National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Wolf Trap National Park for the Performing Arts Natural Resource Condition Assessment

National Capital Region

Natural Resource Report NPS/WOTR/NRR—2015/1030

ON THE COVER
Wolf Trap National Park for the Performing Arts
Photograph by: National Park Service/Thomas Paradis

Wolf Trap National Park for the Performing Arts Natural Resource Condition Assessment

National Capital Region

Natural Resource Report NPS/WOTR/NRR—2015/1030

Brianne Walsh[1], Simon Costanzo[2], William C. Dennison[2]
[1]Integration and Application Network
University of Maryland Center for Environmental Science
1 Park Place, Suite 325
Annapolis, MD 21401

[2]Integration and Application Network
University of Maryland Center for Environmental Science
2020 Horns Point Road
Cambridge, MD 21613

J. Patrick Campbell, Mark Lehman and Megan Nortrup
National Capital Region Inventory & Monitoring
National Park Service
4598 MacArthur Blvd NW, Washington DC 20007

Betsy Chittenden, Phillip Goetkin, and Christopher Schuster
Wolf Trap National Park for the Performing Arts
1551 Trap Road
Vienna, VA 22182-1643

September 2015

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

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.

Data in this report were collected using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the National Capital Region Network website (http://science.nature.nps.gov/im/units/ncrn/index.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Walsh, B. M., S. D. Costanzo, W. C. Dennison, J. P. Campbell, M. Lehman, M. Nortrup, B. Chittenden, P. Goetkin, and C. Schuster. 2015. Natural resource condition assessment for Wolf Trap National Park for the Performing Arts. Natural Resource Report NPS/WOTR/NRR—2015/1030. National Park Service, Fort Collins, Colorado.

NPS 627/129718, September 2015

Contents

Figures

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Tables (continued)

Page

Executive Summary

Background

Wolf Trap National Park for the Performing Arts (WOTR) is a 117-acre park located approximately 18 miles west of Washington, D.C. in Vienna, Virginia. Established in 1966, the park was designated as the first national park for the performing arts. The park provides a natural sanctuary for native bird, plants, and animal species in a developing region. Less than half of Wolf Trap's land is developed, leaving approximately 65 acres of woodland, streams, and wetland with a variety of plants, animals, birds, and wildflowers. The natural areas within WOTR add critical green space in a dense suburban area, offer a migration stop for wildlife, and serve as a living biology classroom to the surrounding community. WOTR consists of a diversity of natural resources including streams, ponds, wetlands, and two acres of upland forests. The park encourages education through two miles of hiking trails, as well as several demonstration gardens. WOTR also supports sustainable vegetable gardens, and several extensive native plant gardens.

Multiple regional and local stressors challenge the natural resources within WOTR. Air pollution from power plants, industry, and vehicle emissions result in reduced air quality through large regions of the eastern United States. The park is therefore subjected to high ozone and atmospheric deposition, potentially impacting flora, fauna, and park visitors. WOTR is one of the largest green spaces near Tysons Corner, Virginia, and will likely see increased visitation with increased nearby development. Watershed-wide urbanization and development result in challenges to water quality and pest management.

Natural Resource Condition Assessment

Assessment of natural resource condition within WOTR was carried out using the National Park Service Inventory and Monitoring Program Vital Signs ecological monitoring framework. Twenty-five metrics were analyzed in four categories: Air Quality, Water Resources, Biological Integrity, and Landscape Dynamics. The assessment of condition was based on the comparison of available data collected between 2002 and 2014 to ecological threshold values. Overall, the natural resources of Wolf Trap National Park for the Performing Arts were in degraded condition – based on very degraded air quality and landscape dynamics; moderate biological integrity; and good water resources.

Recommendations and Data Gaps

Degraded air quality is a problem throughout the eastern United States, and while the causes of degraded air quality are largely out of the park's control, the specific implications to the habitats and species in the park are not well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts, particularly in the face of climate change and the conclusion by the U.S. EPA that ozone concentrations and particle pollution can worsen with climate change.

Water resources within the park were in good condition overall, despite the majority of water inflows to the park originating from developed/urban areas outside the park. Maintaining good water quality and associated habitat in this intensely developed area requires identification and management of existing nutrient sources, and mitigation of "flashy" inflows to reduce streambank erosion. Water temperature increase is one of the most immediate threats from climate change, and this would result in the loss of fish and other organisms that depend upon cooler water.

Biological integrity was, on average, in moderate condition despite variability in the specific indicators. Elevated deer density is negatively impacting seedling regeneration highlighting that deer management should be a top priority. It was also identified that there was a lack of comprehensive information on exotic species, pests and diseases within the park. Expanded monitoring and education in these fields is recommended as well as research into methods for analyzing non-forest bird communities and models of the effects of climate change and other stressors on the region's forests.

Due to the small size of the park, its cultural design, regional development, and urban encroachment – the parks' landscape dynamics were very degraded. Forest interior area, forest cover, and impervious surface (at multiple spatial scales) were all in very degraded condition, as was road density within the park. This condition will likely continue with new developments in the area (e.g. Tysons Corner) putting additional stress on the natural habitats of Wolf Trap, while also adding pressure on the park to provide recreational opportunities and open space for growing populations. Research needs for the park mostly relate to its function as a habitat refuge in the region

Acknowledgments

Geoff Sanders, John Paul Schmit, Jim Pieper, Marian Norris, and NPS National Capital Region Network, Inventory & Monitoring staff, who provided data support. Scott Bates, and staff at the National Capital Region Office of Natural Resources and Science (formerly known as the Center for Urban Ecology) who assisted with data sources and scoping. Drew Bingham and Ellen Porter, NPS Air Resources Division, for advice on air quality metrics. Jane Thomas, Jamie Testa, Nicole Lehmer, and Catherine Ward at the Integration and Application Network for assistance with project scoping, initiation, and document review.

NRCA Background Information

> **NRCAs strive to provide** credible condition reporting for a subset of important park natural resources and indicators.

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 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 GIS (map) products;[4]
- summarize key findings by park areas; and[5]
- 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 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

---

[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 or quantitative terms, and as a single value or a range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological reference conditions 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 coverage's 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.

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 members are 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.

Important NRCA success factors

Obtaining good input from the park and other NPS subject matter experts 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.

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.

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

***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 the park areas and natural resouces 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*

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.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm

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.

Introduction and Resource Setting

Introduction

Wolf Trap National Park for the Performing Arts (WOTR) is located in Vienna, Virginia, approximately 29 km (18 miles) west of Washington, D.C. Originally established under the name Wolf Trap Farm Park (October 15, 1966, Public Law 89-671 89th Congress, S. 3423), the park was designated as the first national park for the performing arts (NPS 2013b) in 2002. Catherine Filene Shouse founded Wolf Trap by the donation of farmland to the United States government, as well as some of the funds to construct a 7,024-seat outdoor theater (Figure 2-1). The Filene Center opened in 1971 and was designed to be in harmony with the pastoral setting of the National Park in which it is situated. In addition to its value as a venue devoted to the presentation of the performing arts, the 117-acre park provides a natural sanctuary for native bird, plant, and animal species in a continually developing region (Thornberry-Ehrlich 2008).

Figure 2-1. A bust of Catherine Filene Shouse. Photo: NPS.

On April 4, 1982, a fire completely destroyed the Filene Center, and a temporary structure was constructed in Wolf Trap's meadow. Both the 1982 and 1983 seasons were held in the "meadow center" while the Filene Center was rebuilt. The current structure opened July 30, 1984, and is a steel structure clad with Douglas fir. A little over half of the seating, 3874 seats, are under cover with open sides that look out onto the forested areas and rolling hills of the park; the lawn area seats another 3150 (Figure 2-2). The Filene Center season usually runs from the end of May to the beginning of September with an average of 90 outdoor performances a year.

Figure 2-2. A crowd attending a Filene Center performance. Photo: NPS.

Two additional performance venues also exist within the park. The Children's Theatre-in-the-Woods is an outdoor amphitheater in the woods near Wolf Trap Run (Figure 2-3). The Meadow Pavilion also serves as a stage area within the park, offering a smaller venue for shows and performances (NPS 2013b).

Figure 2-3. The Children's Theatre-in-the-Woods. Photo: NPS.

Wolf Trap National Park for the Performing Arts is managed by the National Park Service (NPS) in partnership with the Wolf Trap Foundation for the Performing Arts. The NPS cares for the 117-acre park grounds and facilities, provides interpretive and educational programs, is responsible for visitor services and safety, and directs the operation and maintenance of the technical equipment and backstage facilities that serve the performing artists. The foundation is responsible for the artistic programming, ticketing, public relations, and marketing of the Filene Center and the Children's Theatre-in-the-Woods (NPS 2013b).

Less than half of WOTR's land is developed, leaving approximately 65 acres of woodland, streams, and wetland with a variety of plants, animals, birds, and wildflowers. The natural areas within WOTR add critical green space in a dense suburb, offer a migration stop for wildlife, and serve as a living biology classroom to the surrounding community (NPS 2013b). The park encourages education through two miles of hiking trails, as well as several demonstration gardens. Wolf Trap National Park for the Performing Arts also supports sustainable vegetable gardens and several extensive native plant gardens.

Park legislation

In October 1966, Public Law 89-671 (80 Stat. 950) authorized the establishment of Wolf Trap Farm Park for the Performing Arts *"…for the purpose of establishing in the National Capital area a park for the performing arts and related educational programs and recreation use in connection therewith…*"

Along with the park's enabling legislation, several laws and documents guide natural resource management for WOTR. The primary one is the National Park Service Organic Act of August 25, 1916 ("Organic Act," Ch. 1, 39 Stat 353) that established the National Park Service (NPS). It states,

"the service thus established shall promote and regulate the use of Federal areas known as national parks, monuments and reservations . . . by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

As stated in the Foundation Document of the park, the purpose of Wolf Trap National Park is:

"*to provide opportunities to experience live performances, related educational programs, and associated recreation in a pastoral setting within the National Capital area."* (NPS 2013a: 6).

Several other laws and documents guide management for Wolf Trap National Park for the Performing Arts. Under Public Law 97-310, the Secretary of the Interior was directed to enter into agreements with the Wolf Trap Foundation, a private not-for-profit organization, to establish responsibilities regarding the presentation of performing arts and related educational and cultural programs in the park (NPS 2005). This gives the park legislative authority to work with the Wolf Trap Foundation.

