted	45,496	20.22%	45,748	20.33%	45,856	20.38%
Natural	179,540	79.78%	179,287	79.67%	179,180	79.62%
Total	**225,035**	**100%**	**225,035**	**100%**	**225,035**	**100%**

Appendix B. Change in land cover types from the 2001, 2006, and 2011 NLCD for the OBRI AOA (Homer et al. 2007, Fry et al. 2011, Homer et al. 2015). Results were calculated using NPScape tools. All area values are in hectares.

	2001		2006		2011	
Cover Type	**Total Area**	**Percent of AOA**	**Total Area**	**Percent of AOA**	**Total Area**	**Percent of AOA**
Agriculture	*24,486*	*10.88%*	*24,115*	*10.72%*	*2,3910*	*10.62%*
Cultivated crop	297	0.13%	332	0.15%	331	0.15%
Hay/pasture	2,4189	10.75%	23,783	10.57%	2,3579	10.48%
Developed	*21,009*	*9.34%*	*21,633*	*9.61%*	*21,946*	*9.75%*
Low intensity developed	5,153	2.29%	5,336	2.37%	5,360	2.38%
Medium intensity developed	1,546	0.69%	1,671	0.74%	1,760	0.78%
High intensity developed	423	0.19%	485	0.22%	525	0.23%
Open space developed	13,887	6.17%	14,141	6.28%	14,301	6.36%
Natural	*179,539*	*79.78%*	*179,287*	*79.67%*	*179,180*	*79.62%*
Open water	2,082	0.93%	2,071	0.92%	2,037	0.91%
Emergent herbaceous wetland	3	> 0.01%	7	> 0.01%	40	0.02%
Woody wetland	487	0.22%	481	0.21%	481	0.21%
Herbaceous/grassland	20,744	9.22%	22,722	10.10%	21,260	9.45%
Shrub/scrub	96	0.04%	1,195	0.53%	2,891	1.28%
Deciduous forest	116,616	51.82%	114,229	50.76%	112,855	50.15%
Mixed forest	32,994	14.66%	32,249	14.33%	31,895	14.17%
Evergreen forest	4,916	2.18%	5,104	2.27%	6,539	2.91%
Barren land	1,601	0.71%	1,229	0.55%	1,183	0.53%
Total	**225,035**	**100%**	**2,250.35**	**100%**	**225,035**	**100%**

Appendix C. List of non-native and invasive flora found in OBRI, according to Nordman (2010) and the NPS (2015).

Scientific Name	Common Name	Nordman (2010)	NPSpecies list (2015)
Achillea millefolium	common yarrow	X	X
Ailanthus altissima	tree of heaven	–	X
Albizia julibrissin	mimosa	X	X
Allium sativum	cultivated garlic	–	X
Alnus glutinosa	European alder	–	X
Anthoxanthum odoratum	sweet vernalgrass	X	X
Asparagus officinalis	garden asparagus	X	–
Barbarea vulgaris	garden yellow rocket	X	X
Berberis thunbergii	Japanese barberry	–	X
Brassica napus	rape	–	X
Bromus commutatus	meadow brome	–	X
Bromus tectorum	cheatgrass	–	X
Cardamine hirsuta	hairy bittercress	–	X
Cerastium glomeratum	sticky chickweed	–	X
Clematis terniflora	sweet autumn virginsbower	–	X
Dactylis glomerata	orchardgrass	–	X
Daucus carota	Queen Anne's lace	X	X
Dianthus armeria	Deptford pink	X	X
Digitaria ischaemum	smooth crabgrass	–	X
Dioscorea oppositifolia	Chinese yam	–	X
Draba verna	spring draba	–	–
Duchesnea indica	Indian strawberry	X	–
Echinochloa muricata	rough barnyard grass	–	X
Elaeagnus umbellata var. *parvifolia*	autumn olive	X	X
Eleusine indica	Indian goosegrass	–	X
Fallopia scandens	climbing false buckwheat	–	X
Geranium carolinianum	Carolina crane's-bill	–	X
Holcus lanatus	common velvetgrass	–	X
Hydrilla verticillata	hydrilla	–	X
Ipomoea coccinea	redstar	–	X
Ipomoea hederacea	ivyleaf morning-glory	–	X
Kummerowia striata	Japanese clover	–	X
Lamium purpureum	purple deadnettle	–	X
Lathyrus latifolius	perennial pea	–	X
Lespedeza bicolor	shrubby lespedeza	X	X
Lespedeza cuneata	Chinese lespedeza	X	X

Scientific Name	Common Name	Nordman (2010)	NPSpecies list (2015)
Leucanthemum vulgare	oxeye daisy	–	X
Ligustrum vulgare	European privet	–	X
Linaria vulgaris	butter and eggs	–	X
Lolium multiflorum	Italian ryegrass	–	X
Lonicera japonica	Japanese honeysuckle	X	X
Luzula multiflora	common woodrush	–	X
Medicago lupulina	black medick	X	–
Melilotus officinalis	yellow sweetclover	–	X
Microstegium vimineum	Japanese stiltgrass	X	X
Paulownia tomentosa	princess tree	–	X
Persicaria longiseta	oriental lady's thumb	X	–
Phleum pratense	timothy	X	X
Plantago lanceolata	narrowleaf plantain	X	X
Poa annua	annual bluegrass	–	X
Poa pratensis	Kentucky bluegrass	–	X
Rosa multiflora	multiflora rose	X	X
Rumex acetosella	common sheep sorrel	–	X
Saponaria officinalis	bouncing bet	–	X
Schedonorus pratensis	meadow ryegrass	X	X
Setaria faberi	Japanese bristlegrass	–	X
Setaria viridis	green bristle grass	–	X
Sonchus asper	spiny sowthistle	X	X
Sorghum halepense	Johnsongrass	–	X
Spiraea japonica	Japanese meadowsweet	X	X
Spiraea prunifolia	bridalwreath spirea	–	X
Stellaria media	common chickweed	X	X
Taraxacum officinale	common dandelion	–	X
Trifolium campestre	field clover	–	X
Trifolium pratense	red clover	X	X
Trifolium repens	white clover	X	–
Triticum aestivum	common wheat	–	X
Verbascum blattaria	moth mullein	X	X
Verbascum thapsus	common mullein	–	X
Veronica hederifolia	iveleaf speedwell	X	–
Veronica officinalis	common gypsyweed	–	X
Veronica serpyllifolia	thymeleaf speedwell	–	X
Xanthium strumarium	Canada cocklebur	–	X

Appendix D. Ozone-sensitive plant species identified in OBRI according to Kohut (2007) and the NPSpecies list (NPS 2015).

Scientific Name	Common Name	Kohut (2007)	NPSpecies (2015)	Native	Occurrence	Biological Indicator
Ailanthus altissima	tree-of-heaven	X	X	No	Present	Yes
Asclepias exaltata	poke milkweed	X	X	Yes	Present	Yes
Asclepias syriaca	common milkweed	X	–	Yes	Unconfirmed	Yes
Cercis canadensis	redbud	X	X	Yes	Present	Yes
Clematis virginiana	devil's daring needles	–	X	Yes	Present	No
Doellingeria umbellata	flat-topped aster	X	–	Yes	Present	No
Fraxinus americana	white ash	X	X	Yes	Present	Yes
Fraxinus pennsylvanica	green ash	X	–	Yes	Unconfirmed	No
Liquidambar styraciflua	sweetgum	X	X	Yes	Present	No
Liriodendron tulipifera	tuliptree	X	X	Yes	Present	Yes
Lyonia ligustrina	he-huckleberry	–	X	Yes	Present	Yes
Parthenocissus quinquefolia	Virginia creeper	X	X	Yes	Present	No
Pinus taeda	loblolly pine	X	X	Yes	Present	No
Pinus virginiana	Virginia pine	X	X	Yes	Present	No
Platanus occidentalis	American sycamore	X	X	Yes	Present	Yes
Prunus serotina	black cherry	X	–	Yes	Present	Yes
Robinia pseudoacacia	black locust	X	X	Yes	Present	No
Rubus allegheniensis	Allegheny blackberry	X	X	Yes	Present	Yes
Rudbeckia laciniata	cut-leaf coneflower	X	X	Yes	Present	Yes
Sambucus nigra ssp. *canadensis*	American elder	X	X	Yes	Present	Yes
Sassafras albidum	sassafras	X	X	Yes	Present	No
Verbesina occidentalis	crownbeard	X	X	Yes	Present	Yes
Vitis labrusca	northern fox grape	X	X	Yes	Present	Yes

Appendix E. Potential change in habitat suitability by 2100 for select forest species at OBRI due to climate change, according to Fisichelli (2015) Change categories are a decrease in habitat, increase in habitat, new potential habitat (e.g., species not currently found in OBRI), or no change**.**

Potential Habitat Change	Scientific Name	Common Name
Decreases in Potential Habitat	*Acer rubrum*	red maple
	Acer saccharum	sugar maple
	Amelanchier spp.	serviceberry
	Betula lenta	sweet birch
	Fagus grandifolia	American birch
	Fraxinus americana	white ash
	Juglans nigra	black walnut
	Liriodendron tulipifera	tuliptree
	Magnolia acuminata	cucumbertree
	Pinus strobus	white pine
	Quercus coccinea	scarlet oak
	Quercus michauxii	chestnut oak
	Robinia pseudoacacia	black locust
No Change in Potential Habitat	*Aesculus flava*	yellow buckeye
	Carya ovata	shagbark hickory
	Prunus serotina	black cherry
	Tsuga canadensis	eastern hemlock
Increases in Potential Habitat	*Carya tomentosa*	mockernut hickory
	Celtis laevigata	sugarberry
	Celtis occidentalis	hackberry
	Diospyros virginiana	common persimmon
	Ilex opaca	American holly
	Liquidambar styraciflua	sweetgum
	Ostrya virginiana	eastern hophornbeam
	Pinus echinata	shortleaf pine
	Pinus taeda	loblolly pine
	Plantanus occidentalis	American sycamore
	Quercus falcata	southern red oak
	Quercus marilandica	blackjack oak
	Quercus stellata	post oak
	Quercus velutina	black oak
	Ulmus alata	winged elm
	Ulmus americana	American elm
	Ulmus rubra	slippery elm
New Potential Habitat	*Carya texana*	black hickory
	Pinus elliottii	slash pine
	Pinus glabra	spruce pine

Potential Habitat Change	Scientific Name	Common Name
New Potential Habitat (continued)	*Pinus palustris*	longleaf pine
	Quercus laurifolia	laurel oak
	Quercus macrocarpa	bur oak
	Quercus nigra	water oak
	Quercus texana	Nuttall's oak
	Ulmus crassifolia	cedar elm

Appendix F. Mammal species present or probably present at OBRI according to the NPS Certified Mammals Species List (NPS 2015a) and Taylor et al. (1981).

Scientific Name	Common Name	NPS (2015a)	Taylor et al. (1981)
Blarina brevicauda	northern short-tailed shrew	Present	–
Canis familiaris	domestic dog	Probably present	–
Canis latrans	coyote	Probably present	–
Castor canadensis	American beaver	Present	X
Corynorhinus rafinesquii	eastern big-eared bat	Present	–
Cryptotis parva	least shrew	Present	–
Dasypus novemcinctus	long-nosed armadillo	Probably present	–
Didelphis virginiana	Virginia opossum	Present	X
Eptesicus fuscus	big brown bat	Present	–
Felis catus	domestic cat	Probably present	–
Glaucomys volans	southern flying squirrel	Present	X
Lasionycteris noctivagans	silver-haired bat	Probably present	–
Lasiurus borealis	eastern red bat	Present	X
Lasiurus cinereus	hoary bat	Present	–
Lontra canadensis	river otter	Probably present	–
Lynx rufus	bobcat	Present	X
Marmota monax	woodchuck	Probably present	X
Martes pennanti	fisher	Probably present	–
Mephitis mephitis	striped skunk	Probably present	X
Microtus pennsylvanicus	meadow vole	Probably present	X
Microtus pinetorum	woodland vole	Probably present	–
Mus musculus	house mouse	Unconfirmed	–
Mustela frenata	long-tailed weasel	Probably present	X
Myotis grisescens	gray myotis	Present	–
Myotis leibii	eastern small-footed bat	Present	–
Myotis lucifugus	little brown myotis	Present	–
Myotis septentrionalis	northern long-eared bat	Present	–
Myotis sodalis	Indiana bat	Unconfirmed	–
Napaeozapus insignis	woodland jumping mouse	Probably present	–
Neotoma magister	Allegheny woodrat	Present	–
Neovison vison	mink	Present	X
Nycticeius humeralis	evening bat	Probably present	–
Ochrotomys nuttalli	golden mouse	Present	X
Odocoileus virginianus	white-tailed deer	Present	X
Ondatra zibethicus	muskrat	Present	–
Parascalops breweri	Brewer's mole	Unconfirmed	–

Scientific Name	Common Name	NPS (2015a)	Taylor et al. (1981)
Peromyscus gossypinus	cotton mouse	Present	X
Peromyscus leucopus	white-footed mouse	Present	X
Peromyscus maniculatus	deer mouse	Unconfirmed	X
Pipistrellus subflavus subflavus	eastern pipistrelle	Present	–
Procyon lotor	common raccoon	Present	X
Rattus norvegicus	Norway rat	Unconfirmed	–
Reithrodontomys humulis	eastern harvest mouse	Unconfirmed	–
Scalopus aquaticus	eastern mole	Present	X
Sciurus carolinensis	eastern gray squirrel	Present	X
Sciurus niger	eastern fox squirrel	Probably present	X
Sigmodon hispidus	hispid cotton rat	Unconfirmed	–
Sorex cinereus	masked shrew	Probably present	X
Sorex fumeus	smoky shrew	Present	–
Sorex hoyi	American pygmy shrew	Presents	–
Sorex longirostris	southeastern shrew	Present	X
Spilogale putorius	eastern spotted skunk	Probably present	X
Sus scrofa	feral hog	Probably present	X
Sylvilagus floridanus	eastern cottontail rabbit	Present	X
Tamias striatus	eastern chipmunk	Present	X
Urocyon cinereoargenteus	gray fox	Present	X
Vulpes vulpes	red fox	Probably present	X

Appendix G. Fish species present within OBRI (Russ 2006, Scott 2010a), along with abundance, nativeness, and status (resident vs. breeder) (NPS 2015a).

Family	Scientific Name	Common Name	Abundance	Nativeness	Status
Family Clupeidae	*Dorosoma cepedianum*	gizzard shad	Uncommon	Native	Breeder
Family Catostomidae	*Hypentelium nigricans*	northern hog sucker	Common	Native	Breeder
	Ictiobus bubalus	smallmouth buffalo	Occasional	Native	Breeder
	Ictiobus niger	black buffalo	–	Native	–
	Minytrema melanops	spotted sucker	Occasional	Native	–
	Moxostoma duquesnii	black redhorse	Occasional	Native	Breeder
	Moxostoma erythrurum	golden redhorse	Common	Native	Breeder
Family Cyprinidae	*Campostoma oligolepis*	largescale stoneroller	Abundant	Native	Resident
	Ctenopharyngodon idella	grass carp	–	Non-native	–
	Cyprinella galactura	whitetail shiner	Abundant	Native	Breeder
	Cyprinella spiloptera	spotfin shiner	Rare	Native	Breeder
	Cyprinus carpio	common carp	–	Non-native	–
	*Erimonax monachus**	spotfin chub	Common	Native	Resident
	Hybopsis amblops	bigeye chub	Unknown	Unknown	–
	Luxilus chrysocephalus	striped shiner	Rare	Non-native	Breeder
	Luxilus coccogenis	warpaint shiner	Abundant	Native	Breeder
	Lythrurus fasciolaris	scarlet shiner	Rare	Native	Breeder
	Nocomis micropogon	river chub	Common	Native	Breeder
	Notemigonus crysoleucas	golden shiner	Rare	Non-native	–
	Notropis leuciodus	Tennessee shiner	Abundant	Native	Breeder
	Notropis micropteryx	highland shiner	–	Native	–
	Notropis photogenis	silver shiner	Occasional	Native	Breeder
	Notropis stramineus	sand shiner	Rare	Native	Breeder
	Notropis telescopus	telescope shiner	Abundant	Native	Breeder
	Notropis volucellus	mimic shiner	Common	Native	Breeder
	Rhinichthys atratulus	blacknose dace	Common	Native	Breeder
	Semotilus atromaculatus	creek chub	Common	Native	Breeder
Family Esocidae	*Esox masquinongy ohioensis*	muskellunge	Rare	Native	Resident
Family Centrarchidae	*Ambloplites rupestris*	rock bass	Common	Native	Breeder
	Lepomis auritus	redbreast sunfish	Common	Non-native	Breeder
	Lepomis cyanellus	green sunfish	Common	Native	Breeder
	Lepomis macrochirus	bluegill	Common	Native	Breeder
	Lepomis megalotis	longear sunfish	Common	Native	Breeder
	Lepomis microlophus	redear sunfish	Occasional	Native	–
	Micropterus coosae	redeye bass	Common	Non-native	Breeder

*Management priority species

Family	Scientific Name	Common Name	Abundance	Nativeness	Status
Family Centrarchidae (continued)	*Micropterus dolomieu*	smallmouth bass	Common	Native	Breeder
	Micropterus punctulatus	spotted bass	Uncommon	Native	Breeder
	Micropterus salmoides	largemouth bass	Uncommon	Native	Breeder
Family Percidae	*Etheostoma blennioides*	greenside darter	Abundant	Native	Breeder
	Etheostoma camurum	bluebreast darter	Common	Native	Breeder
	*Etheostoma cinereum**	ashy darter	Rare	Native	Breeder
	Etheostoma rufilineatum	redline darter	Abundant	Native	Breeder
	Etheostoma simoterum	snubnose darter	Uncommon	Native	Breeder
	Etheostoma vulneratum	wounded darter	Common	Native	Breeder
	Percina aurantiaca	tangerine darter	Abundant	Native	Breeder
	Percina caprodes	logperch	Uncommon	Native	Breeder
	Percina evides	gilt darter	Unknown	Native	Breeder
	Percina squamata	olive darter	Rare	Native	Breeder
Family Sciaenidae	*Aplodinotus grunniens*	freshwater drum	Common	Native	Breeder
Family Lepisosteidae	*Lepisosteus osseus*	longnose gar	Uncommon	Native	Breeder
Family Ictaluridae	*Ameiurus melas*	black bullhead	Occasional	Native	Breeder
	Ameiurus natalis	yellow bullhead	Rare	Native	Breeder
	Ameiurus nebulosus	brown bullhead	–	Native	–
	Ictalurus punctatus	channel catfish	Common	Native	Breeder
	Pylodictis olivaris	flathead catfish	Common	Native	Breeder

* Management priority species

Appendix H. Fish species diversity and abundance by watershed within OBRI during 2004–2006 sampling (Russ 2006). Numbers in parentheses indicate the number of 200 m sampling transects within OBRI in each watershed.

Scientific Name	Common Name	Clear Creek (5)	Daddy's Creek (2)	Obed River (5)	Emory River (1)
Ambloplites rupestris	rock bass	66	44	37	10
Ameiurus melas	black bullhead	1	–	–	–
Ameiurus natalis	yellow bullhead	1	1	–	–
Aplodinotus grunniens	freshwater drum	–	–	1	1
Campostoma oligolepis	largescale stoneroller	353	10	111	53
Cyprinealla galactura	whitetail shiner	198	80	156	2
Cyprinella spiloptera	spotfin shiner	10	18	57	1
Dorosoma cepedianum	gizzard shad	–	–	1	10
Erimonax monachus	spotfin chub	3	3	25	3
Etheostoma blennioide	greenside darter	66	6	59	26
Etheostoma camurum	bluebreast darter	–	–	15	–
Etheostoma cinereum	ashy darter	–	–	–	1
Etheostoma rufilineatum	redline darter	156	11	98	26
Etheostoma simoterum	snubnose darter	–	–	3	2
Etheostoma vulneratum	wounded darter	–	4	7	–
Hypentelium nigricans	northern hog sucker	13	2	12	3
Lepisosteus osseus	longnose gar	–	–	1	1
*Lepomis auritus**	redbreast sunfish	37	3	92	2
Lepomis cyanellus	green sunfish	5	8	36	–
Lepomis macrochirus	bluegill	8	1	6	5
Lepomis megalotis	longear sunfish	7	–	2	3
*Lepomis microlophus**	redear sunfish	–	–	1	–
Luxilus chrysocephalus	striped shiner	–	–	–	2
Luxilus coccogenis	warpaint shiner	257	11	38	16
Lythrurus fasciolaris	scarlet shiner	28	–	–	–
Micropterus dolomieu	smallmouth bass	33	18	20	2
Micropterus punctulatus	spotted bass	–	–	–	1
Micropterus salmoides	largemouth bass	–	–	1	–
Moxostoma spp.	redhorse	1	–	1	–
Nocomis micropogon	river chub	92	19	42	7
*Notemigonus crysoleucas**	golden shiner	1	–	–	–
Notropis leuciodus	Tennessee shiner	–	33	350	151
Notropis photogenis	silver shiner	–	–	2	–

* Non-native

Scientific Name	Common Name	Clear Creek (5)	Daddy's Creek (2)	Obed River (5)	Emory River (1)
Notropis stramineus	sand shiner	–	–	5	–
Notropis telescopus	telescope shiner	210	54	379	43
Notropis volucellus	mimic shiner	–	–	49	2
Percina aurantiaca	tangerine darter	45	8	13	5
Percina caprodes	logperch	–	–	–	3
Percina evides	gilt darter	–	–	–	1
Percina squamata	olive darter	2	–	1	1
Pylodictis olivaris	flathead catfish	4	–	1	2
Total Species		**24**	**19**	**32**	**29**
Total Fish		**1,597**	**334**	**1,622**	**385**
Density (per m)		**1.60**	**0.84**	**1.62**	**1.93**

* Non-native

Appendix I. Fish species diversity and abundance by watershed within OBRI during 2004–2006 sampling (Scott 2010b). Numbers in parentheses indicate the number of sampling sites in each watershed.

Scientific Name	Common Name	Clear Creek (2)	Daddy's Creek (1)	Obed River (10)	Emory River (5)
Ambloplites rupestris	rock bass	6	18	67	20
Ameiurus natalis	yellow bullhead	1	1	4	–
Aplodinotus grunniens	freshwater drum	–	–	50	–
Campostoma oligolepis	largescale stoneroller	169	10	454	155
Cyprinealla galactura	whitetail shiner	111	68	951	90
Cyprinella spiloptera	spotfin shiner	–	–	3	1
Dorosoma cepedianum	gizzard shad	–	–	10	1
Erimonax monachus	spotfin chub	–	–	35	15
Esox masquinongy ohioensis	muskellunge	–	–	–	5
Etheostoma blennioide	greenside darter	17	3	85	44
Etheostoma camurum	bluebreast darter	–	–	25	6
Etheostoma rufilineatum	redline darter	56	14	123	59
Etheostoma simoterum	snubnose darter	–	–	4	5
Etheostoma vulneratum	wounded darter	–	–	8	1
Hybopsis amblops	bigeye chub	–	–	–	1
Hypentelium nigricans	northern hog sucker	4	–	51	15
Ictalurus punctatus	channel catfish	–	–	–	12
Ictiobus bubalus	smallmouth buffalo	–	–	20	–
Ictiobus niger	black bullhead	1	–	–	–
Lepisosteus osseus	longnose gar	–	–	20	–
Lepomis auritus[A]	redbreast sunfish	17	2	41	14
Lepomis cyanellus	green sunfish	4	8	45	–
Lepomis macrochirus	bluegill	6	–	8	–
Lepomis megalotis	longear sunfish	–	–	18	2
Lepomis microlophus[A]	redear sunfish	–	–	1	–
Luxilus chrysocephalus[A]	striped shiner	–	–	3	12
Luxilus coccogenis	warpaint shiner	137	4	170	68
Lythrurus fasciolaris	scarlet shiner	11	–	–	1
Micropterus coosae[A]	redeye bass	–	–	16	–

[A] Non-native.

[B] Species was observed during snorkeling survey but individuals were not counted.

Scientific Name	Common Name	Clear Creek (2)	Daddy's Creek (1)	Obed River (10)	Emory River (5)
Micropterus dolomieu	smallmouth bass	9	5	116	17
Micropterus punctulatus	spotted bass	–	–	1	–
Micropterus salmoides	largemouth bass	–	–	4	–
Moxostoma duquesnii	black redhorse	–	–	–	1
Moxostoma erythrurum	golden redhorse	–	–	25	3
Nocomis micropogon	river chub	1	16	30	11
Notropis leuciodus	Tennessee shiner	–	–	366	235
Notropis micropteryx	highland shiner	–	–	1	1
Notropis photogenis	silver shiner	–	–	3	–
Notropis stramineus	sand shiner	–	–	5	3
Notropis telescopus	telescope shiner	96	–	566	426
Notropis volucellus	mimic shiner	–	–	109	5
Perca flavescens	yellow perch	–	–	–[B]	–
Percina aurantiaca	tangerine darter	11	5	135	28
Percina caprodes	logperch	–	–	–	3
Percina squamata	olive darter	–	–	1	1
Pylodictis olivaris	flathead catfish	–	–	2	1
Rhinichthys atratulus	blacknose dace	15	–	–	–
Semotilus atromaculatus	creek chub	–	–	2	–
Total Species		**18**	**13**	**40**	**34**
Total Fish		**672**	**158**	**3,579**	**1,262**

[A] Non-native.

[B] Species was observed during snorkeling survey but individuals were not counted.

Appendix J. Plant species of concern documented on OBRI cobble bars (reproduced from Murdock et al. [2013]). “aff.” = affinis, meaning a plant is similar or has an affinity to the species given but is not identical to it.

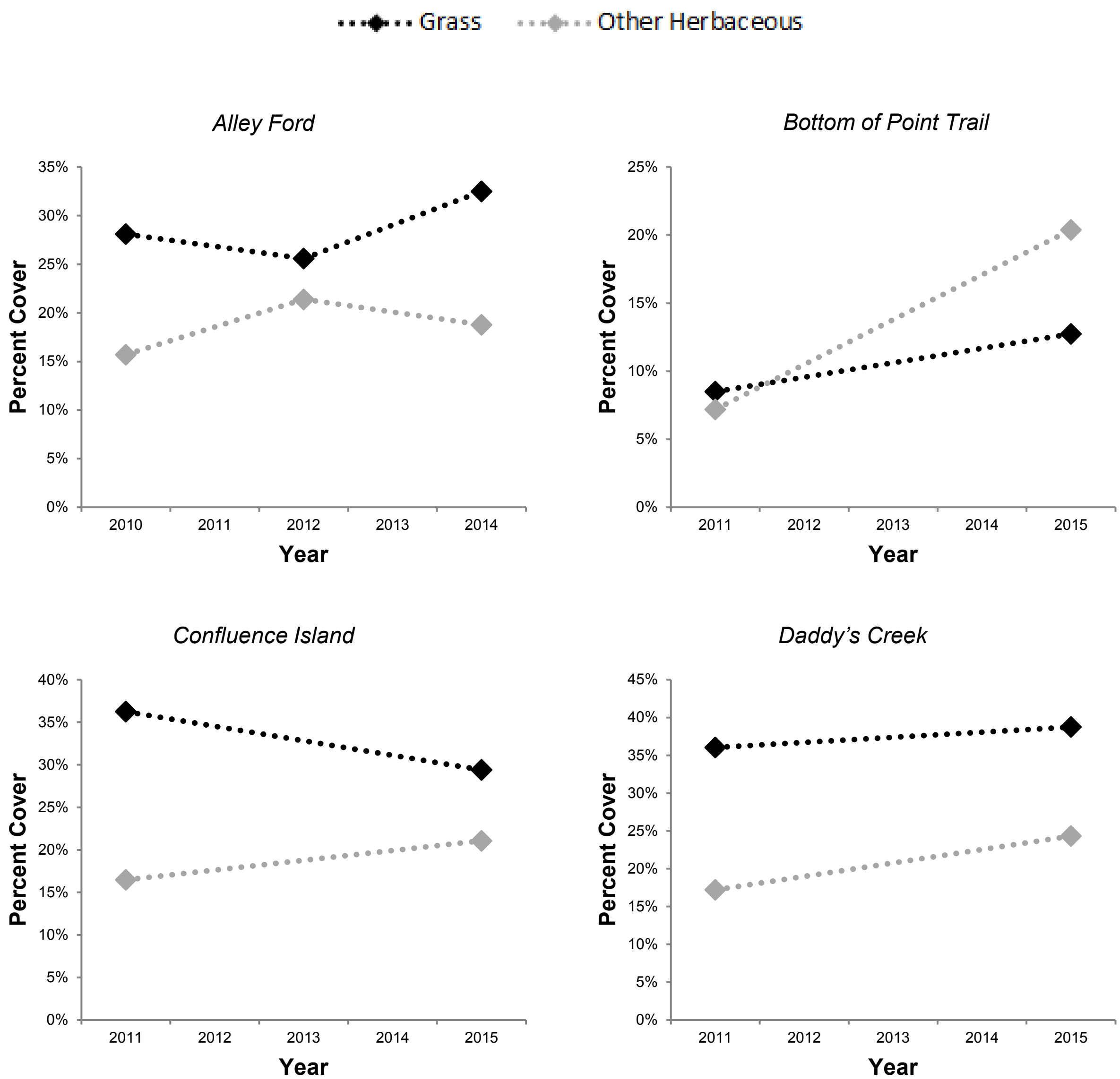
Scientific Name	Common Name	Special Status	Notes
Amelanchier sanguinea	roundleaf serviceberry	state threatened	–
Berberis canadensis	American barberry	state special concern	–
Calamovilfa arcuata	Cumberland sandreed	state endangered, considered for federal listing	–
Clematis aff. *reticulata*	–	–	Potential new species, found by Wofford et al. (2008) in 2008
Conradina verticillata	Cumberland rosemary	state endangered, federally threatened	–
Danthonia sericea	Carolina oatgrass	state special concern	–
Helenium brevifolium	shortleaf sneezeweed	state endangered	–
Helianthus aff. *eggertii*	–	–	A sunflower mistakenly documented previously as *H. eggertii*; taxonomic status needs to be determined, but it could be an undescribed species endemic to the Cumberland Plateau*
Hieracium scabrum	rough hawkweed	state threatened	–
Eubotrys racemosa	swamp doghobble	state threatened	–
Marshallia grandiflora	Monongahela Barbara’s buttons	state endangered, considered for federal listing	–
Oenothera perennis	little evening primrose	–	Possibly on cobble bars
Polygonella americana	southern jointweed	state threatened	–
Rhynchosia tomentosa	twining snoutbean	–	Cobble bar form may be an undescribed taxon*
Solidago arenicola	southern racemose goldenrod	state threatened	–
Spiraea virginiana	Virginia spiraea	state endangered, federally threatened	More on boulder bars, but possibly on cobble bars
Sporobolus junceus	pineywoods dropseed	state special concern	–
Symphyotrichum aff. *dumosum*	–	–	Possible new species of aster*
Thalictrum coriaceum	maid of the mist	state threatened	–
Thyrsanthella difformis	climbing dogbane	–	OBRI is the only location on the Cumberland Plateau in TN*