After the devastating fire in 1982, Public Law 97-310, dated October 14, 1982, was passed to provide "financial assistance to the Wolf Trap Foundation for the Performing Arts for reconstruction of the Filene Center in Wolf Trap Farm Park, and for other purposes". The financing was later restructured under Public Law 101-636, dated November 28, 1990.

Geographic Setting

Park description

Wolf Trap National Park for the Performing Arts is located in Fairfax County, Virginia near the town of Vienna (Figure 2-4). The park is bordered by residential neighborhoods on its east, west, and north, and by VA Route 267 (Dulles Access and Toll Road) to the south and southwest (Figure 2-5). Additionally, Trap Road, a minor arterial road maintained by the Virginia Department of Transportation runs through the park. The park is located approximately 2.4 miles northwest of Tysons Corner, VA, and eighteen miles west of Washington, D.C.

The park lies within the Piedmont Physiographic Province. Varied hydrological influences acting on the underlying geology have built a complex topography at WOTR. The landscape consists of wooded rolling hills, a stream valley, and flat to gently sloping areas. The overall elevation range is about 30 m (100 ft.). The highest hills in the park are in the southeast corner; the lowest points are in the flood plain in the northwest corner. These topographic and elevation differences in addition to seasonal flooding support a diversity of habitats ranging from year-round wetlands to dry, steep, forested slopes (Thornberry-Ehrlich 2008).

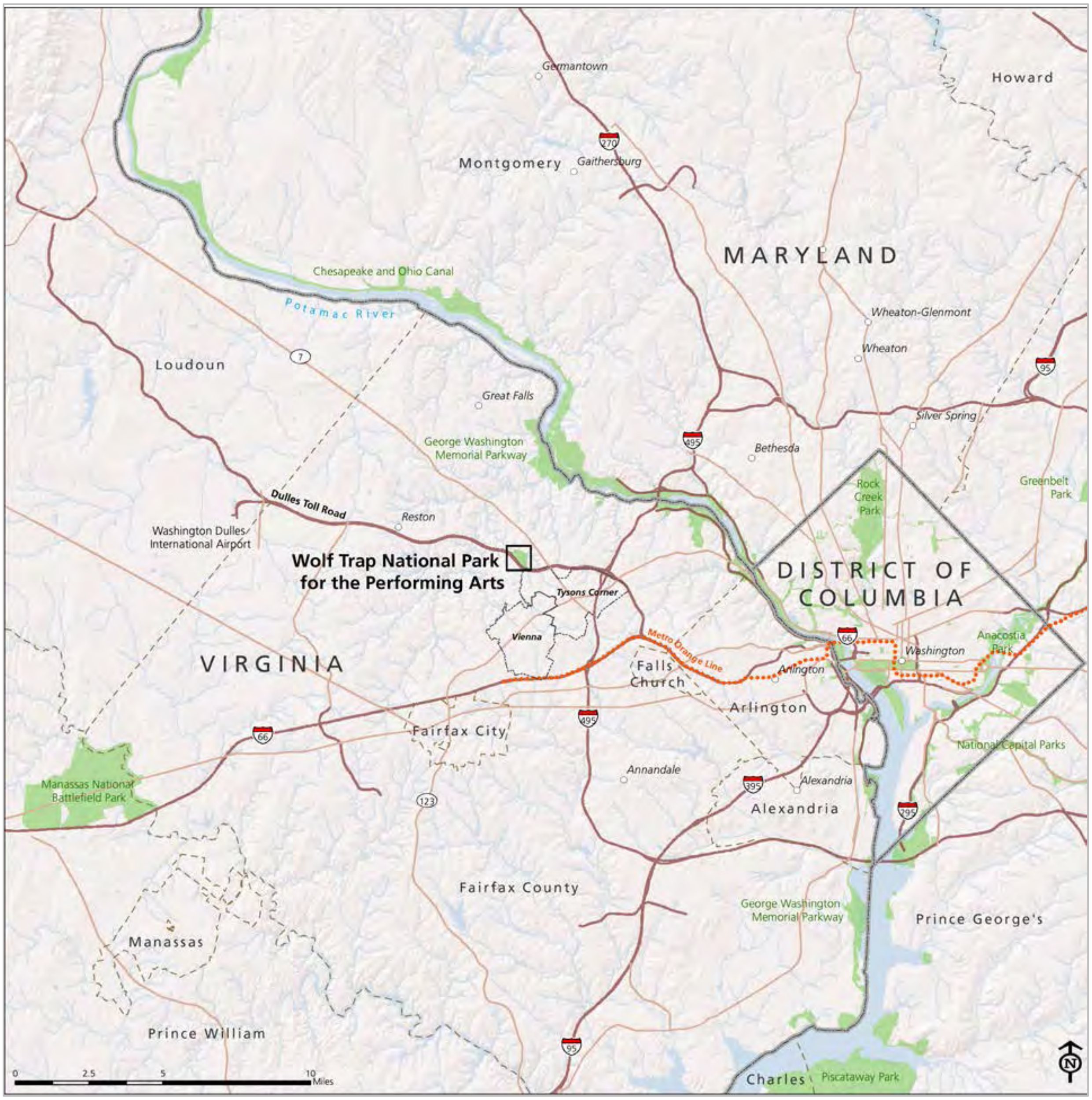


Figure 2-4 Location of WOTR in northern Virginia (NPS).

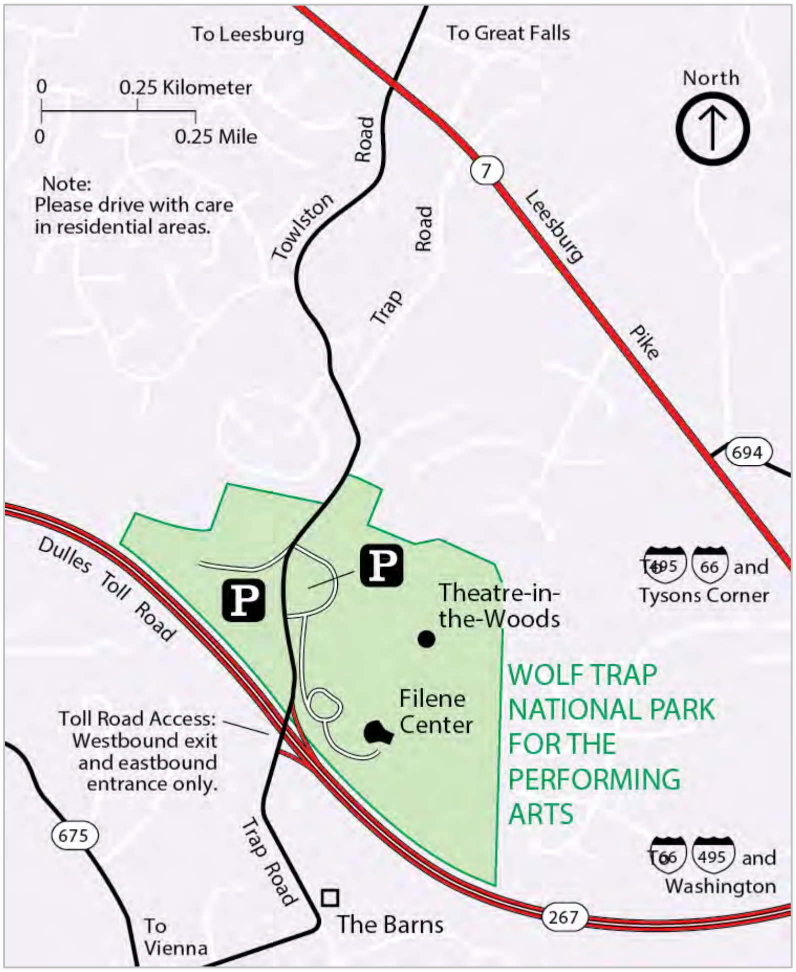


Figure 2-5 NPS Map of Wolf Trap National Park for the Performing Arts (NPS).

Land Use

Wolf Trap National Park for the Performing Arts lies within the Potomac River watershed, in north-central Fairfax County (Figure 2-6). Land cover in the Potomac River watershed is approximately 58% forest, 32% agriculture, 5% water and wetlands, and 5% developed (Figure 2-7) (ICPRB 2012). The basin's major industries include: agricultural and forestry throughout; coal mining and pulp and paper production along the North Branch Potomac River; chemical production and agriculture in Shenandoah Valley; high-tech, service, and light industry, as well as military and government installations in the Washington metropolitan area; and fishing in the lower Potomac estuary (ICPRB 2012).

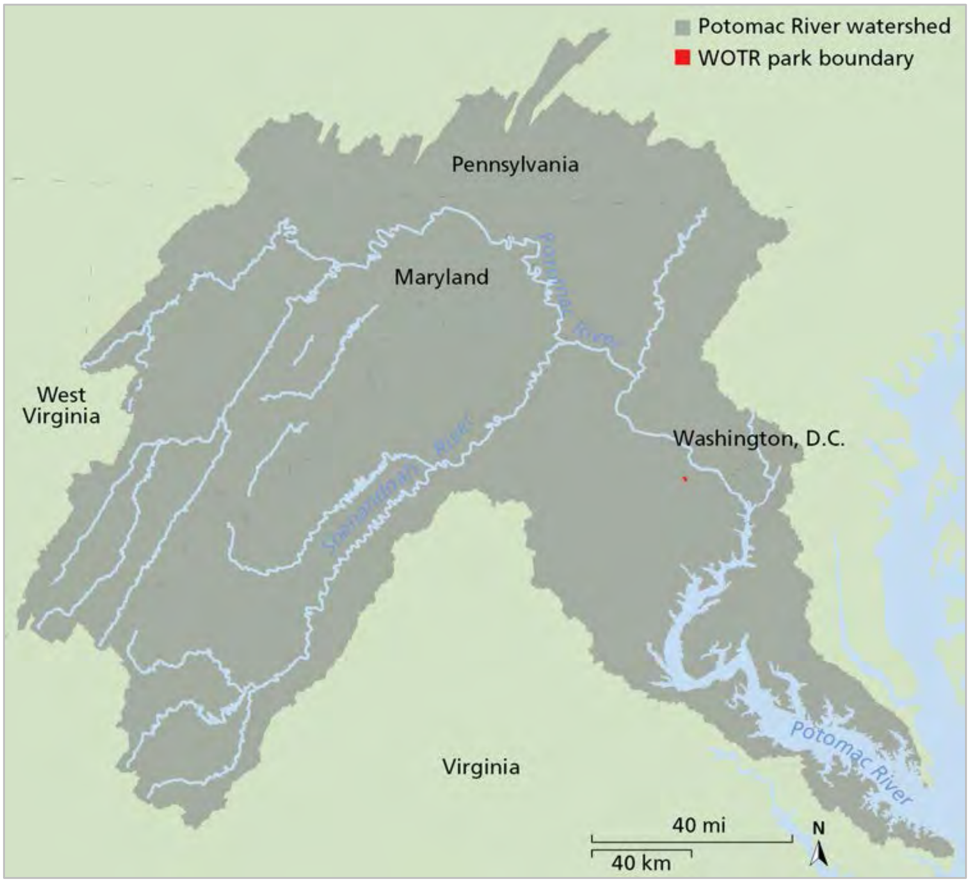


Figure 2-6 The Potomac River Watershed (USGS).

About half of the park is heavily developed and maintained, with structures, parking lots, paved roads, trails, mowed lawns, and meadows (Figure 2-8). Within the park are four distinctive areas—fenced grassy fields that convey the pastoral quality of past farm use; the Filene Center theater complex; the old farmhouse and its associated buildings and gardens, and the remainder, a relatively undisturbed forest (NPS 2005). With progressive distance away from the park boundary (up to 30 km analyzed), the amount of green space decreases. The proportions of land use within the 30 km boundary have remained relatively stable since 2001, with the exception of forested areas within the 5x area of the park, which showed an approximate 5% decline between 2001 and 2006 (Figure 2-8).

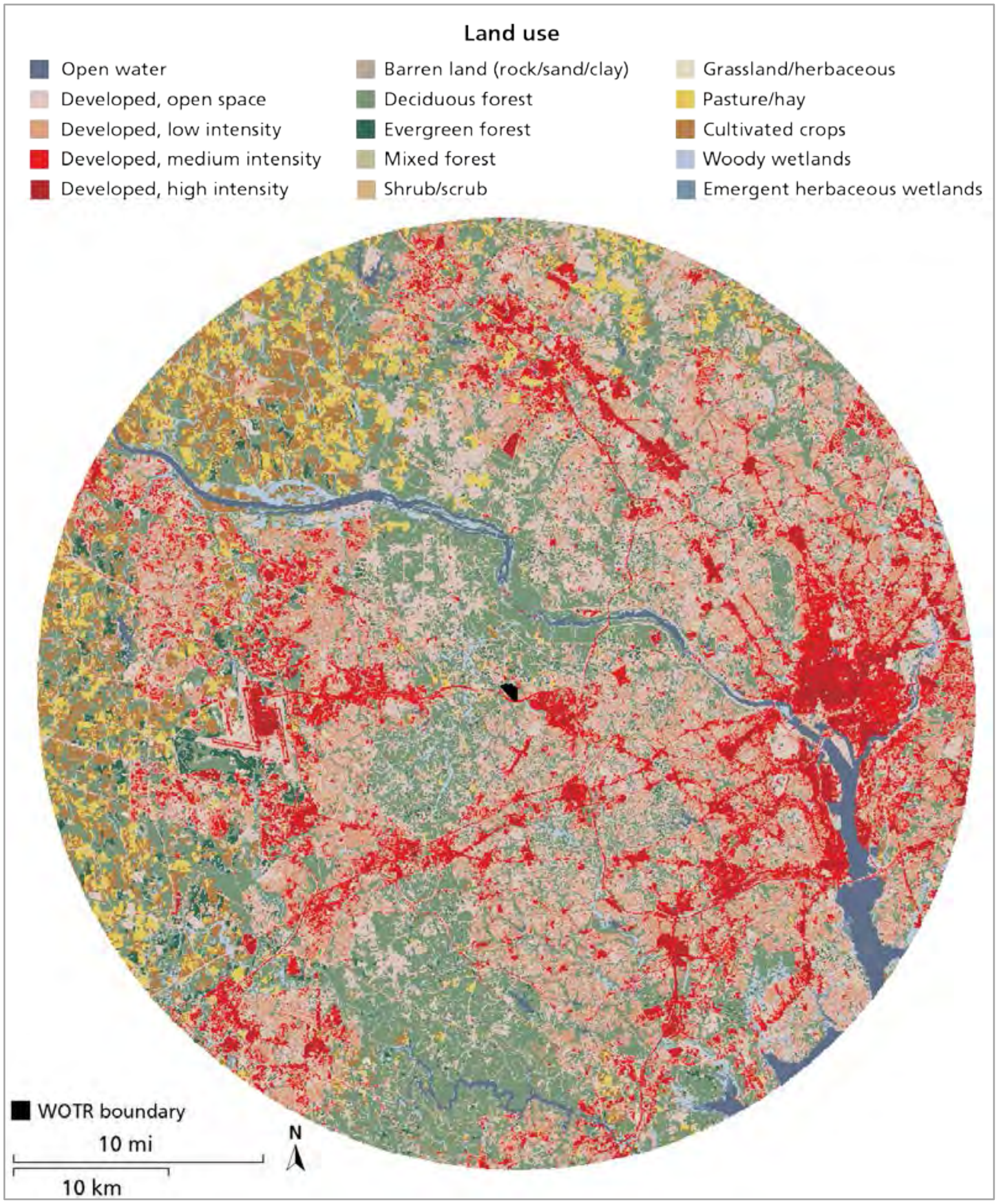


Figure 2-7 Adjacent land use within a 30 km area surrounding WOTR in 2011 (Jin et al. 2013; NPS 2011a).

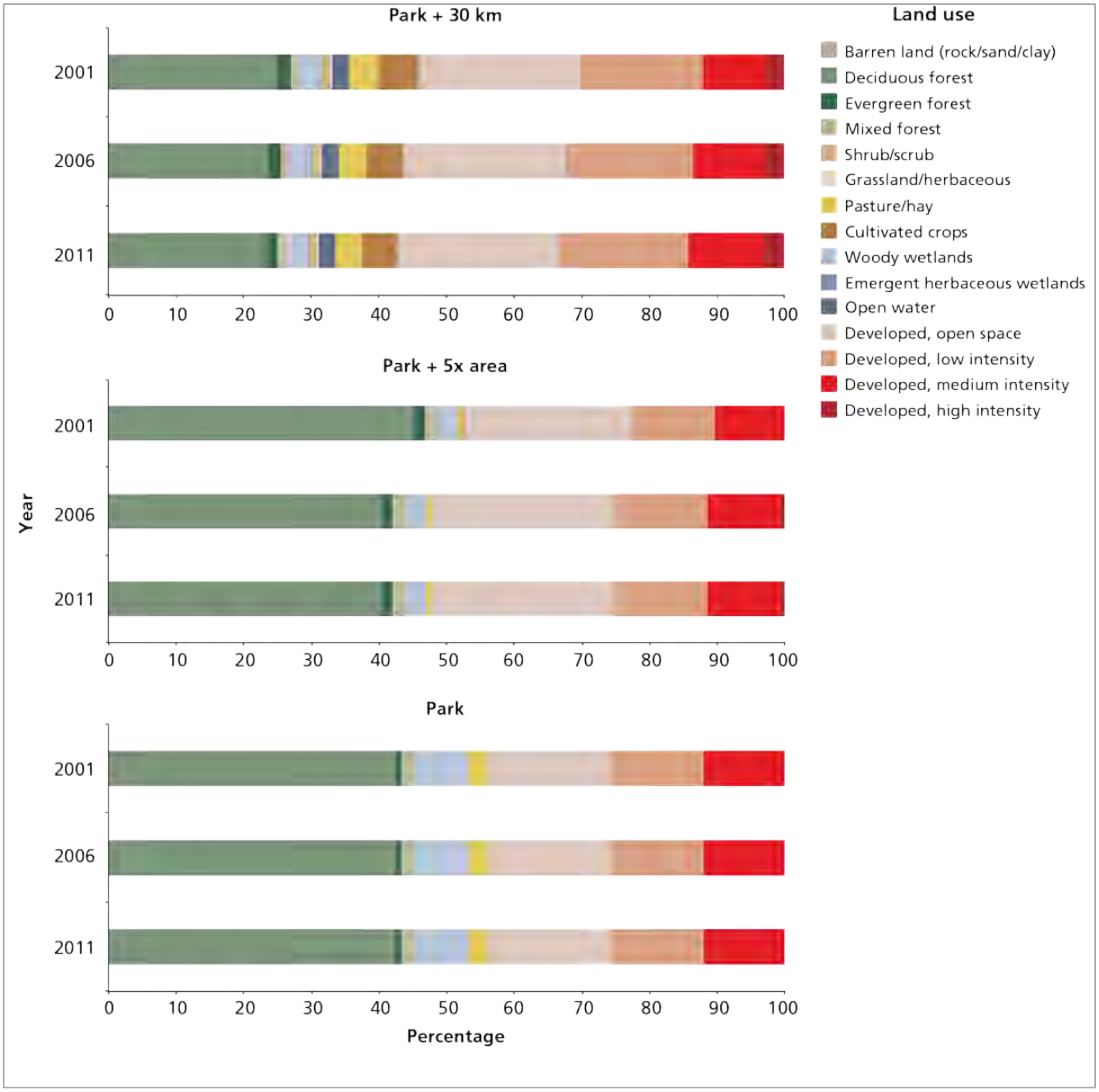


Figure 2-8 Changes in land use from 2001 to 2011 at three scales (Park + 30 km, Park + 5x area, Within Park) surrounding WOTR (Jin et al. 2013; NPS 2011a).

Fairfax County is an intensely developed suburban area, lying within the Washington, D.C. metropolitan area. Most of the area directly bordering the park is residential neighborhoods, consisting of low density, single-family houses. Housing density surrounding the park has grown rapidly in the past ten years (Figure 2-10) coinciding with increased population in northern Virginia and the D.C. metropolitan region. The Dulles Access and Toll Roads, a major commuting corridor, form the southwestern border of the park. While there are no commercial or industrial facilities directly bordering the park, Tysons Corner, only a few miles away, is a major employment and retail center, with numerous high- and mid-rise buildings as well as high density housing (NPS 2005).