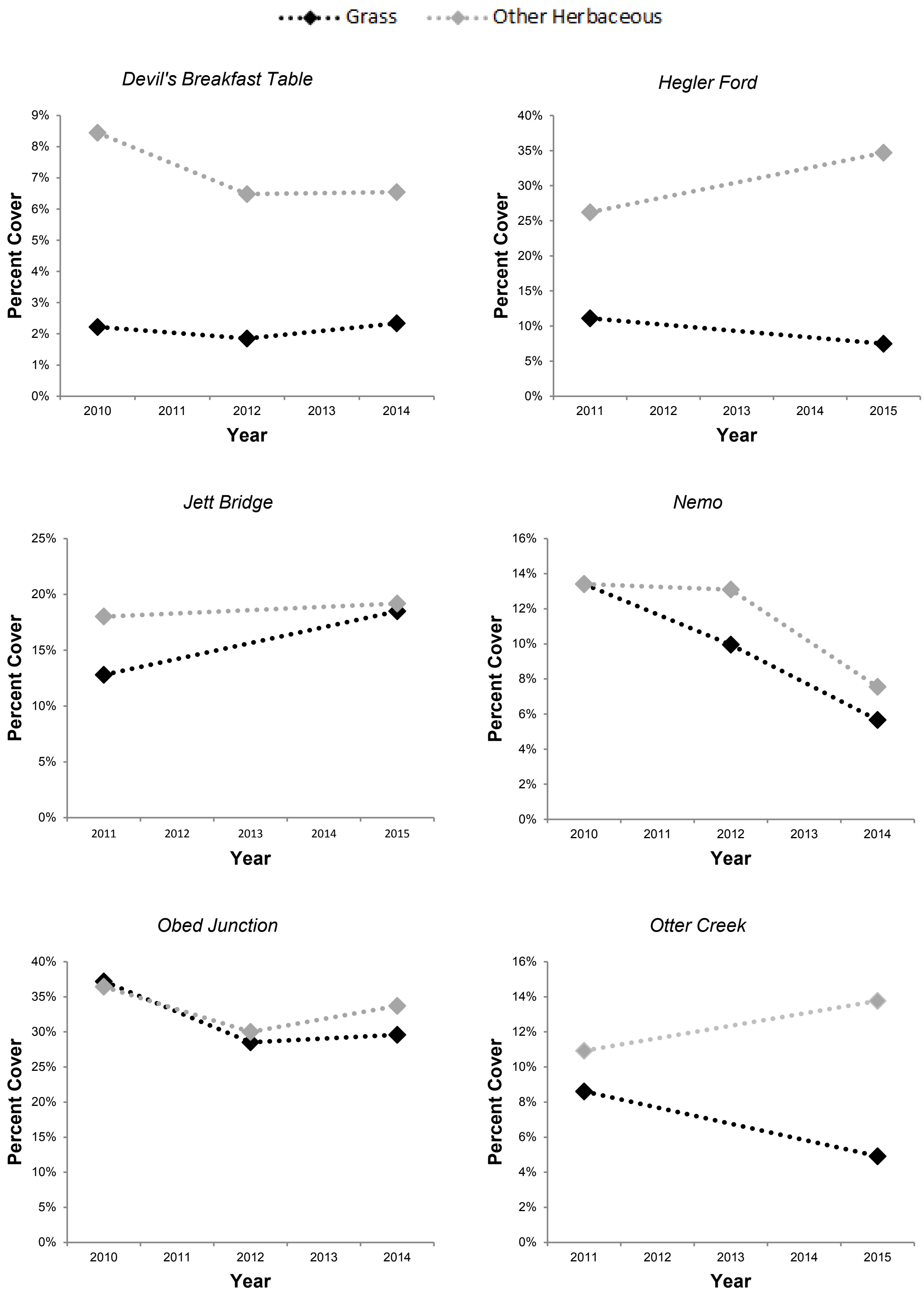
* According to Wofford et al. (2008).

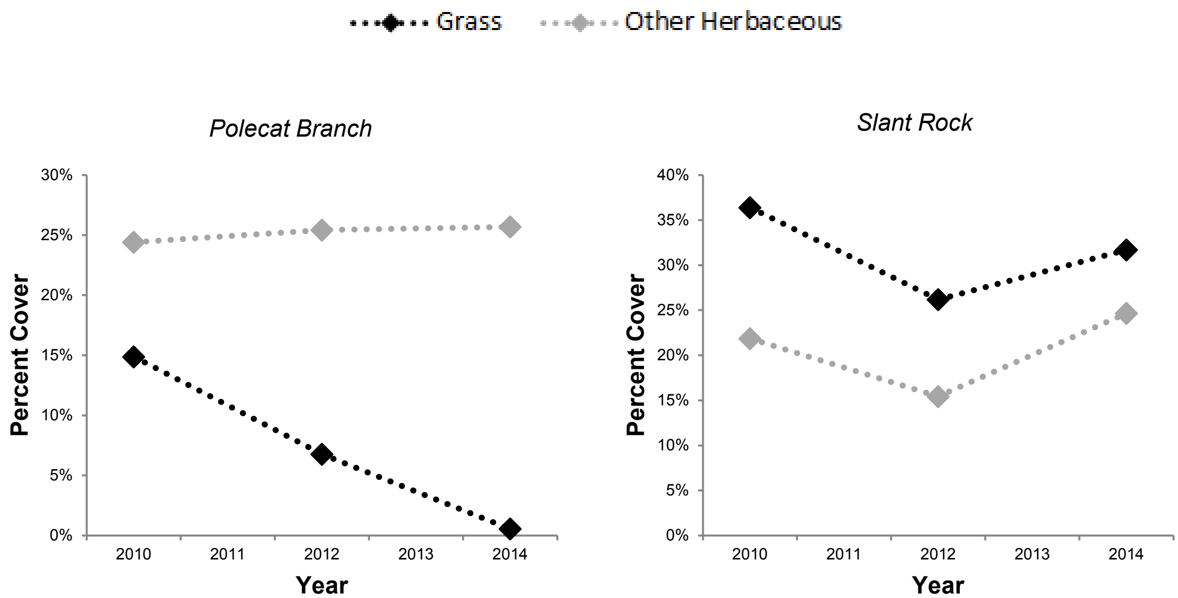
Scientific Name	Common Name	Special Status	Notes
Tridens flavus var. *chapmanii*	Chapman's tridens	state special concern	Known from only a single record in TN from the 1950s, and not seen again until 2008, when Wofford et al. (2008) documented a single clump at OBRI.
Utricularia subulata	zigzag bladderwort	state threatened	–

* According to Wofford et al. (2008)

Appendix K. Percent cover of grass and herbaceous species over time at OBRI cobble bar monitoring locations (APHN 2015).




Grass
Other Herbaceous
Devil's Breakfast Table
Hegler Ford
Jett Bridge
Nemo
Obed Junction
Otter Creek
Percent Cover
Year
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
40%
35%
30%
25%
20%
15%
10%
5%
16%
14%
12%
10%
8%
6%
4%
2%
2010
2011
2012
2013
2014
2015


Grass
Other Herbaceous
Polecat Branch
Percent Cover
30%
25%
20%
15%
10%
5%
0%
2010
2011
2012
2013
2014
Year
Slant Rock
Percent Cover
40%
35%
30%
25%
20%
15%
10%
5%
0%
2010
2011
2012
2013
2014
Year

Appendix L. Element occurrence (EO) information for plant species known to occur in OBRI cobble bar communities, as of 2015 (TWRA 2015). Ranks are described in Table 23. Basic EO rank definitions are; A = excellent estimated viability, B = good estimated viability, C = fairy estimated viability, D = poor estimated viability, E = verified extant (viability not assessed), and H = historical. For those species that are given range ranks, the definitions are; AB = exvellent or good viability, AC = excellent to fair viability, BC = good or fair vialbitiy, and CD = fair or poor viability (NatureServe 2016).

Scientific Name	Most recent observation	EO rank
Berberis Canadensis (American barberry)	1966	H
	1977	H
	2008	B
Calamovilfa arcuate (Cumberland sandreed)	1980	H
	1980	D
	1980	D
	2009	CD
	1980	B
	1980	D
	1980	C
	1980	BC
	2000	D
	2009	C
	1980	D
Conradina verticillata (Cumberland rosemary)	2007	B
	2007	B
	2007	B
	2007	B
	2007	B
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	C
	2007	C
	2009	D
	1980	H
	1980	H
	1980	H
	2009	C
	2007	A
	2007	A
	2007	A

* APHN staff observed several populations of this species at OBRI during 2014–2016 but it is not known what EOs these populations correspond to, if any (Raskin, written communication, 10 August 2016).

Scientific Name	Most recent observation	EO rank
Conradina verticillata (Cumberland rosemary) *(continued)*	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2007	A
	2010	CD
	2009	D
	2007	C
	2007	C
	2007	C
	2007	D
	2009	B
	2012	A
	2007	B
	2007	B
	2007	B
	2007	B
	2007	B
	2007	B
	2007	D
	2007	D
	2007	CD
	2007	CD
	2007	CD
	2009	BC
	2009	BC
	2009	BC
	2010	B
	2008	B
	2008	B
	2008	B
	2009	C
	2009	C
	2007	BC
	2007	BC
	2007	BC
	2007	BC
	2007	BC
	2007	D
	2007	D
	2007	AC

* APHN staff observed several populations of this species at OBRI during 2014–2016 but it is not known what EOs these populations correspond to, if any (Raskin, written communication, 10 August 2016).

Scientific Name	Most recent observation	EO rank
Conradina verticillata (Cumberland rosemary) *(continued)*	2007	AC
	2007	AC
	2007	AC
	1980	H
Helianthus aff. *Eggertii* (N/A)	1982	H
	1982	H
	1982	H
Marshallia grandiflora (Monongahela Barbara's buttons)	1980	E
	2000	CD
	1977	H
	1977	H
	2000	C
	2007	CD
	2003	C
	1980	C
	1979	BC
	2000	A
	2000	A
	1980	C
*Polygonella Americana** (southern jointweed)	1977	H
	1977	H
	1980	E
	1979	E
	1979	E
	1980	E
Spiraea virginiana (Virginia spiraea)	2007	D
	2007	AB
Sporobolus junceus (pineywoods dropseed)	1980	E
Utricularia subulata (zigzag bladderwort)	1965	H

* APHN staff observed several populations of this species at OBRI during 2014–2016 but it is not known what EOs these populations correspond to, if any (Raskin, written communication, 10 August 2016).

Appendix M. Freshwater mussel species occurring at OBRI: P=present, PP=probably present, U=unconfirmed, NL=not listed, N/C=not counted.

Scientific Name	Common Name	Ahlstedt et al. (2001)	Ahlstedt and Bakaletz (2006)	Dinkins and Faust (2015)	NPS (2015)
Amblema plicata	threeridge	–	–	–	U
Corbicula fluminea	Asian clam	–	N/C	–	P
Elliptio crassidens	elephantear	–	–	–	U
Elliptio dilatata	spike	38	–	25	P
Epioblasma turgidula	turgid blossom	–	–	–	U
Fusconaia cuneolus	fine-rayed pigtoe	–	–	–	U
Fusconaia subrotunda	longsolid	–	–	–	PP
Lampsilis cardium	plain pocketbook	1	–	–	P
Lampsilis fasciola	wavy-rayed lampmussel	110	30	46	P
Lampsilis ovata	pocketbook	–	–	1	NL
Lampsilis virescens	Alabama lampmussel	–	–	–	P
Lasmigona costata	flutedshell	–	–	–	U
Leptodea fragilis	fragile papershell	–	–	–	U
Medionidus conradicus	Cumberland moccasinshell	81	–	82	P
Pleurobema oviforme	Tennessee clubshell	5	–	15	P
Pleuronaia barnesiana	Tennessee pigtoe	–	–	1	NL
Potamilus alatus	pink heelsplitter	6	–	2	P
Potamilus ohiensis	pink papershell	–	–	–	U
Ptychobranchus fasciolaris	kidneyshell	–	–	–	U
Pyganodon grandis	giant floater	–	–	–	U
Toxolasma lividum	purple lilliput	–	–	1	P
Truncilla donaciformis	fawnsfoot	–	–	–	U
Utterbackia imbecillis	paper pondshell	–	–	–	U
Utterbackia suborbiculata	flat floater	–	–	–	U
Villosa iris	rainbow mussel	323	98	89	P
Villosa perpurpurea	purple bean	19	–	4	P
Villosa trabalis	Cumberland bean	–	–	–	U
Villosa vanuxemensis	mountain creekshell	–	–	–	PP

Appendix N. Aquatic invertebrate taxa, which were identified to species when possible, observed in the park according to Cook and Hutton (2009). Many aquatic insects that are identified to species do not have common names associated with them at this time.