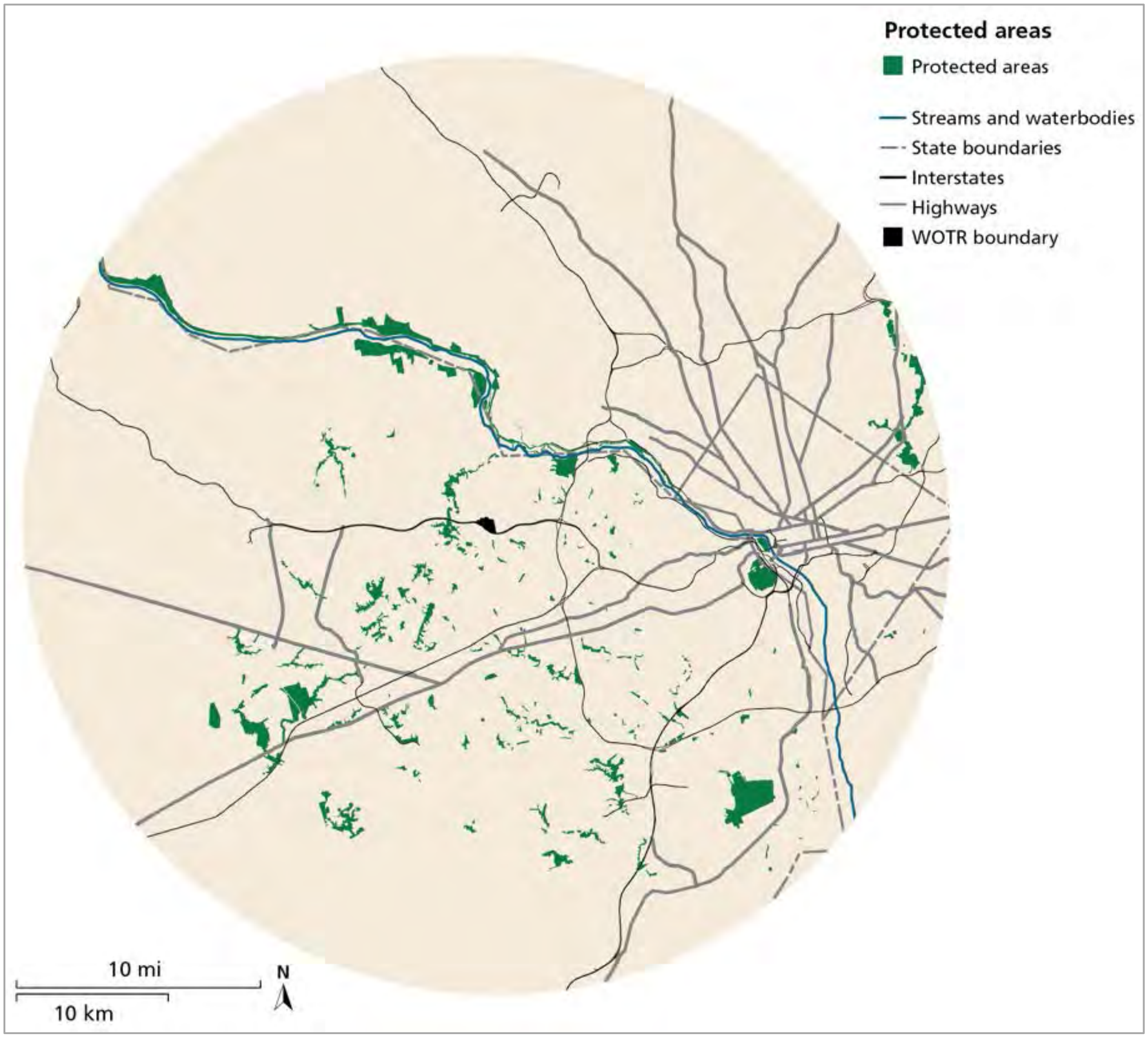


Figure 2-9 Protected areas within a 30-km area surrounding WOTR in 2011 (NPS 2011a).

Population

An estimated 6.11 million people live in the Potomac River watershed (Figure 2-6) (U.S. Bureau of the Census 2013). Three-quarters of the basin's population (approximately 5.36 million people) live within the Washington, D.C. metropolitan area. Fairfax County's population has grown steadily in recent years, increasing from a population of 969,749 in 2000 to a population of 1,081,700 in 2010 (Figure 2-11), making it the most populous jurisdiction in both Virginia and the Washington, D.C. metropolitan area (Fairfax County 2013b). This 11.5% increase is in comparison to a 13% increase in population statewide (U.S. Bureau of the Census 2013a).

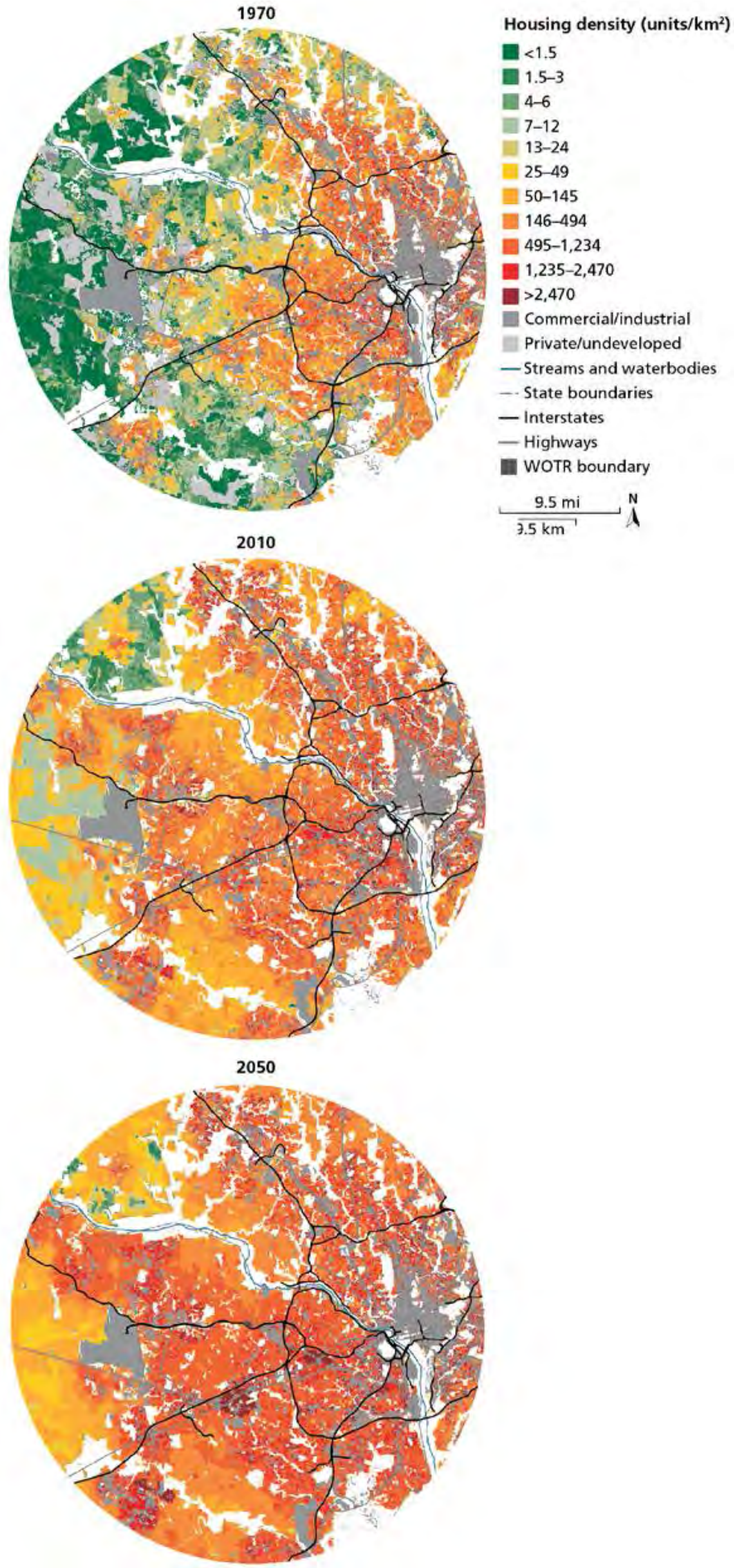


Figure 2-10 Housing density within a 30-km area surrounding WOTR in 1970, 2010, and projected for 2050 (NPS 2011a; NPS 2014a).

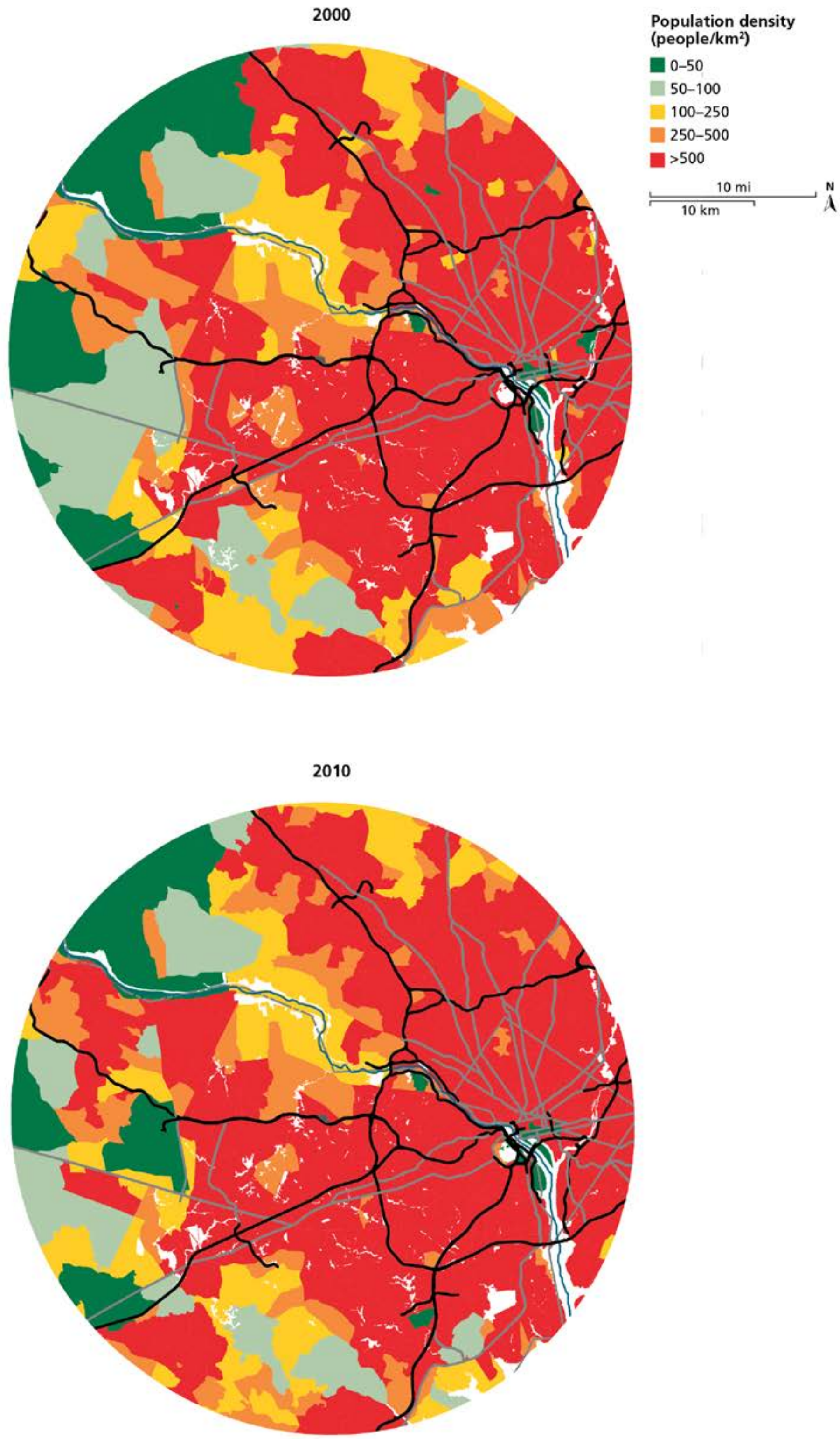


Figure 2-11 Population density around the park in 2000 and 2010 (NPS 2011, U.S. Census 2011).

Climate

Wolf Trap National Park for the Performing Arts and the surrounding areas experience all four seasons, with an annual average temperature of 12.9°C (55.3°F) (National Weather Service 2013a). Spring and fall are generally comfortable with some precipitation possible. Summers can be hot and humid with an average temperature of 23.8°C (74.9°F), and can experience sudden thunderstorms. Winters are cold with an average temperature of 1.8°C (35.3°F) (National Weather Service 2013b), and variable precipitation. The average annual precipitation in Wolf Trap is 1.1 meter (41.54 inches) (National Weather Service 2013c). The average annual snowfall for the area is 0.6 meters (22.0 inches) (National Weather Service 2013c).

There are no weather or climate stations located within WOTR. There are 26 National Weather Service Cooperative Observer Program (COOP) stations that are currently in operation within 10 km of WOTR. Because the park is located close to Dulles International Airport, real time climate observations are readily available (Davey et al. 2006).

Visitation Statistics

While visitors use the park year-round, the majority of visitation coincides with the performance season, running from mid-May to mid-September (Figure 2-12). Annual visitation is currently between 400,000 and 450,000 per year; in 2012 approximately 426,996 people visited WOTR for recreational purposes (NPS 2013c). An average of about 5,000 people are present for each performance in the park and maximum seating (a sold out show) is 7,024 audience members (NPS 2005).

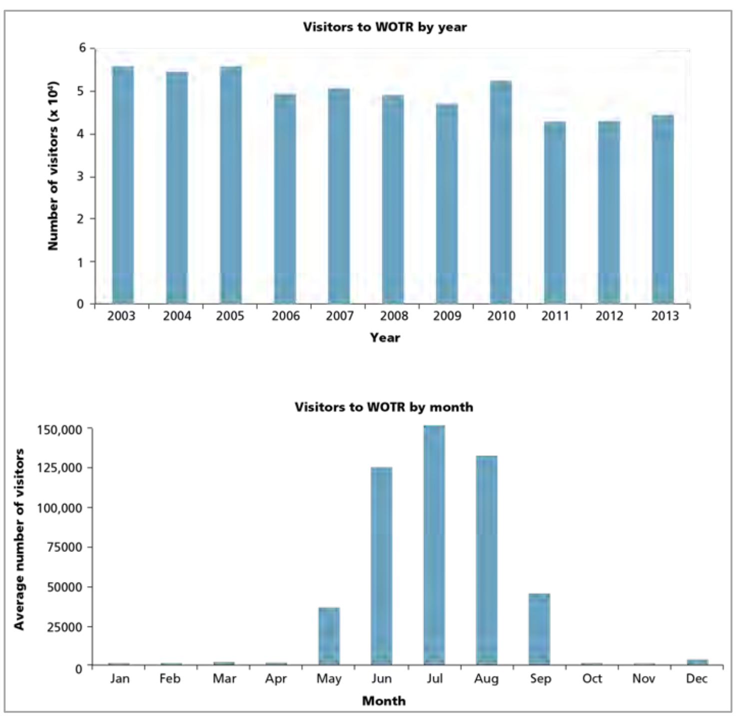


Figure 2-12 Visitors to WOTR over the past decade (2003-2013) by year (top) and by month (bottom) (NPS 2013c).

Natural Resources

Resource descriptions

Wolf Trap National Park for the Performing Arts consists of 117-acres, about half of which make up a designed landscape. The park consists of a diversity of natural resources including streams, ponds and two acres of upland forests; making up a large area of green space in an otherwise urbanized region. WOTR is one of the largest green spaces near Tysons Corner, VA and will likely see increased visitation with increased nearby development.

WOTR forests consist mostly of bottomland hardwood species and mixed deciduous species on small ridges. The understory and herbaceous layers are dominated in many areas by exotic invasive species, especially in the flood plain of Wolf Trap Creek. Humans have created other habitats within the park, such as rights-of-way, roads, trails, ponds, and mowed lawns (Pauley *et al.* 2005).

Geology

Wolf Trap National Park for the Performing Arts is located at the narrow north end of the Western Piedmont physiographic province in northern Virginia. The park is near the Fall Line (between the Piedmont and Atlantic Coastal Plain) to the east, and the Blue Ridge province to the west (Thornberry-Ehrlich 2008).

Lower Paleozoic metasedimentary and metaigneous rocks, associated with the suture zone between the Blue Ridge and the Piedmont, constitute some of the underlying rocks of WOTR (Thornberry-Ehrlich 2008). The oldest rock underlying the park is the Precambrian-Early Cambrian Peters Creek Schist (NPS 2013b). The Peters Creek Schist contains a variety of metamorphic rocks including metagraywackes and schists. Granodiorite, an intrusive (subsurface) igneous rock, has also been mapped in the park. The western portion of WOTR has been mapped as Quaternary (recent) Alluvium (Figure 2-13) (NPS 2013b).

The landscape of WOTR consists of wooded rolling hills, a stream valley, and flat to gently sloping areas (Figure 2-14). The park has a complex topography due to varied hydrological influences acting on the underlying geology (Thornberry-Ehrlich 2008). The overall elevation range in WOTR is about 30 m (100 ft.) where the highest hills are situated in the southeast corner, and the lowest points made up of a floodplain are in the northwest corner (Thornberry-Ehrlich 2008). The park can thus support a diversity of habitats ranging from year-round wetlands to dry, steep, forested slopes.

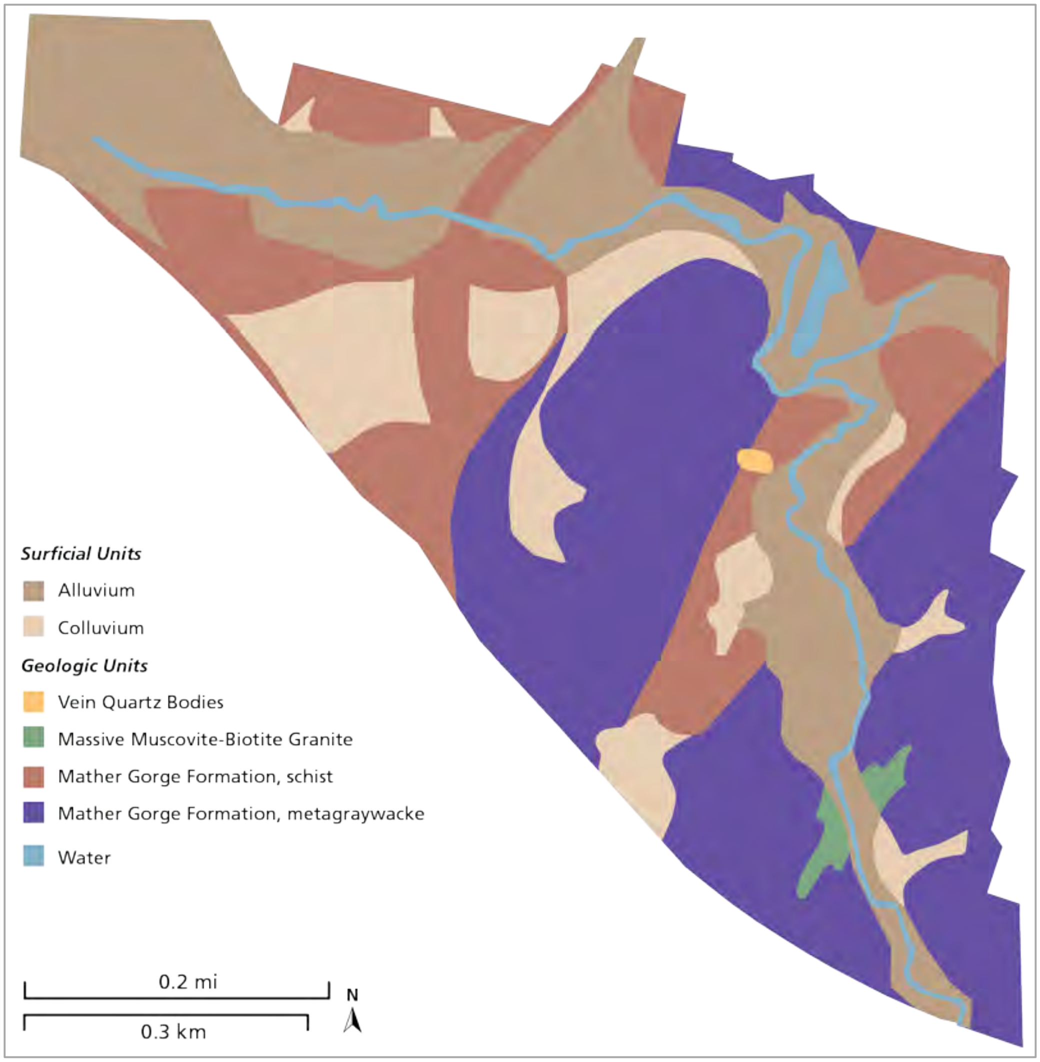


Figure 2-13 Geology of WOTR (Thornberry-Ehrlich 2008).