Order	Scientific Name	Common Name	Number collected
Acari	–	mites and ticks	2
Coleoptera	*Anchytarsus bicolor*	N/A	1
	Ancyronyx variegata	N/A	9
	Dineutus sp.	whirligig beetles	3
	Dubiraphia vittata	N/A	3
	Ectopria sp.	N/A	6
	Gonielmis dietrichi	N/A	21
	Helichus basalis	N/A	1
	Helichus fastigiatus	N/A	26
	Limnius latiscularis	N/A	1
	Macronychus glabratus	N/A	81
	Microcylloepus pusillus	N/A	53
	Microcylloepus pusillus aptus	N/A	7
	Microcylloepus pusillus pusillus	N/A	52
	Optioservus ovalis	N/A	19
	Optioservus sp.	N/A	141
	Promoresia elegans	N/A	40
	Psephenus herricki	N/A	98
	Stenelmis bicarinata	N/A	55
	Stenelmis crenata	N/A	8
	Stenelmis mera	N/A	4
	Stenelmis sandersoni	N/A	37
	Stenelmis sp.	N/A	172
Decapoda	*Cambarus* sp.	N/A	4
	Orconectes sp.	N/A	8
Diptera	*Ablabesmyia mallochi*	N/A	6
	Ablabesmyia sp.	N/A	3
	Anopheles sp.	N/A	1
	Antocha sp.	N/A	6
	Apsectrotanypus sp.	N/A	1
	Atherix lantha	N/A	38
	Bezzia sp.	N/A	6
	Cladotanytarsus sp.	N/A	2
	Cnephia sp.	N/A	1
	Conchapelopia sp.	N/A	78
	Corynoneura sp.	N/A	10

Order	Scientific Name	Common Name	Number collected
Diptera (continued)	*Cricotopus sylvestris*	N/A	1
	Cricotopus sp.	N/A	24
	Cryptochironomus fulvus	N/A	1
	Dasyhelea sp.	N/A	7
	Dicrotendipes neomodestus	N/A	1
	Eukiefferiella claripennis	N/A	4
	Eukiefferiella discoloripes	N/A	24
	Eukiefferiella sp.	N/A	11
	Heterotrissocladius sp.	N/A	1
	Hexatoma sp.	N/A	13
	Larsia sp.	N/A	1
	Lopescladius sp.	N/A	1
	Microtendipes caelum	N/A	10
	Microtendipes sp.	N/A	1
	Nilothauma sp.	N/A	1
	Orthocladius obumbratus	N/A	1
	Orthocladius sp.	N/A	3
	Parametriocnemus sp.	N/A	10
	Paratanytarsus sp.	N/A	2
	Paratendipes sp.	N/A	1
	Pentaneura sp.	N/A	3
	Polypedilum flavum	N/A	343
	Polypedilum illinoense	N/A	4
	Polypedilum sp.	N/A	1
	Procladius sublettei	N/A	1
	Procladius sp.	N/A	1
	Prosimulium sp.	N/A	3
	Psectrocladius sp.	N/A	64
	Pseudochironomus sp.	N/A	1
	Psilometriocnemus triannulatus	N/A	4
	Rheocricotopus robacki	N/A	30
	Rheotanytarsus exiguus	N/A	77
	Simulium sp.	N/A	63
	Stictochironomus sp.	N/A	5
	Symbiocladius sp.	N/A	11
	Tanytarsus guerlus	N/A	13
	Tanytarsus sp.	N/A	32
	Thienemanniella sp.	N/A	2

Order	Scientific Name	Common Name	Number collected
Diptera (continued)	*Tipula* sp.	N/A	24
	Xylotopus par	N/A	1
	Zavrelia sp.	N/A	6
Ephemeroptera	*Acentrella* sp.	N/A	27
	Baetis intercalaris	N/A	246
	Baetis sp.	N/A	2
	Caenis sp.	N/A	3
	Drunella cornutella	N/A	6
	Epeorus dispar	N/A	12
	Ephemera sp.	N/A	6
	Ephemerella catawba	N/A	14
	Ephemerella dorothea	N/A	20
	Ephemerella needhami	N/A	1
	Eurylophella sp.	N/A	22
	Heptagenia sp.	N/A	20
	Heterocloeon curiosum	N/A	48
	Isonychia sp.	N/A	184
	Pseudocloeon propinquum	N/A	2
	Leucrocuta juno	N/A	1
	Leucrocuta thetis	N/A	1
	Maccaffertium exiguum	N/A	6
	Maccaffertium ithaca	N/A	34
	Maccaffertium mediopunctatum	N/A	1
	Maccaffertium modestum	N/A	126
	Maccaffertium pudicum	N/A	11
	Maccaffertium smithae	N/A	2
	Maccaffertium terminatum	N/A	41
	Maccaffertium vicarium	N/A	124
	Paraleptophlebia sp.	N/A	10
	Procloeon sp.	N/A	55
	Teloganopsis deficiens	N/A	174
	Serratella serrata	N/A	1
	Stenacron carolina	N/A	2
	Stenacron interpunctatum	N/A	2
	Stenacron pallidum	N/A	17
	Stenonema femoratum	N/A	61
	Timpanago sp.	N/A	2
Hemiptera	*Microvelia* sp.	N/A	7

Order	Scientific Name	Common Name	Number collected
Hemiptera (continued)	*Rhagovelia obesa*	N/A	1
Isopoda	*Lirceus* sp.	N/A	18
Lepidoptera	*Petrophila fulicalis*	N/A	1
Lumbriculida	*Lumbriculus variegatus*	N/A	34
Megaloptera	*Corydalus cornutus*	dobsonfly	66
	Nigronia serricornis	N/A	78
Odonata	*Argia* sp.	N/A	20
	Boyeria vinosa	fawn darner	20
	Gomphus exilis	lancet clubtail	2
	Gomphus quadricolor	rapids clubtail	1
	Hagenius brevistylus	dragonhunter	6
	Gomphus adelphus	mustached clubtail	1
	Lanthus vernalis	southern pygmy clubtail	58
	Neurocordulia yamaskanensis	Stygian shadowdragon	9
	Somatochlora linearis	mocha emerald	1
	Stylogomphus albistylus	eastern least clubtail	8
Plecoptera	*Acroneuria abnormis*	N/A	63
	Acroneuria carolinensis	N/A	107
	Agnetina annulipes	N/A	23
	Agnetina flavescens	N/A	1
	Amphinemura wui	N/A	200
	Isoperla bilineata	N/A	134
	Isoperla sp.	N/A	16
	Leuctra sp.	N/A	456
	Neoperla sp.	N/A	41
	Paragnetina immarginata	N/A	25
	Peltoperla arcuata	N/A	1
	Perlesta placida	N/A	115
Rhynchobdellida	*Placobdella* sp.	N/A	1
Trichoptera	*Brachycentrus numerosus*	N/A	1
	Brachycentrus spinae	N/A	1
	Ceraclea ancylus	N/A	2
	Ceraclea flava	N/A	4
	Ceraclea sp.	N/A	1
	Ceratopsyche cheilonis	N/A	1
	Ceratopsyche macleodi	N/A	1
	Ceratopsyche sparna	N/A	118
	Ceratopsyche ventura	N/A	5

Order	Scientific Name	Common Name	Number collected
Trichoptera (continued)	*Ceratopsyche* sp.	N/A	2
	Cheumatopsyche sp.	N/A	552
	Chimarra sp.	N/A	222
	Dolophilodes distinctus	N/A	25
	Helicopsyche borealis	N/A	8
	Heteroplectron americanum	N/A	1
	Hydatophylax argus	N/A	4
	Hydropsyche betteni	N/A	7
	Hydropsyche demora	N/A	57
	Hydropsyche hageni	N/A	7
	Hydropsyche simulans	N/A	10
	Hydropsyche venularis	N/A	70
	Ironoquia punctatissima	N/A	1
	Lepidostoma sp.	N/A	2
	Lype diversa	N/A	1
	Macrostemum zebratum	N/A	13
	Micrasema rusticum	N/A	3
	Micrasema wataga	N/A	33
	Micrasema sp.	N/A	23
	Nectopsyche exquisita	N/A	3
	Neotrichia sp.	N/A	1
	Neureclipsis crepuscularis	N/A	72
	Oecetis inconspicua	N/A	4
	Oecetis nocturna	N/A	1
	Oecetis persimilis	N/A	5
	Oecetis sp.	N/A	4
	Polycentropus sp.	N/A	15
	Ptilostomis ocellifera	N/A	2
	Pycnopsyche antica	N/A	6
	Pycnopsyche sp.	N/A	1
	Rhyacophila carolina	N/A	17
	Rhyacophila formosa	N/A	16

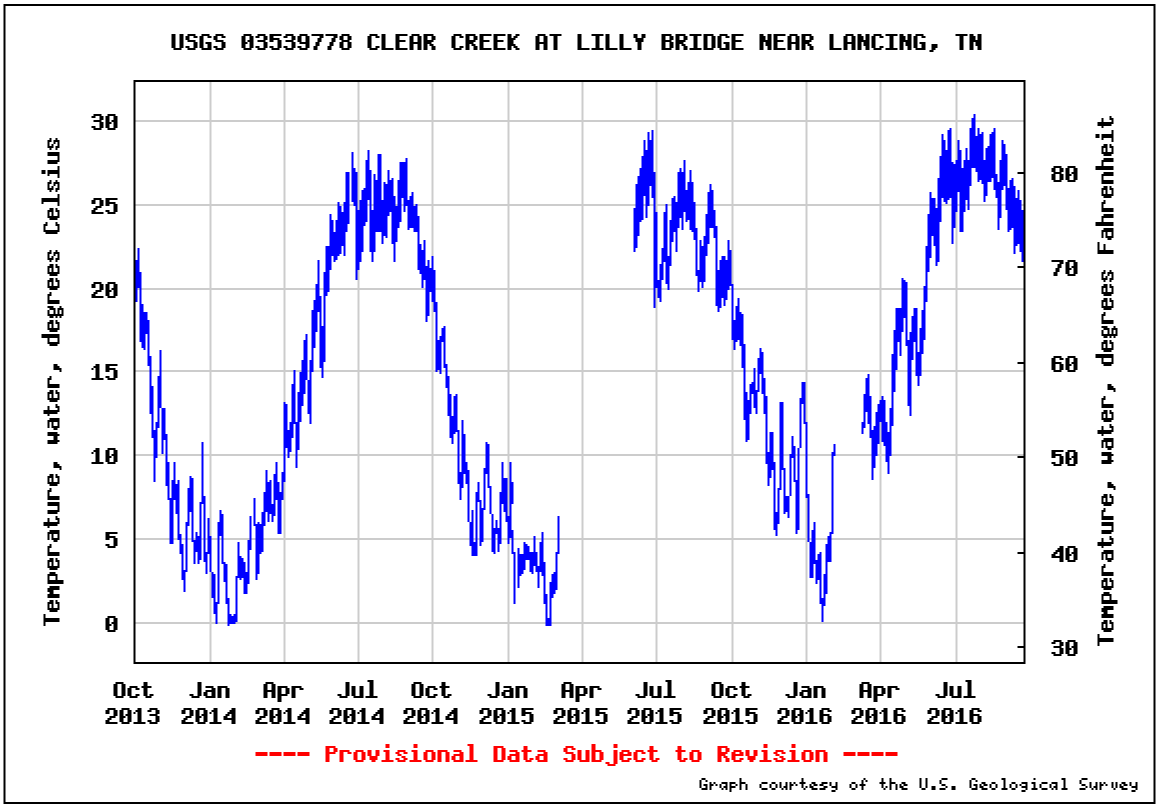
Appendix O. Water temperature in °C (°F), pH, and dissolved oxygen (mg/l) results from OBRI water quality sampling sites (by watershed/stream), spring-fall 2007 (Hutton 2009).

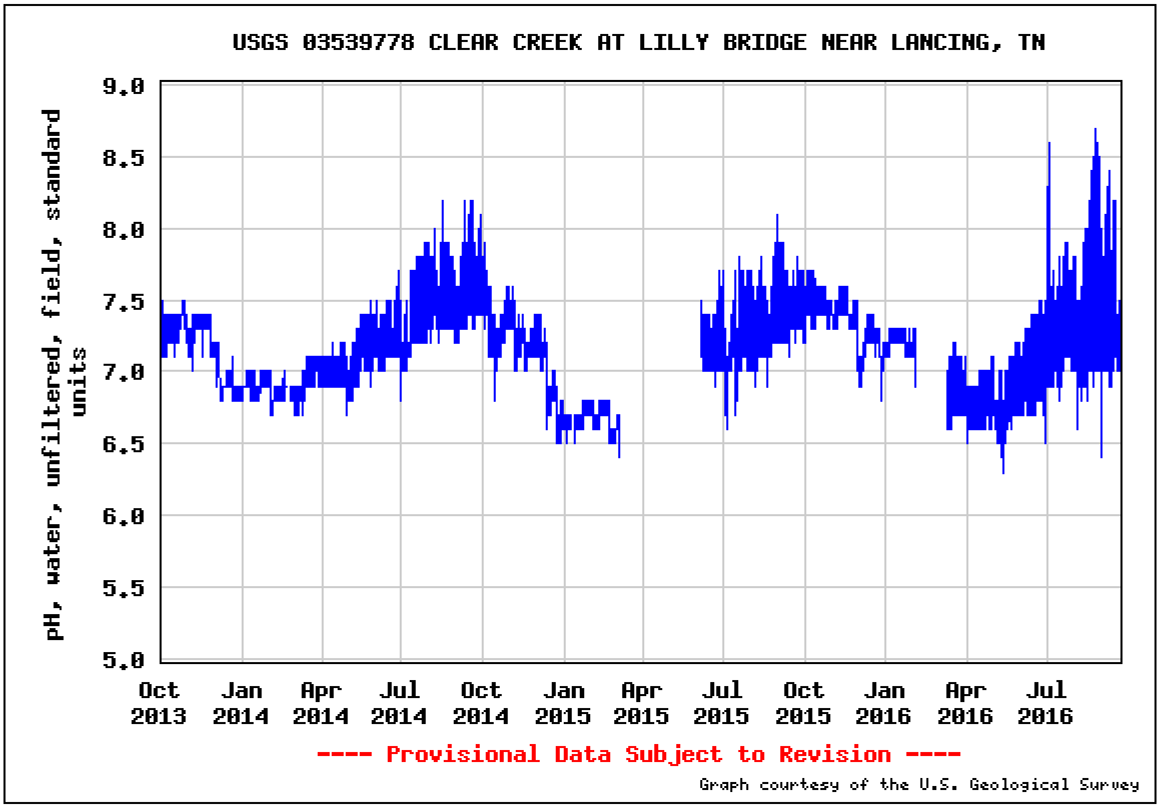
Watershed/Stream	Sampling Site	Temperature	pH	DO
Clear Creek	Norris Ford	19.9 (67.8)	7.03	6.1
	Jett Bridge	23.0 (73.4)	7.49	7.4
	Lilly Bridge	24.8 (76.6)	7.35	7.4
	Barnett Bridge	22.6 (72.7)	7.6	7.2
	Overall Mean	22.6 (72.6)	7.31	7.0
White Creek (Clear Creek watershed)	Lavender Bridge	20.2 (68.4)	7.09	6.7
	at Twin Bridge Rd.	21.9 (71.4)	6.93	8.4
	White Cr. Mouth	16.0 (60.1)	7.81	5.7
	Overall Mean	19.4 (66.9)	7.15	6.9
Daddy's Creek watershed	Yellow Creek	17.0 (62.6)	7.4	8.9
	Yellow Cr. At Hebbertsburg Rd.	19.0 (66.2)	7.14	7.0
	Devils Breakfast Table	25.1 (77.2)	7.75	7.8
	Daddy's Cr. At Antioch Bridge	24.5 (76.1)	7.42	7.5
	Daddy's Cr. At Obed Junction	27.1 (80.8)	8.13	8.1
	Overall Mean	22.5 (72.5)	7.45	7.9
Obed River	Adams Bridge	20.0 (68.0)	7.71	7.5
	Potters Ford	22.0 (71.6)	7.26	7.4
	at Obed Junction	27.0 (80.6)	7.71	7.6
	at Canoe Hole	20.8 (69.4)	7.59	8.9
	Alley Ford	18.7 (65.7)	7.23	6.9
	Overall Mean	21.7 (71.0)	7.45	7.7
Emory River watershed	at Montgomery Rd.	22.1 (71.8)	6.48	3.3
	Nemo	27.3 (81.1)	7.87	7.4
	Rock Creek at Hwy 62	20.6 (69.1)	6.72	4.2
	Island Cr. At Catoosa Rd.	15.7 (60.3)	6.9	8.8
	Overall Mean	21.4 (70.5)	6.78	5.9

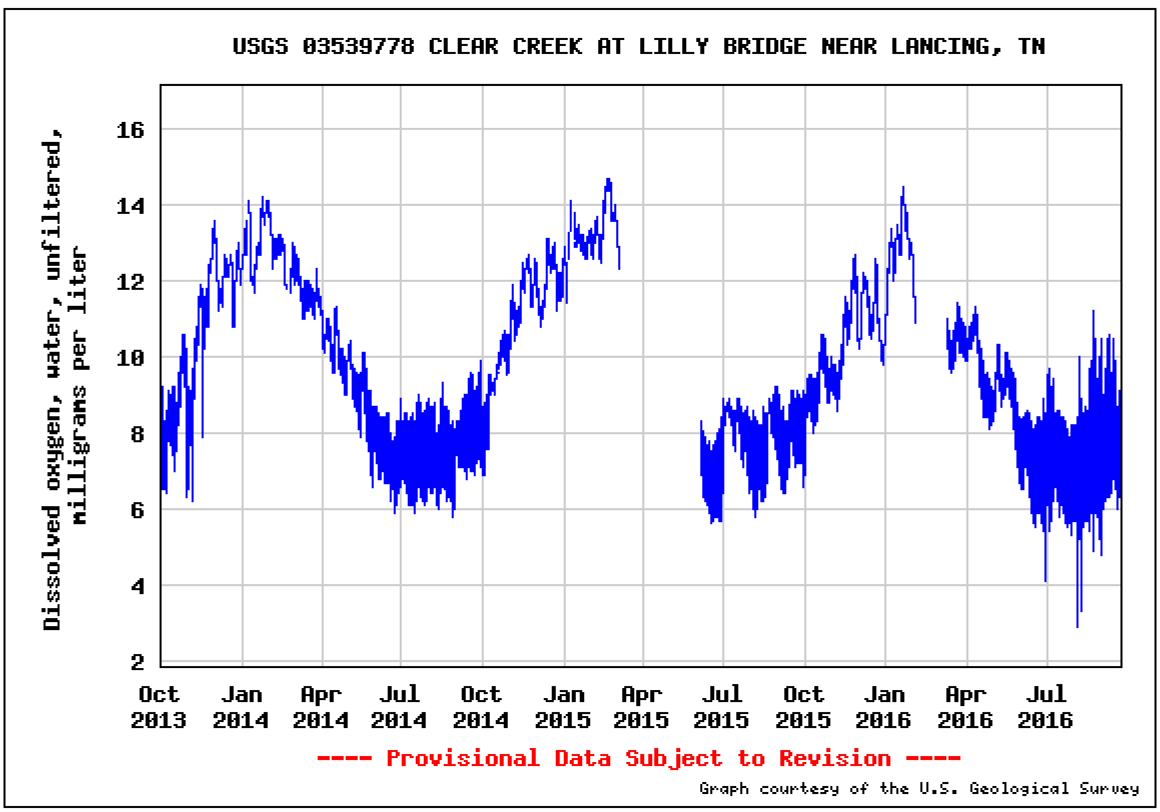
Appendix P. Conductivity (µS/cm) and turbidity (NTU) results from OBRI water quality sampling sites (by watershed/stream), spring-fall 2007 (Hutton 2009).

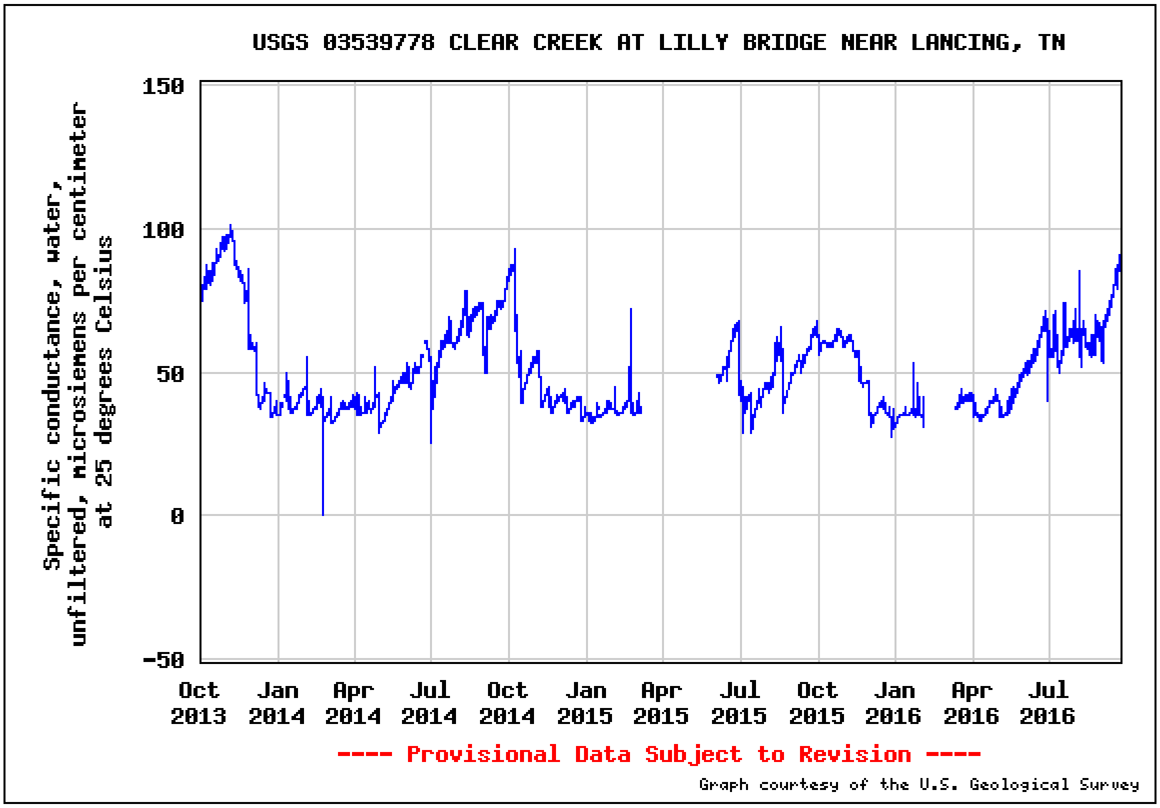
Watershed/Stream	Sampling Site	SpC	Turbidity
Clear Creek	Norris Ford	49.4	0.34
	Jett Bridge	54.5	0.13
	Lilly Bridge	57.4	0.18
	Barnett Bridge	51.3	0.12
	Overall Mean	53.1	0.19
White Creek (Clear Creek watershed)	Lavender Bridge	64.2	0.25
	at Twin Bridge Rd.	62.9	0.53
	White Cr. Mouth	65.4	1.42
	Overall Mean	64.2	0.73
Daddy's Creek watershed	Yellow Creek	887.5	0.24
	Yellow Cr. At Hebbertsburg Rd.	46.7	0.58
	Devils Breakfast Table	90.6	0.05
	Daddy's Cr. At Antioch Bridge	111.4	0.26
	Daddy's Cr. At Obed Junction	103.6	0.38
	Overall Mean	247.9	0.30
Obed River	Adams Bridge	182.1	0.05
	Potters Ford	136.4	0.06
	at Obed Junction	110.5	0.25
	at Canoe Hole	242.2	1.28
	Alley Ford	177.8	1.33
	Overall Mean	169.8	0.59
Emory River watershed	at Montgomery Rd.	105.0	0.46
	Nemo	74.9	0.33
	Rock Creek at Hwy 62	72.4	0.96
	Island Cr. At Catoosa Rd.	1,342.0	0.97
	Overall Mean	398.6	0.68

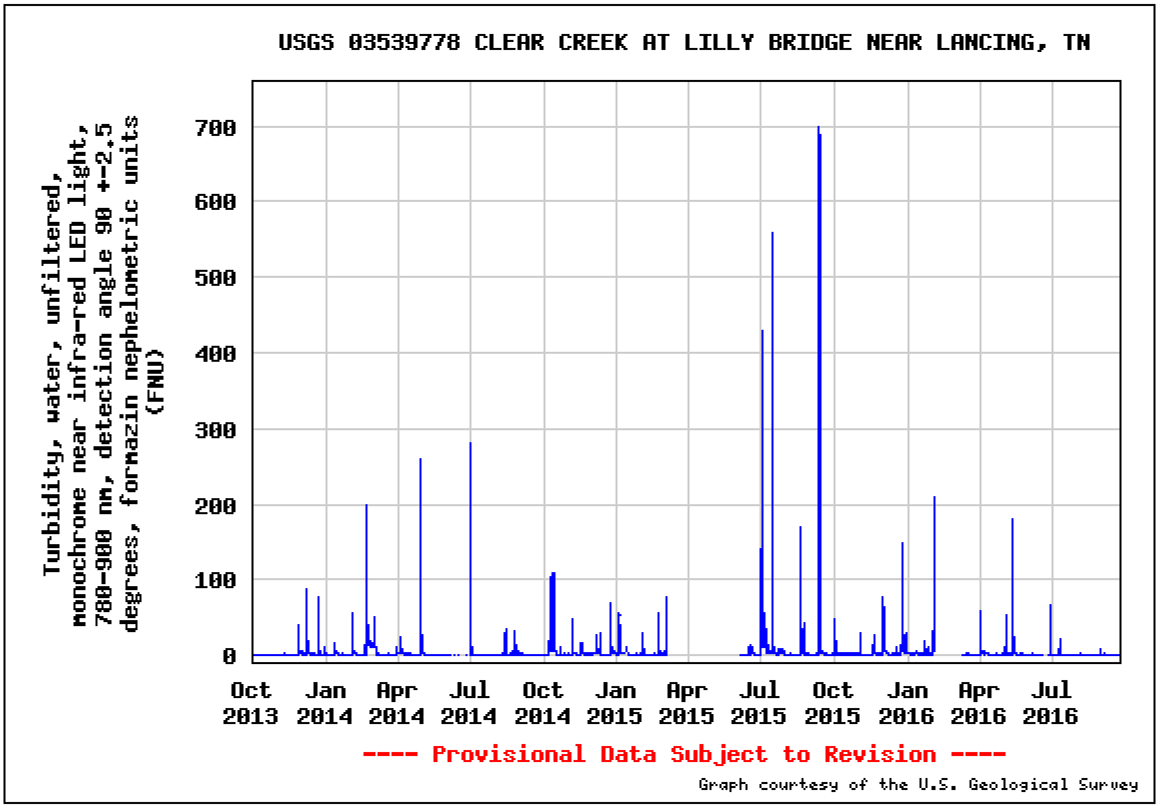
Appendix Q. Continuous water quality data (recordings every half-hour) for three stations in or near OBRI, October 2013-September 2016 (USGS 2016).

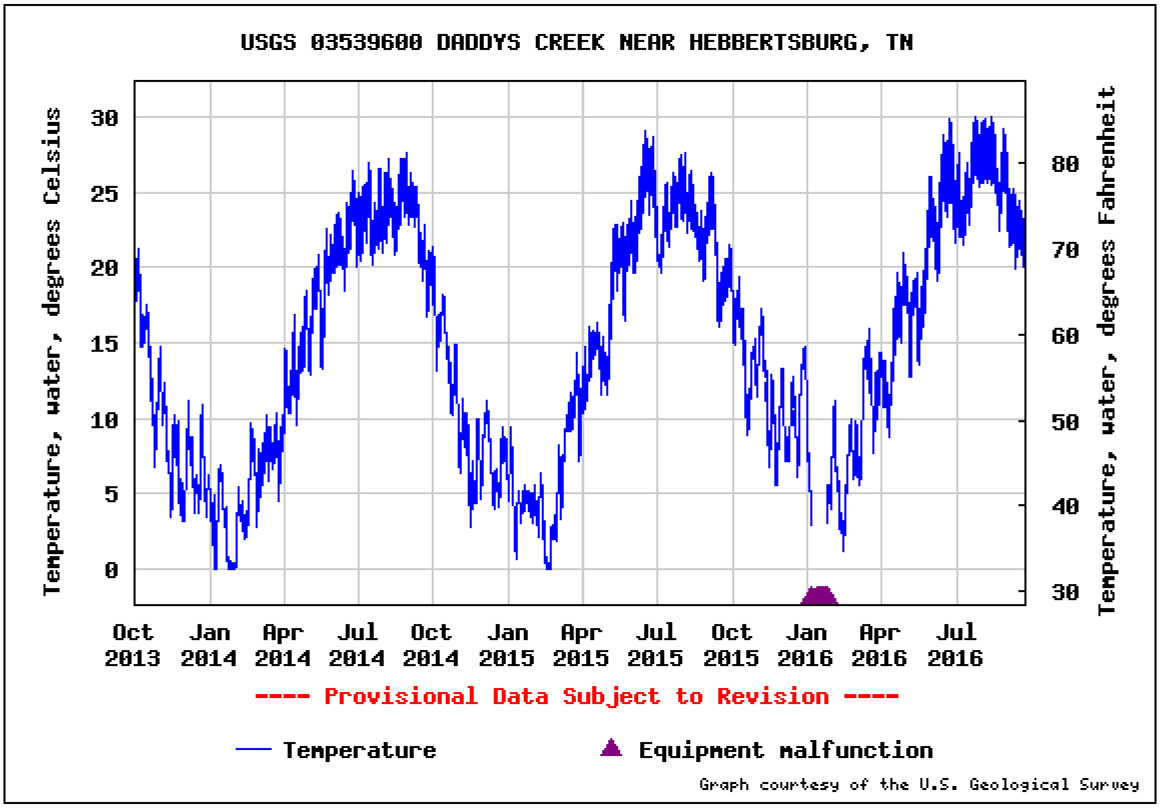



USGS 03539778 CLEAR CREEK AT LILLY BRIDGE NEAR LANCING, TN
pH, water, unfiltered, field, standard units
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey

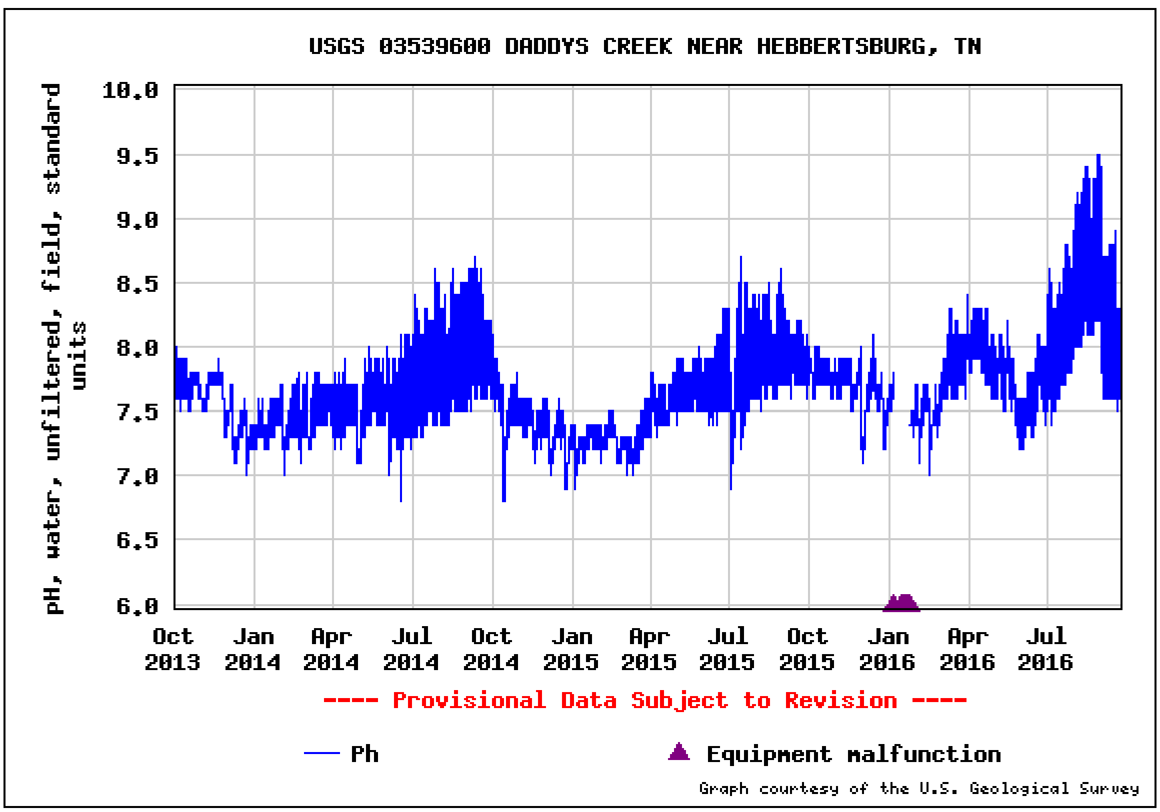

USGS 03539778 CLEAR CREEK AT LILLY BRIDGE NEAR LANCING, TN
Dissolved oxygen, water, unfiltered, milligrams per liter
16
14
12
10
8
6
4
2
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey


USGS 03539778 CLEAR CREEK AT LILLY BRIDGE NEAR LANCING, TN
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
150
100
50
0
-50
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey

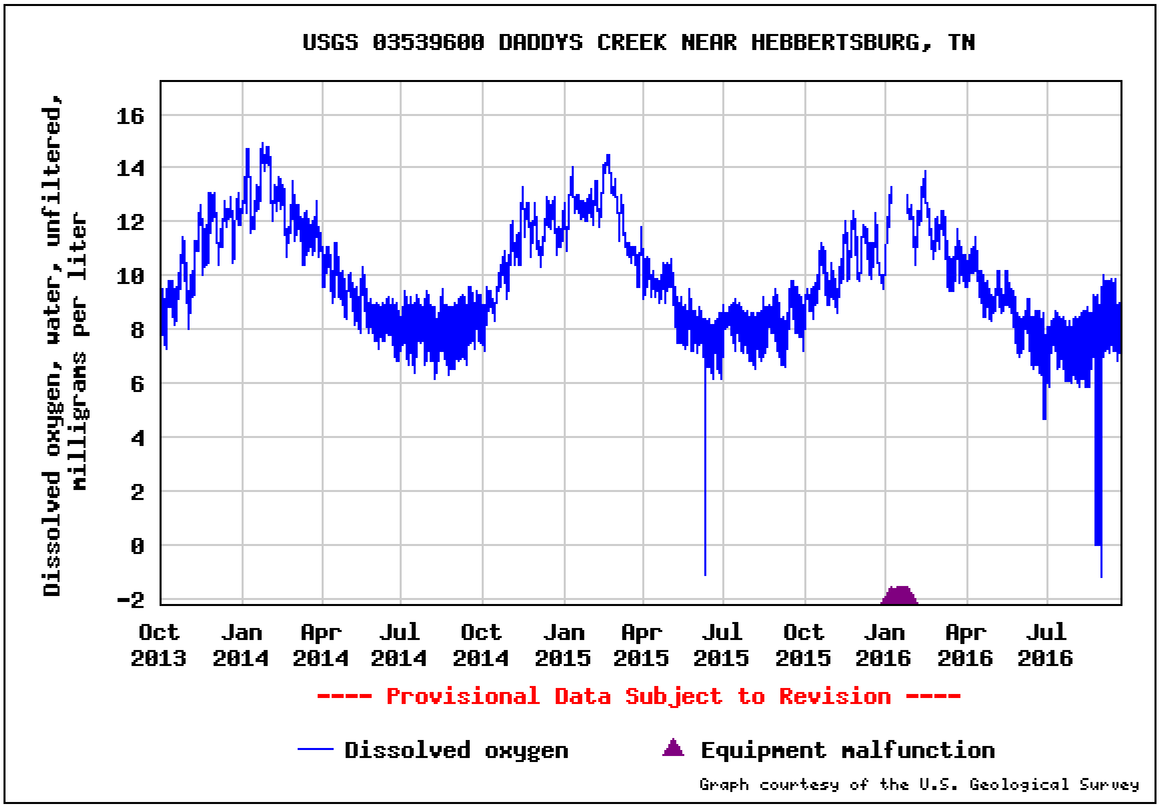

USGS 03539778 CLEAR CREEK AT LILLY BRIDGE NEAR LANCING, TN
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +-2.5 degrees, formazin nephelometric units (FNU)
700
600
500
400
300
200
100
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey

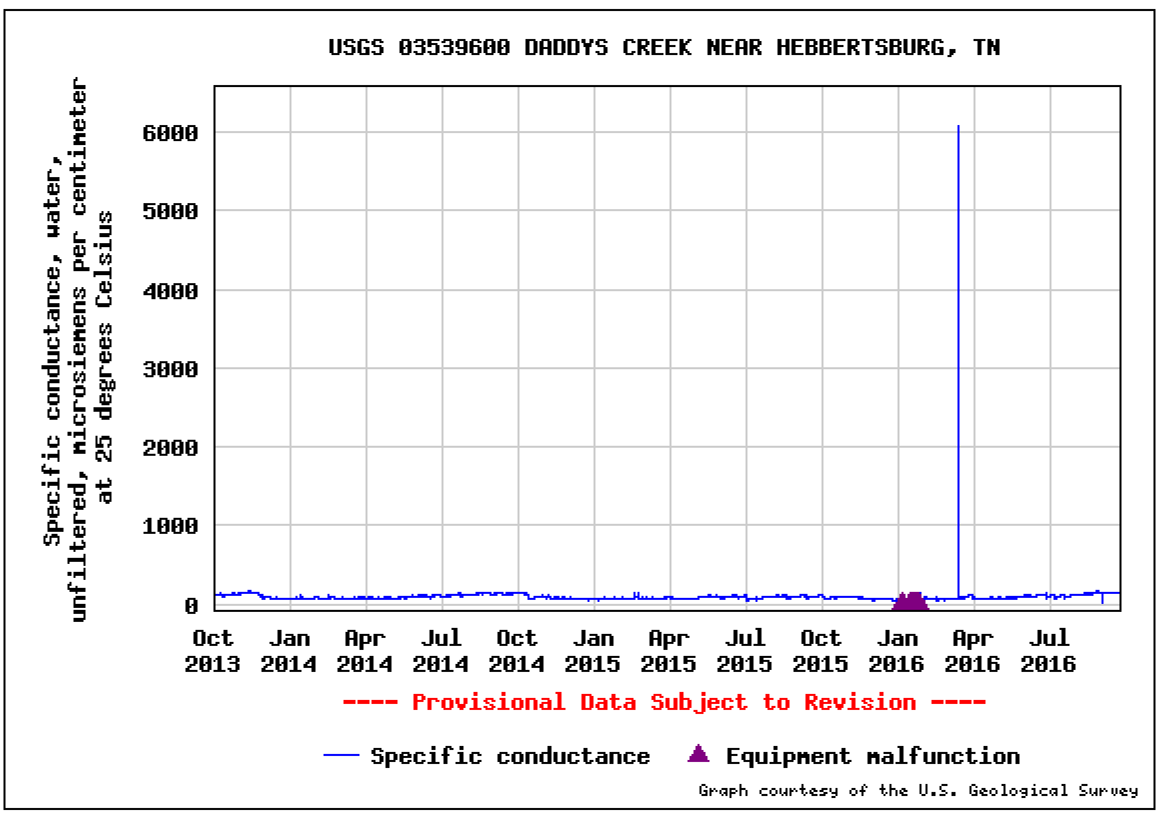


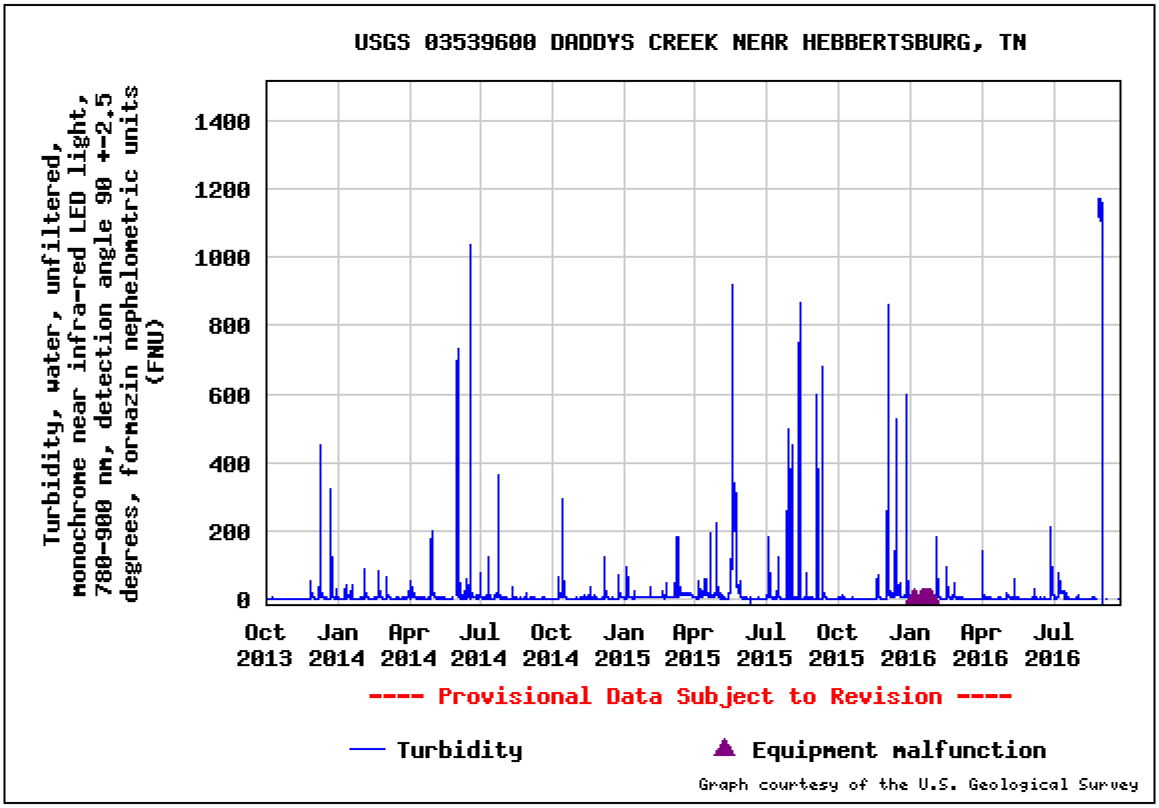
USGS 03539600 DADDYS CREEK NEAR HEBBERTSBURG, TN
Temperature, water, degrees Celsius
30
25
20
15
10
5
0
Temperature, water, degrees Fahrenheit
80
70
60
50
40
30
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Temperature
Equipment malfunction
Graph courtesy of the U.S. Geological Survey