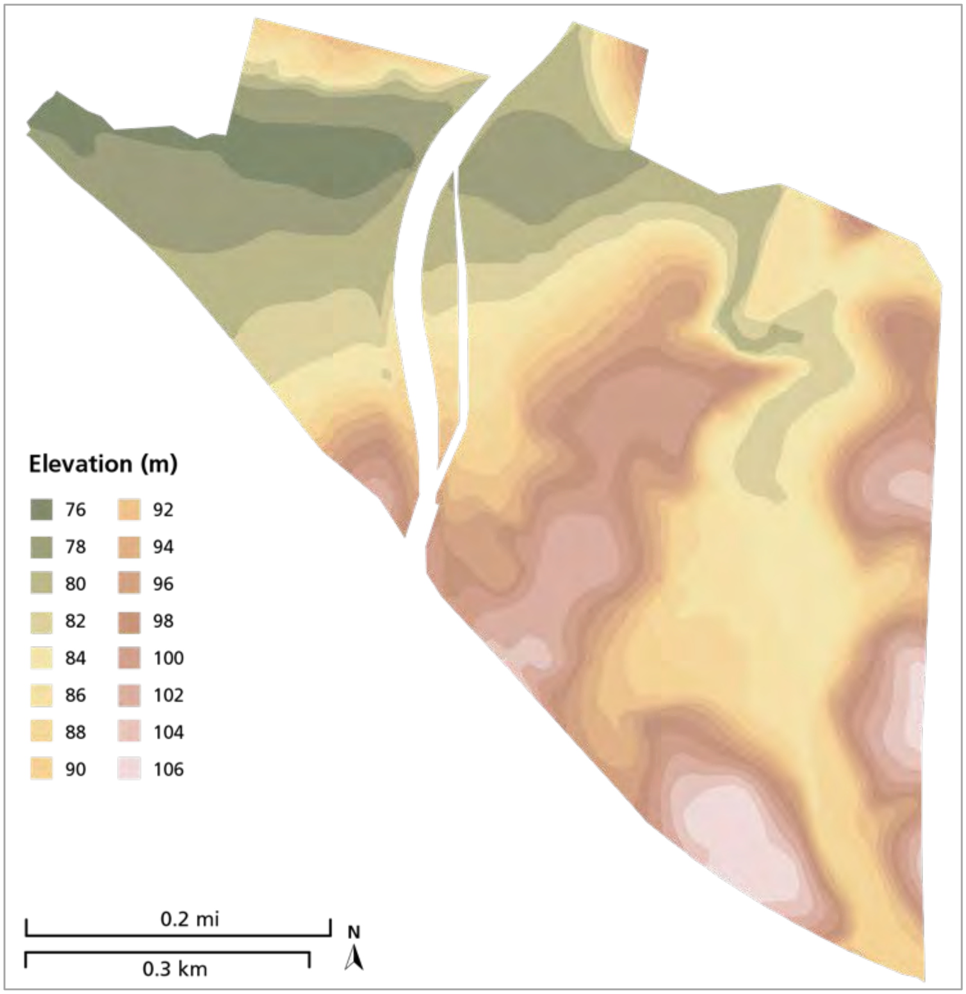


Figure 2-14 Topographic elevation of WOTR (NPS, Nature Serve).

Soils

Within the region of the park, soils have been developed from a variety of basement rocks including limestone, greenstone, red shale, and quartzite (Figure 2-16) (Thornberry-Ehrlich 2008). Soils in the Piedmont province are highly weathered and generally well drained (Figure 2-15).

Soils found in WOTR have been disturbed and altered by agriculture, development, urbanization of the surrounding area, and erosion (Thornberry-Ehrlich 2008). In numerous places throughout the park, unconsolidated soils and sediments are exposed on a slope with sparse vegetation (Figure 2-16). The slope angle and lack of stabilizing vegetation renders the soil materials highly susceptible to erosion and degradation (Thornberry-Ehrlich 2008).

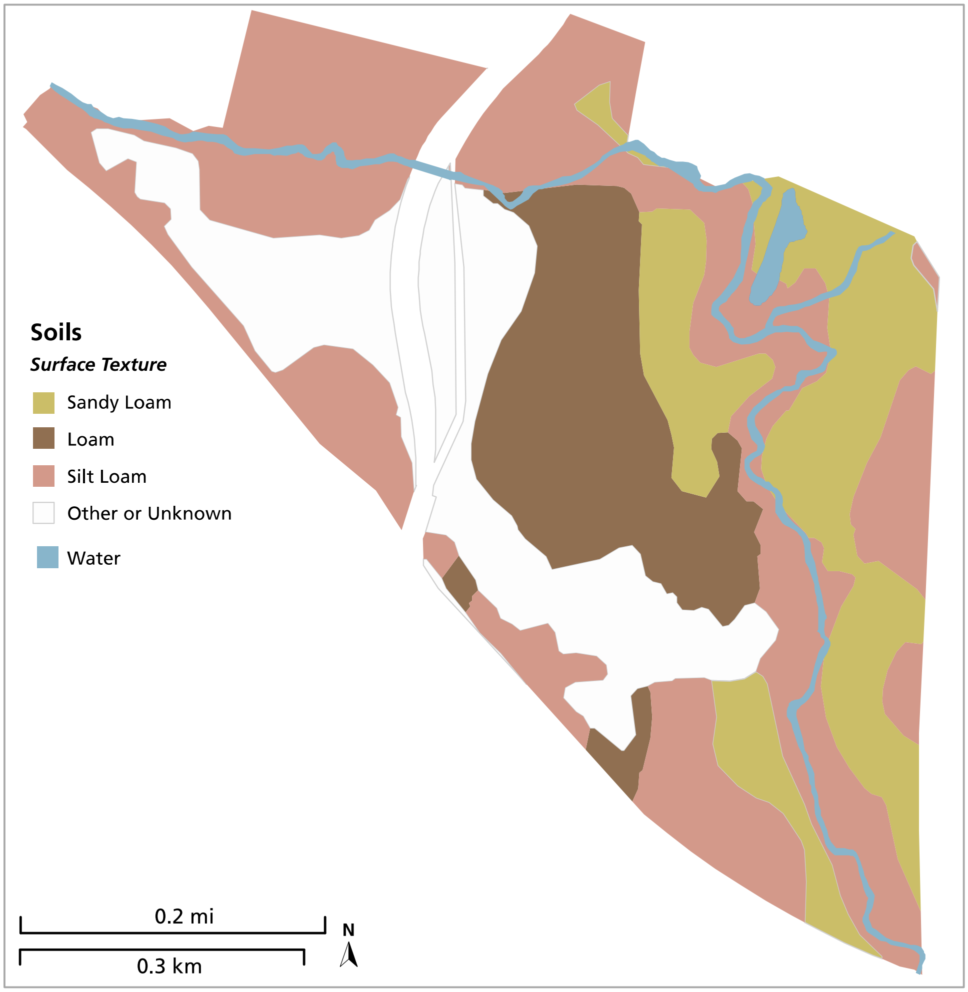


Figure 2-15 Soil texture in WOTR (NPS, USDS NRCS, National Cooperative Soil Survey).

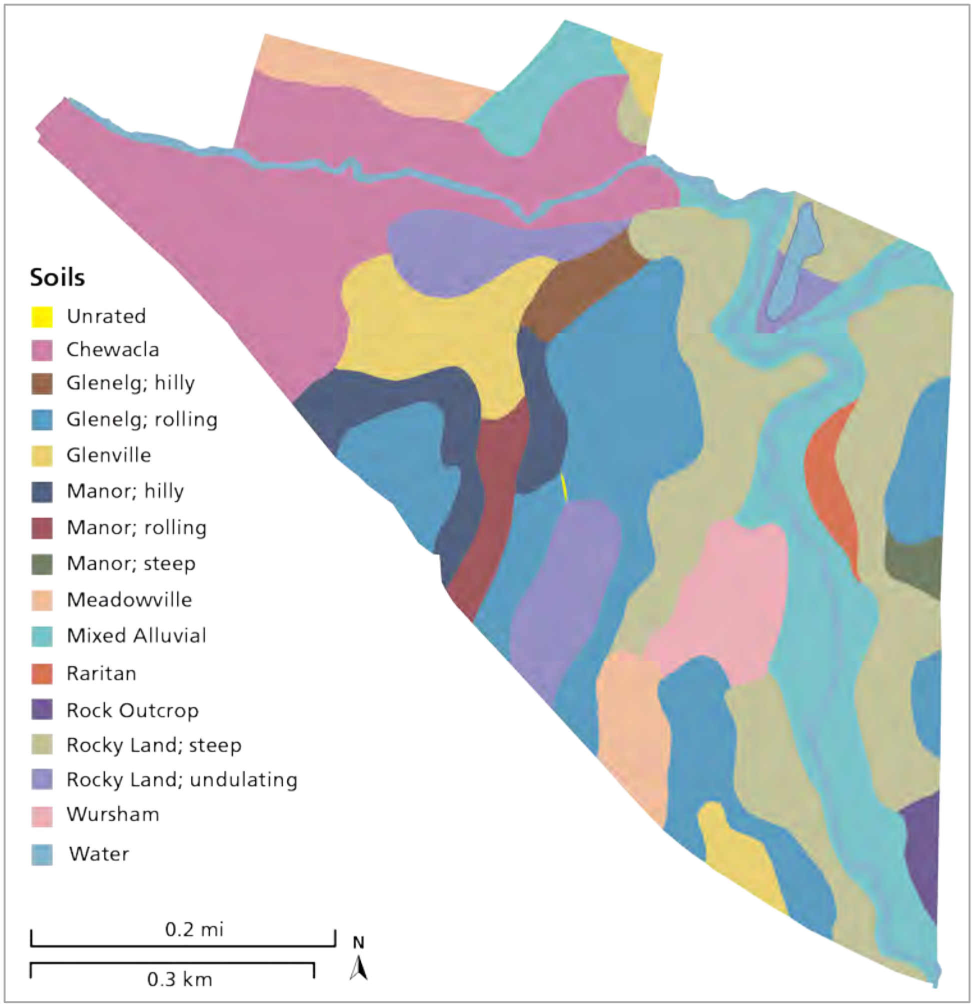


Figure 2-16 Soil taxonomy in WOTR (NPS, USDS NRCS, National Cooperative Soil Survey).

Watershed/Waterways

Wolf Trap National Park for the Performing Arts is located within the Potomac River drainage basin. The Potomac River watershed drains 37,995 km^2 (14,670 mi^2) across Maryland, Virginia, West Virginia, Pennsylvania, and the District of Columbia (Figure 2-6) (ICPRB 2012). After the Susquehanna River, the Potomac is the second largest tributary to Chesapeake Bay. The Bay watershed is 64,000 square miles (166,530 square kilometers, extends into six states—Virginia, Maryland, Delaware, Pennsylvania, and New York; and is home to more than 17 million people (Chesapeake Bay Program 2012).