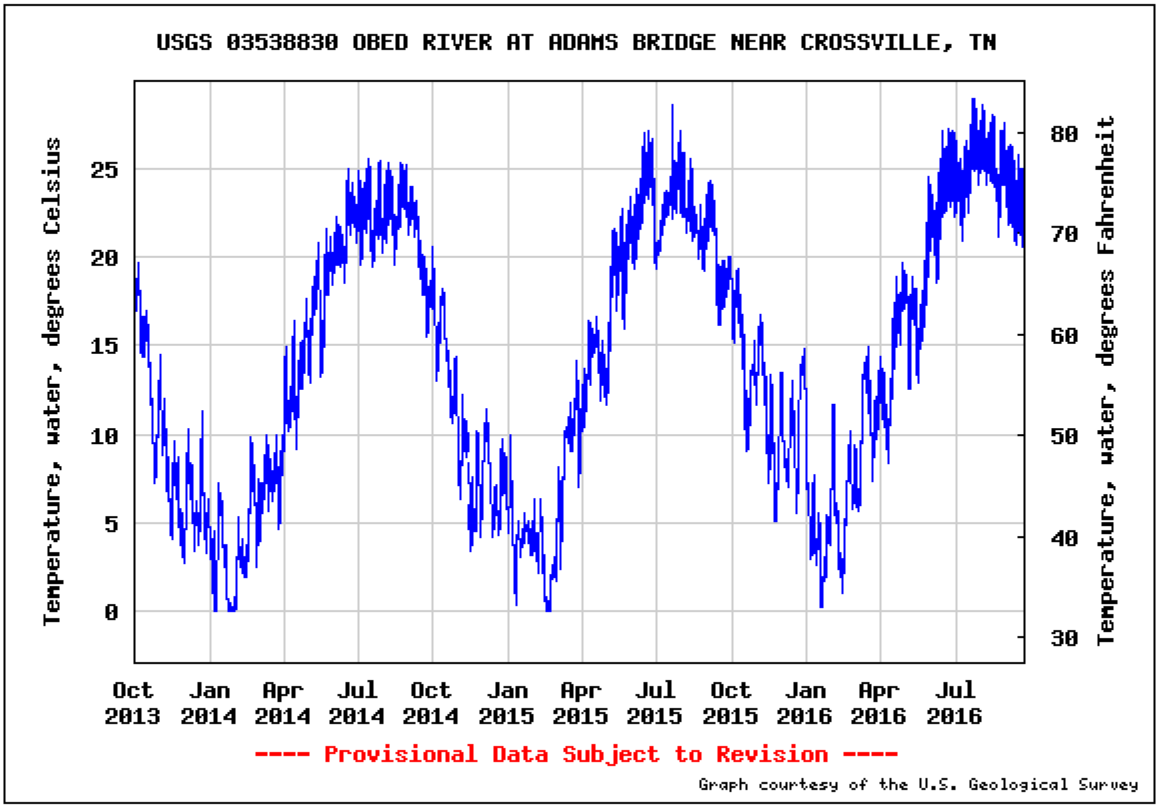


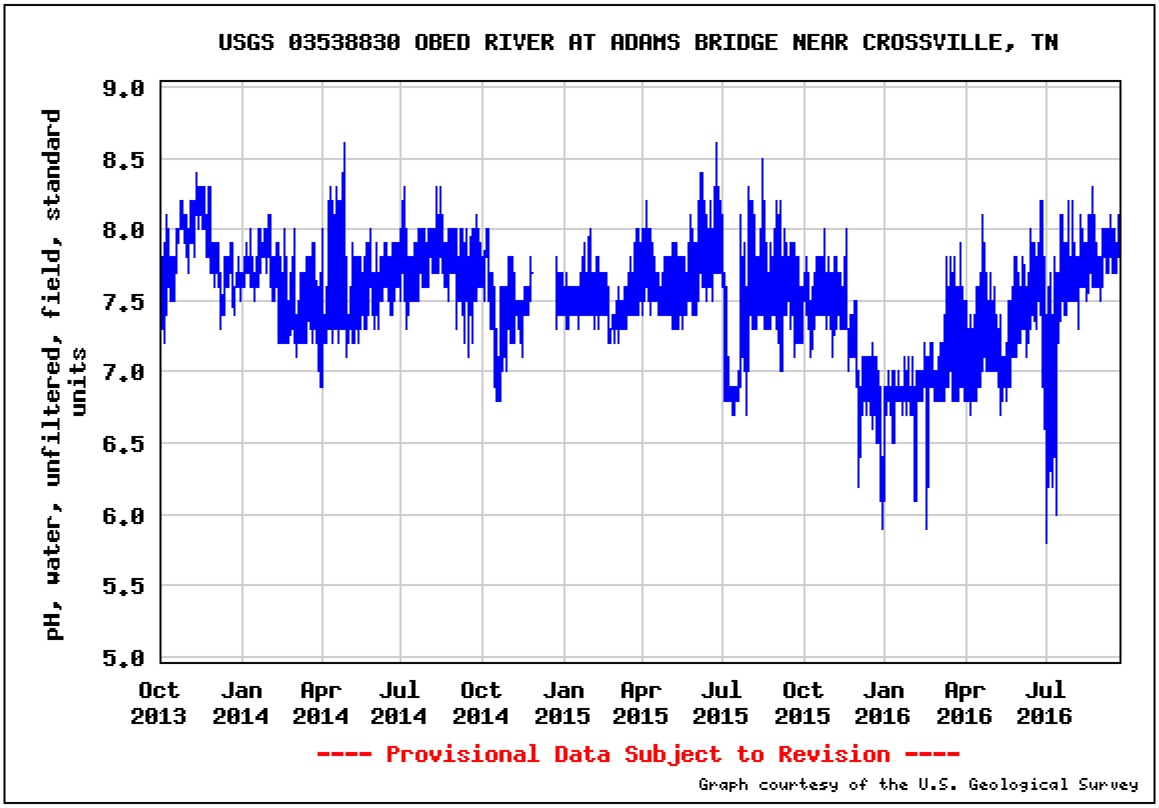
USGS 03539600 DADDYS CREEK NEAR HEBBERTSBURG, TN
pH, water, unfiltered, field, standard units
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Ph
Equipment malfunction
Graph courtesy of the U.S. Geological Survey

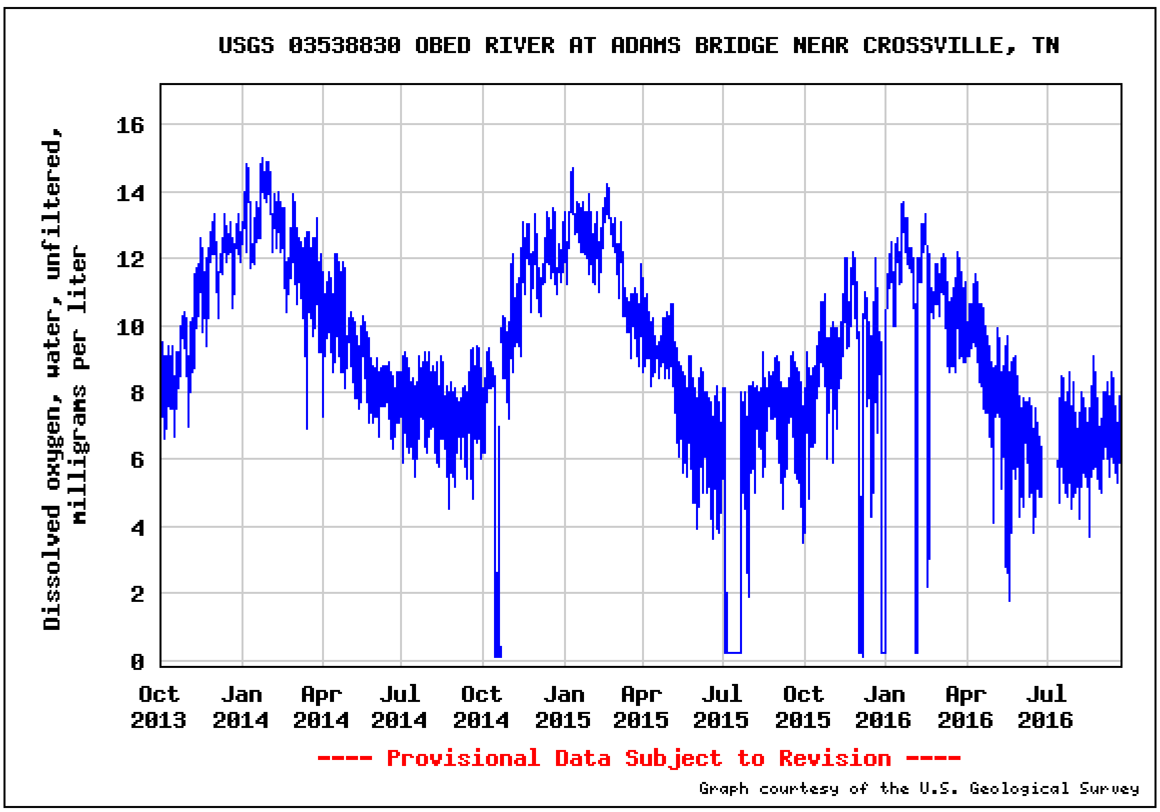

USGS 03539600 DADDYS CREEK NEAR HEBBERTSBURG, TN
Dissolved oxygen, water, unfiltered, milligrams per liter
16
14
12
10
8
6
4
2
0
-2
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Dissolved oxygen
Equipment malfunction
Graph courtesy of the U.S. Geological Survey

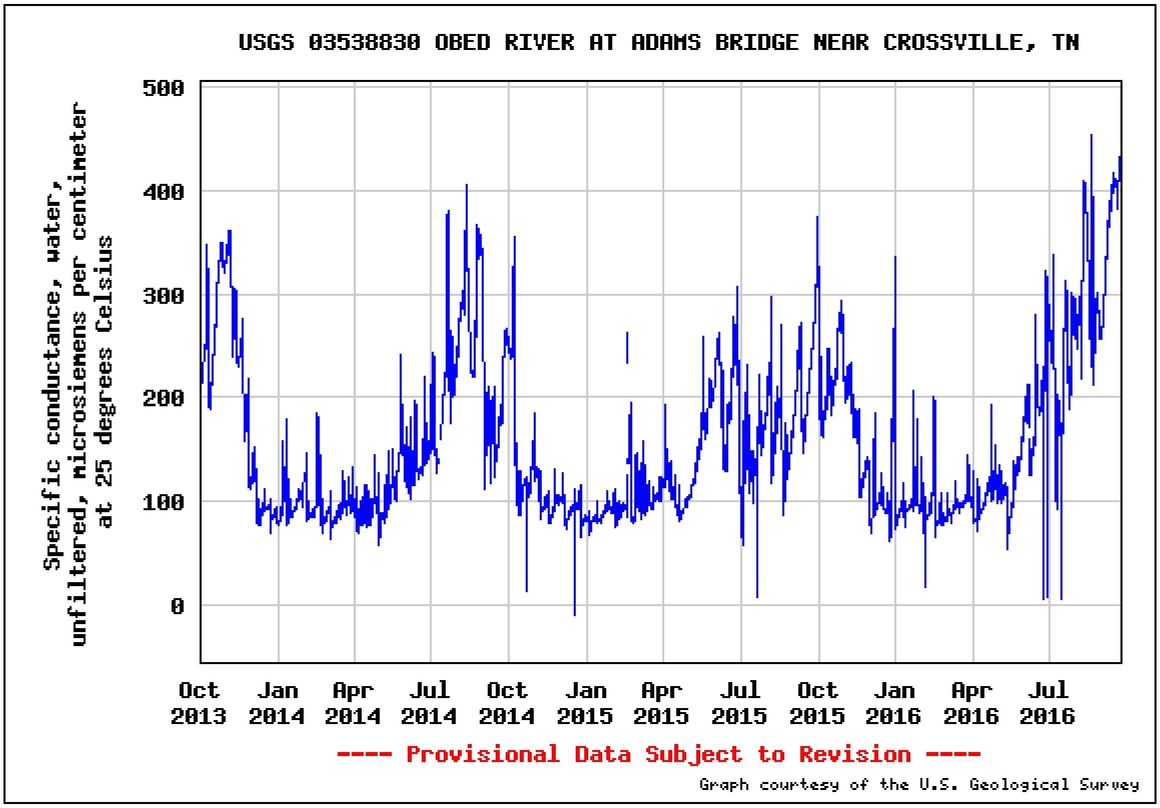

USGS 03539600 DADDYS CREEK NEAR HEBBERTSBURG, TN
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
6000
5000
4000
3000
2000
1000
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Specific conductance
Equipment malfunction
Graph courtesy of the U.S. Geological Survey

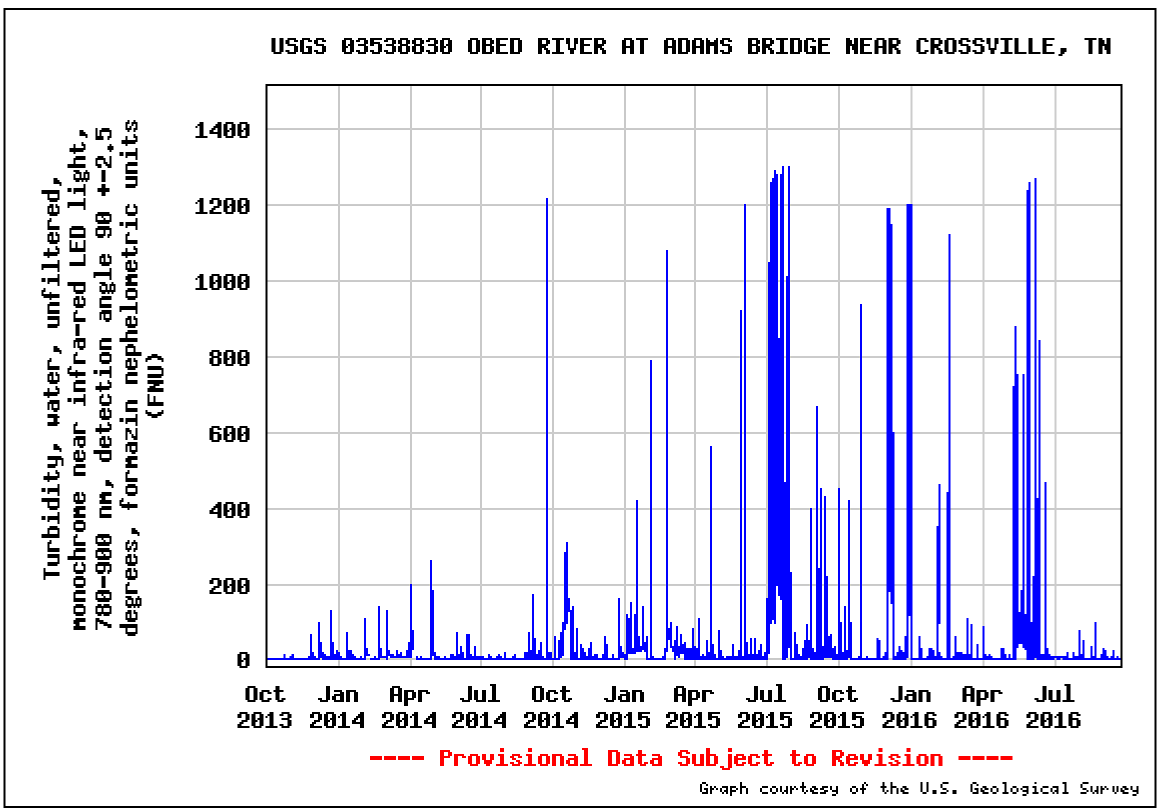

USGS 03539600 DADDYS CREEK NEAR HEBBERTSBURG, TN
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +-2.5 degrees, formazin nephelometric units (FNU)
1400
1200
1000
800
600
400
200
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Turbidity
Equipment malfunction
Graph courtesy of the U.S. Geological Survey


USGS 03538830 OBED RIVER AT ADAMS BRIDGE NEAR CROSSVILLE, TN
Temperature, water, degrees Celsius
25
20
15
10
5
0
Temperature, water, degrees Fahrenheit
80
70
60
50
40
30
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey


USGS 03538830 OBED RIVER AT ADAMS BRIDGE NEAR CROSSVILLE, TN
pH, water, unfiltered, field, standard units
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey


USGS 03538830 OBED RIVER AT ADAMS BRIDGE NEAR CROSSVILLE, TN
Dissolved oxygen, water, unfiltered, milligrams per liter
16
14
12
10
8
6
4
2
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey


USGS 03538830 OBED RIVER AT ADAMS BRIDGE NEAR CROSSVILLE, TN
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
500
400
300
200
100
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey


USGS 03538830 OBED RIVER AT ADAMS BRIDGE NEAR CROSSVILLE, TN
Turbidity, water, unfiltered, monochrome near infra-red LED light, 780-900 nm, detection angle 90 +-2.5 degrees, formazin nephelometric units (FNU)
1400
1200
1000
800
600
400
200
0
Oct 2013
Jan 2014
Apr 2014
Jul 2014
Oct 2014
Jan 2015
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
---- Provisional Data Subject to Revision ----
Graph courtesy of the U.S. Geological Survey

Appendix R. Gage height observations for OBRI watersheds, October 2007-March 2016 (USGS 2016).