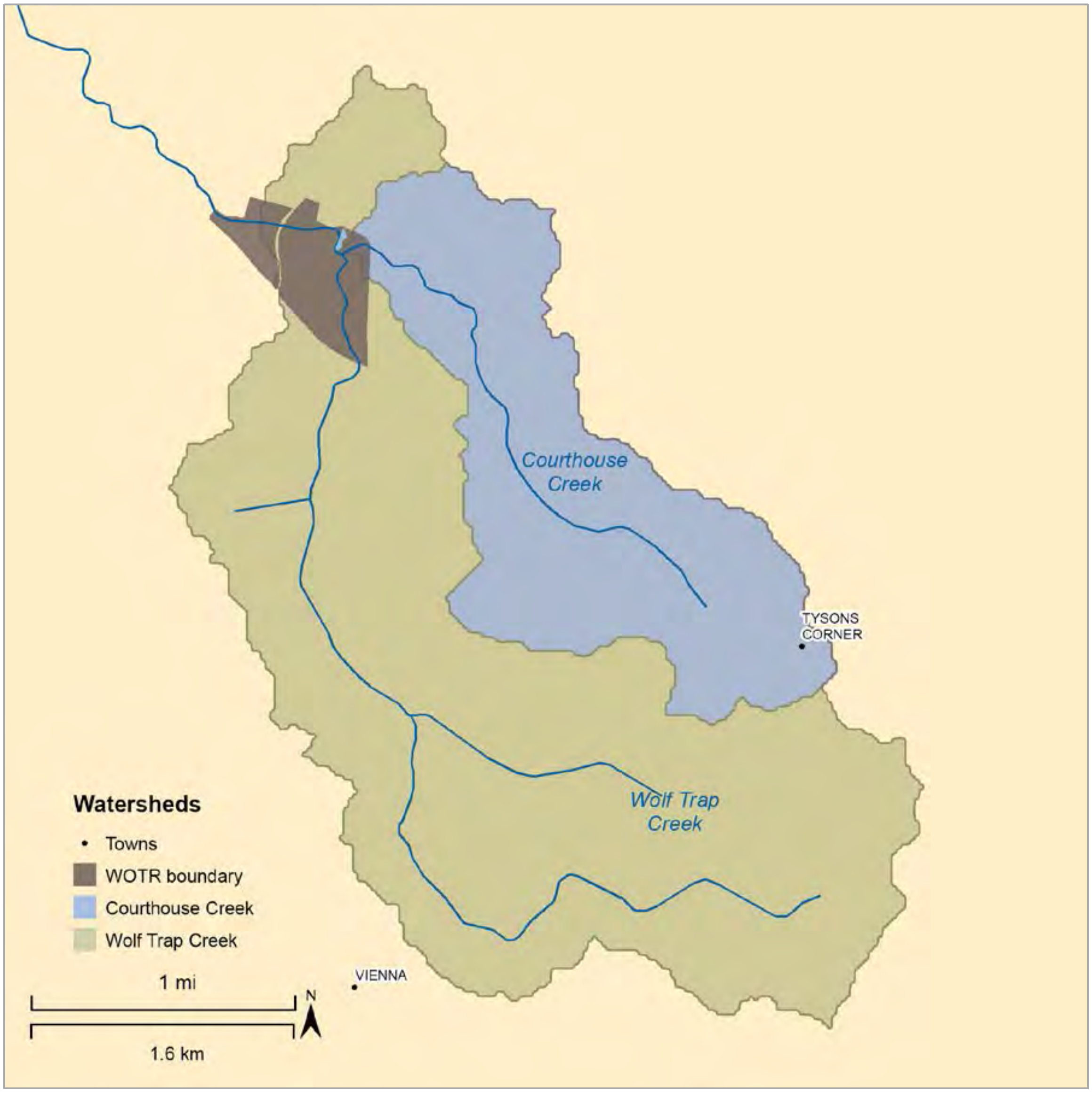


Figure 2-17 Courthouse Creek and Wolf Trap Creek watersheds (USGS 2014).

The park is part of the Difficult Run Watershed, a tributary of the greater Potomac watershed. Two streams, Courthouse Creek and Wolf Trap Creek, meet within the WOTR boundary and flow through the park, eventually draining into Difficult Run (NPS 2013b). The Difficult Run watershed covers 58.3 square miles (150 square kilometers), and is the largest watershed in Fairfax County, Virginia.

These two streams are important natural resources (Pieper et al. 2012). The main stream, Wolf Trap Creek, is a type C low gradient stream with meandering alluvial channels and broad, well-defined floodplains (NPS 2013b). The creek flows to the north from the southeast point of entry into the park. Halfway through its run, in the northeast section of the park, Wolf Trap Creek is joined by Old Court House Branch Creek (Courthouse Creek); where it redirects to the west and exits the park from the park's northwest boundary (NPS 2013b).

Figure 2-18. Wolf Trap Creek in the spring. Photo: NPS.

Wetlands

Wetlands are defined by the presence of one or more of the following: hydrology that supports flooding and saturation, hydric soils, and hydrophytic plants (Cowardin et al. 1979). They provide unique habitat, help control erosion and regulate flooding, and recharge groundwater and stream flow in drought years. Wetlands also act as natural filters for impurities and pollution in the water and are vital components of healthy ecosystems.

Wolf Trap National Park for the Performing Arts has a two-acre former farm pond, now surrounded by forest, that provides valuable habitat for a variety of amphibians, birds and other animals (NPS 2013b). The park also contains several permanent springs and several acres of permanent wetland (NPS 2005).

Managed Landscapes

Much of the area immediately surrounding the Filene Center theater are grass-covered hills, that are managed for overflow parking, picnicking, and recreation. The most heavily managed turf area of the park is the Filene Center's Lawn seating area. The amount of regularly mowed turf in the park has been reduced over the past several years from 35 acres to 25 acres. The park has a Turf Management Plan and is attempting to make changes to be more sustainable when managing grass areas (NPS 2005).

The one relatively flat area, the Meadow, is designated as a picnic area and informal recreation area supporting the primary use of performing arts. Visitors to the Filene Center, Theatre in the Woods, and Meadow Pavilion use the area for picnicking before and after various performances. The Meadow is also used for festival performances and smaller interpretive events, of which there is one or two a year (NPS 2012a).

Much of the landscaping around the park's developed areas consists of shade trees for picnic areas, and some decorative landscaping and gardens in select areas. In 2011, the park planted a demonstration garden with all native plants by the main entrance to the Filene Center. A year later, a prominent one-acre plot directly in front of the Filene Center was converted from mowed turf to a native meadow. Several demonstration vegetable gardens have also been established in the park.

Flora

Wolf Trap National Park for the Performing Arts boasts a rich diversity of habitats, from year-round wetlands to steep, dry slopes, and subsequently is home to dozens of plant species in its woodland areas (Figure 2-19) (NPS 2013b). The forested areas of the park are mainly located on fairly steep slopes, or in swampy areas along the floodplain of Wolf Trap Creek. In some areas of the park, the ecosystem has been changing from open farm field to forest since the early 1980s.

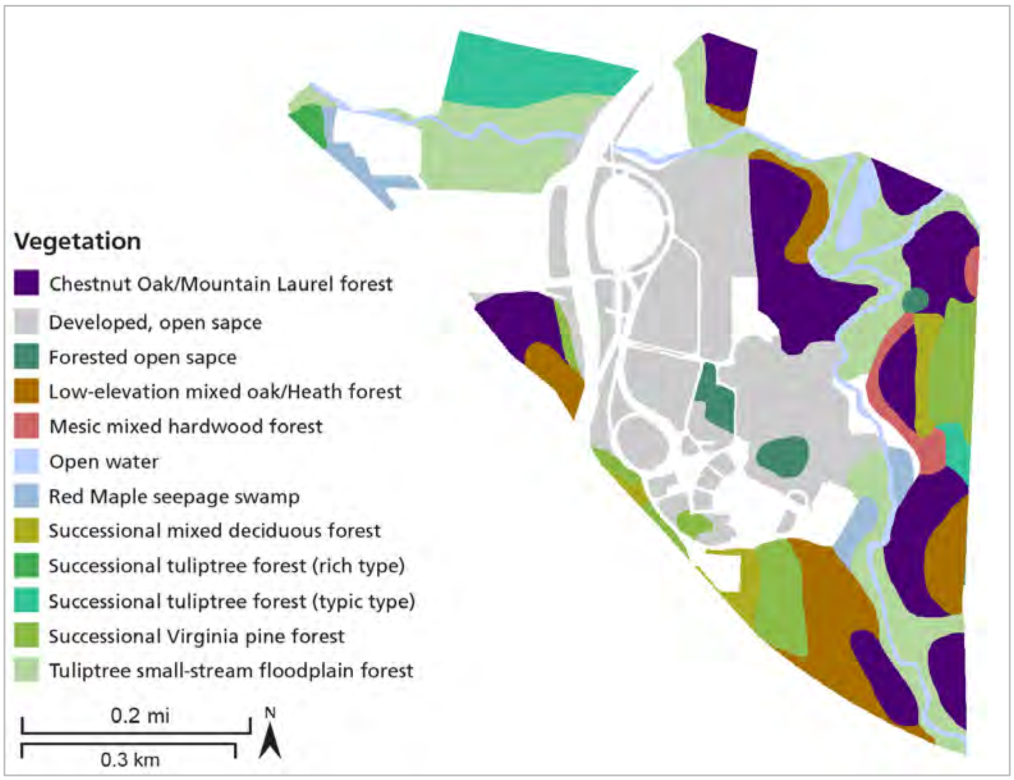


Figure 2-19 Vegetation map of WOTR (Matthews and Schmit 2014).

In the developed areas of the park, such as around the old farmhouse, there are both modern and historic plantings of decorative trees, shrubs, and flowers. Being a former farm, the developed areas of the park house ornamental plants that were popular garden plants in the mid 20th century, including azalea, cherry, dogwood, iris, lilac, rose althea, and spirea (NPS 2013b).

Approximately 65 acres, or just a little more than half the park, is a natural forest community. The forest is the oak-hickory forest that is predominant in this area of Virginia (NPS 2013b). The upland hardwoods consist mainly of dry site species such as red, black, and chestnut oaks, and hickories (NPS 2005). Understory plants include dogwood, sassafras, and mountain laurel. Bottomland forests in the wetlands and floodplain include yellow poplar, red maple, river birch, sycamore, and ironwood; with understories of wild azalea, viburnum, and American holly (NPS 2005).