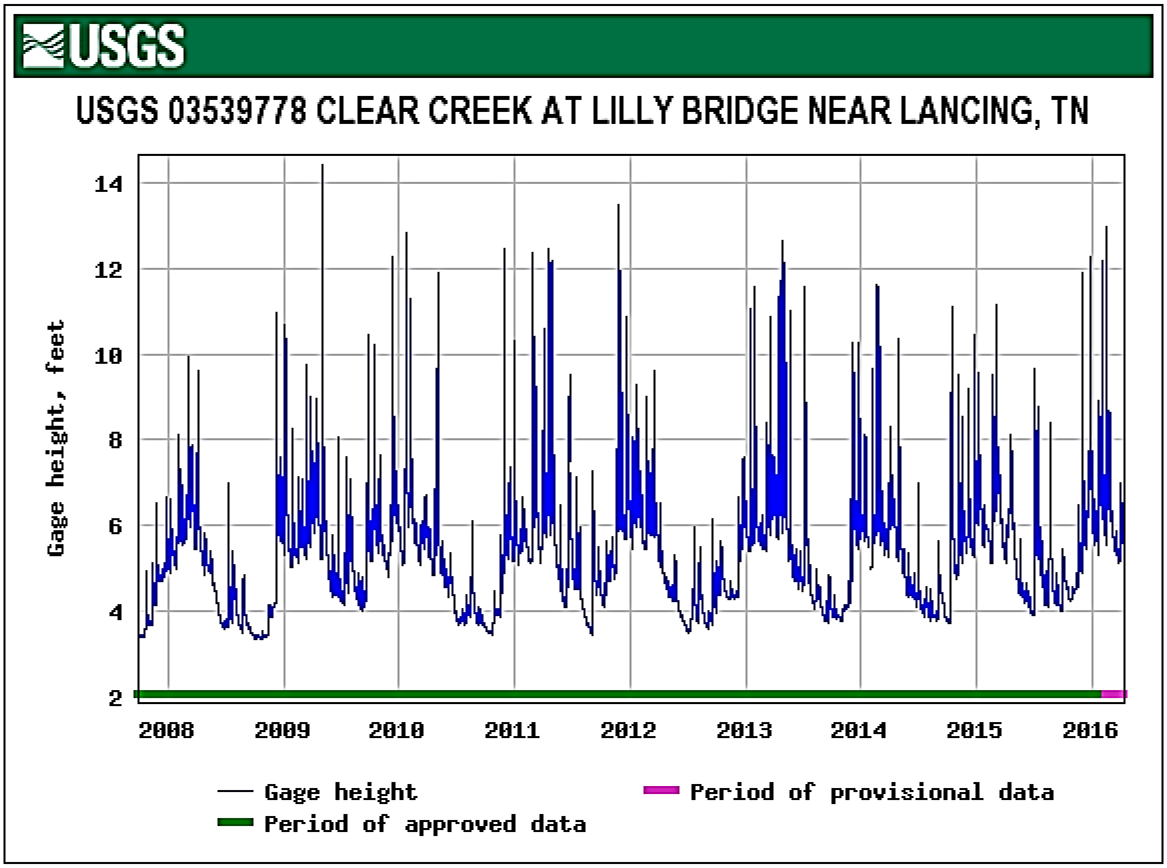


Figure R-1. Gage height (ft) observations for Clear Creek at Lilly Bridge (USGS 2016). For the purposes of this assessment, a gage height above 3.05 m (10 ft) was considered a significant runoff event.

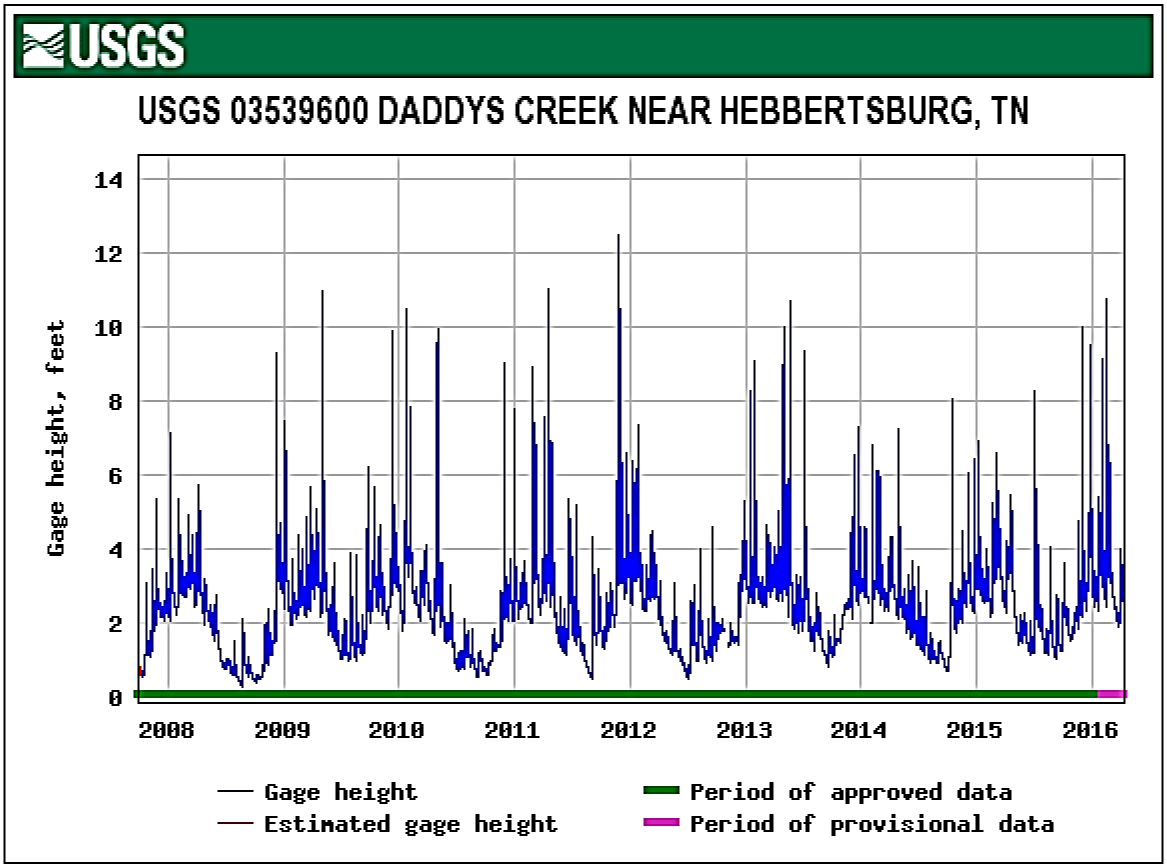


Figure R-2. Gage height (ft) observations for Daddy's Creek near Hebbertsburg (USGS 2016). For the purposes of this assessment, a gage height above 1.83 m (6 ft) was considered a significant runoff event.

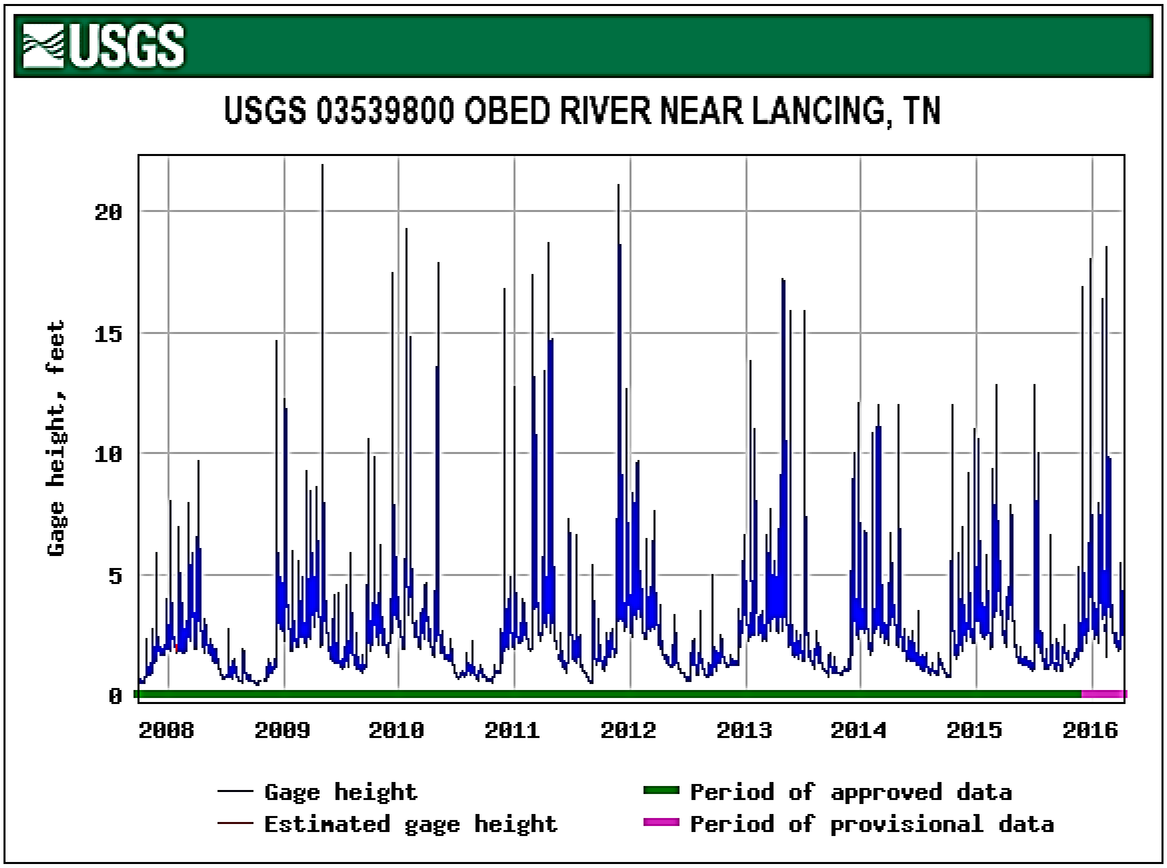


Figure R-3. Gage height (ft) observations for the Obed River near Lancing (USGS 2016). For the purposes of this assessment, a gage height above 3.05 m (10 ft) was considered a significant runoff event.

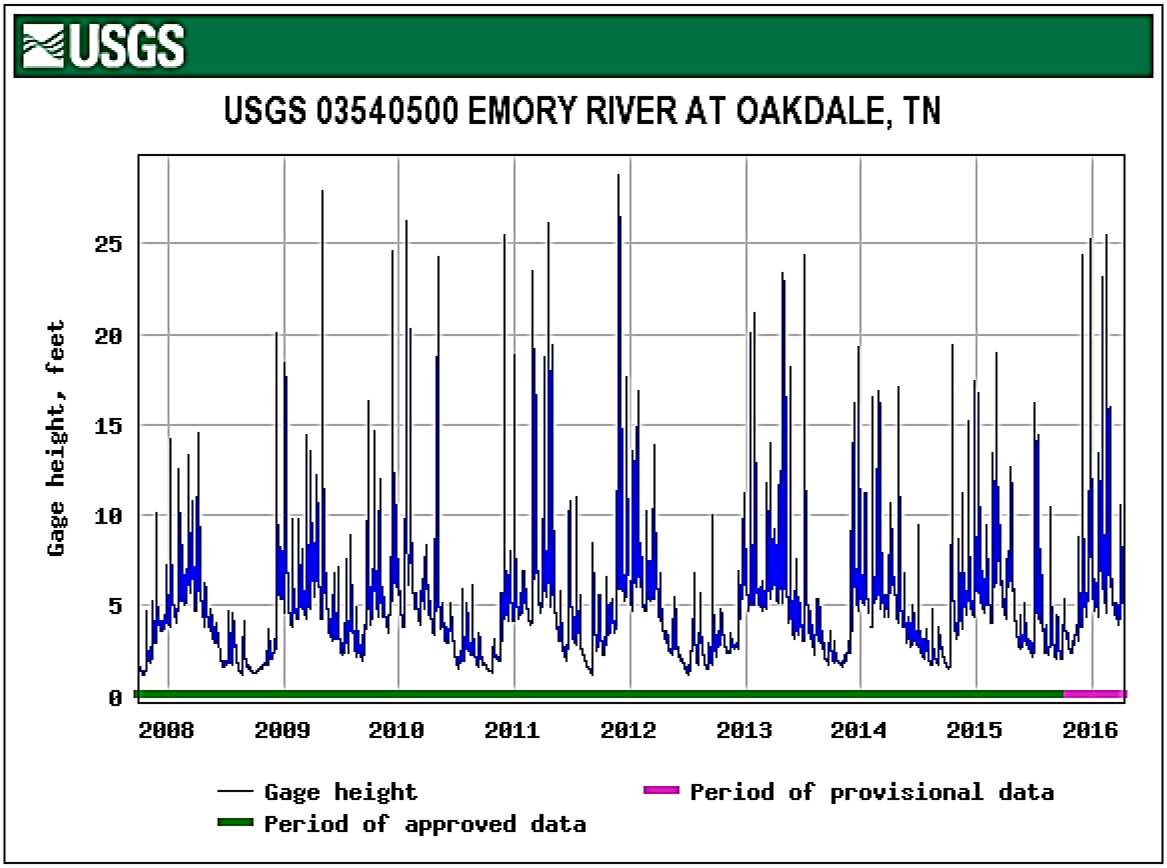


Figure R-4. Gage height (ft) observations for the Emory River at Oakdale (USGS 2016). For the purposes of this assessment, a gage height above 4.57 m (15 ft) was considered a significant runoff event.

NPS 179/141123, November 2017

National Park Service
U.S. Department of the Interior

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