Some meadow areas, used as pasture and recreational space, have not been maintained since the late 1970s and early 1980s, and are now dominated by mature red cedars, Virginia pines, white pines, and other early successional species (NPS 2005; NPS 2013b). In other places, mature pine and cedar trees have been overtaken by the oaks and poplars (NPS 2013b).

Rare, threatened, and endangered plants

No federally listed or proposed endangered or threatened species, or state species, are known to occur in WOTR. The potential for locating rare species and/or unique natural communities is low, based on the park's natural features (soils, topography, geology), intense use, urbanized setting, and recent agricultural history (NPS 2005).

Fauna

Wolf Trap National Park for the Performing Arts offers an important refuge for wildlife in a highly urbanized setting. Several dozen mammals inhabit the park on a permanent or intermittent basis (NPS 2013b). The park also contains habitat conducive to reptiles, amphibians, and fish - including pond and wetland areas. The park is an excellent habitat for birds, with both resident and migratory species utilizing its abundant edge habitat and permanent water sources (NPS 2005). Historically, documentation of wildlife species in the park has been lacking, and projects are now underway to study fauna present in WOTR (NPS 2013b). In 2013, the park initiated an All-Taxa Biodiversity Index (ATBI) with surveys of bees and wasps, butterflies and moths, and birds.

Mammals

Numerous mammals have been documented in the park and resident animals include fox red (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), woodchuck (*Marmota monax*), northern raccoon (*Procyon lotor*), and numerous rodent and bat species (NPS 2013b). A small mammal survey identified southern flying squirrel (*Glaucomys volans*), white-footed mouse (*Peromyscus leucopus*), and eastern gray squirrel (*Sciurus carolinensis*) most abundant within the park (McShea *et al.* 2003).

White-tailed deer (*Odocoileus virginianus*) travel through the park as they move up and down the forested areas along Wolf Trap Creek and Courthouse Creek. American beaver have intermittently lived along Wolf Trap Creek (NPS 2013b). Other species noted in the park include the Virginia opossum (*Didelphis virginiana*), eastern cottontail rabbit (*Sylvilagus floridanus*), and striped skunk (*Mephites mephitis)* (NPS 2013b). Additionally, feral animals, such as domestic dogs (*Canis familiaris*) and domestic cats (*Felis sylvestris*) are commonly observed within the park (NPS 2013b).

Several bat species have been observed within the park, including little brown bat (*Myotis lucifugus*), silver-haired bat (*Lasionycteris noctivagans*), big brown bat (*Eptesicus fuscus*), red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and evening bat (*Nycticeius humeralis*). A 2003-2004 bat inventory at WOTR captured two species within the park—big brown bat (four individuals) and eastern red bat (three individuals) (Gates and Johnson 2005).

Birds

In 2003, the National Capital Region Network (NCRN) initiated a bird inventory that documented 76 species of birds in WOTR (Sinclair *et al.* 2004). A more recent bird inventory at WOTR documented 118 species in the park as of June 2014 (Audubon Society of Northern Virginia 2013). Bird species highlighted by the WOTR Bird Inventory include red-tailed hawk (*Buteo jamaicensis*), barred owl (*Strix varia*), scarlet tanager (*Piranga olivacea*), American kestrel (*Falco sparverius*), Swainson's thrush (*Catharus ustulatus*), Baltimore oriole (*Icterus galbula*), and rose-breasted grosbeak (*Pheucticus ludovicianus*). In addition, six woodpecker species, five species of flycatcher, and at least nine warbler species are present within the park (Figure 2-20) (Audubon Society of Northern Virginia 2013).

NCRN monitoring data from 2007-2013 show the most commonly sighted birds at Wolf Trap include northern cardinal (*Cardinalis cardinalis*), eastern tufted titmouse (*Baeolophus bicolor*), Carolina wren (*Thryothorus ludovicianus*), Carolina chickadee (*Poecile carolinensis*), black-capped chickadee (*Poecile atricapillus*), American robin (*Turdus migratorius*), and American crow (*Corvus bracyrhynchos*). Four species of conservation concern have also been sighted in WOTR, namely the Acadian flycatcher (*Empidonax virescens*), Carolina wren (*Thryothorus ludovicianus*), eastern towhee (*Pipilo erythrophthalamus*), and wood thrush (*Hylocichla mustelina*) (Dawson and Efford 2014).

In conjunction with volunteers from the Audubon Society, WOTR runs a bluebird program throughout the park. Bluebird nesting boxes have been placed in 14 locations in the park, and are monitored throughout the summer. Each year, an average of 40 fledglings are produced from the nesting boxes.

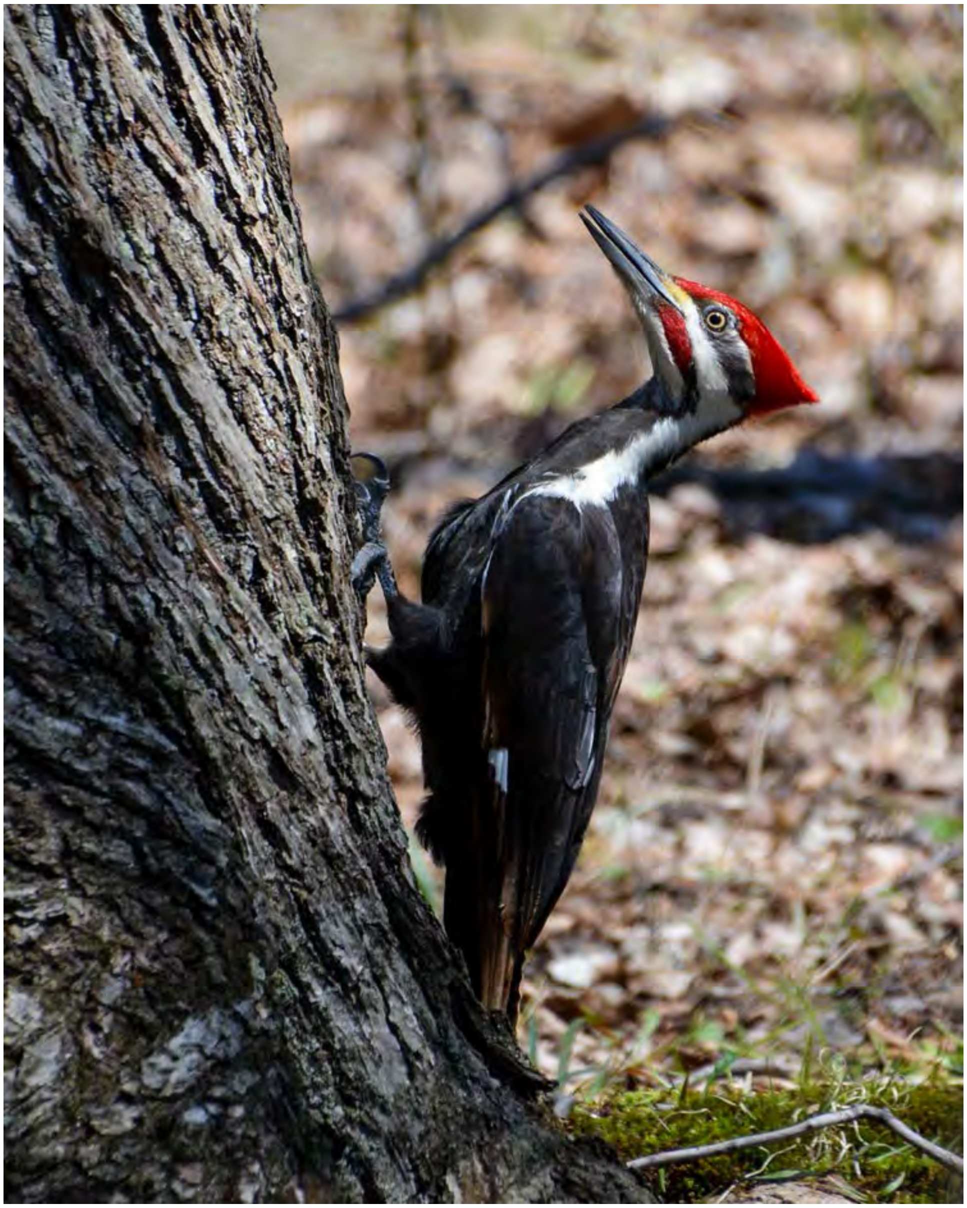


Figure 2-20 A pileated woodpecker in Wolf Trap's forest. Photo: Sheryl Pollock.

Herpetofauna

A 2002-2004 inventory by the National Capital Region Network Inventory & Monitoring program identified 10 amphibian and 6 reptile species present within WOTR (Pauley *et al.* 2005). Despite the fact that WOTR falls within the expected range of numerous amphibian and reptile species, few species were observed and this is likely due to habitat destruction within and adjacent to the park (Pauley *et al.* 2005).

Salamander species identified included spotted salamander (*Ambystoma maculatum*), northern two-lined salamander (*Eurycea bislineata*), red-spotted newt (*Notophthalamus v. viridescens*), and eastern red-backed salamander (*Plethodon cinereus*). Frog species present within WOTR include the eastern American toad (*Anaxyrus americanus*), Cope's grey treefrog (*Hyla chrysoscelis*), northern spring peeper (*Pseudacris crucifer*), northern green frog (*Lithobates clamitans melanota*), pickerel frog (*Lithobates palustris*), and wood frog (*Lithobates sylvaticus*). Four turtle species have been identified within the park, the eastern painted turtle (*Chrysemys picta picta*), northern red-bellied cooter (*Pseudemys rubriventris*), eastern box turtle (*Terrapene c. carolina*), and the snapping turtle (*Chelydra serpentine*).

Fish

The fish of WOTR are characteristic of most streams within the region. There are no species with special conservation status recorded in the park (Raesly *et al.* 2004). Both the pond and streams of WOTR are home to several species of fish (Figure 2-21) (NPS 2013b). Jenkins and Burkhead (1994) recorded 19 species of fish in streams around the park, and a NCRN I&M study in 2004 documented 17 species within the park (Raesly *et al.* 2004). Three native species captured by Jenkins and Burkhead (1994) were not collected during the later survey. These included cutlips minnow (*Exoglossum maxillingua*), golden shiner (*Notemigonus crysoleucas*), and bluntnose minnow (*Pimpehales notatus*).

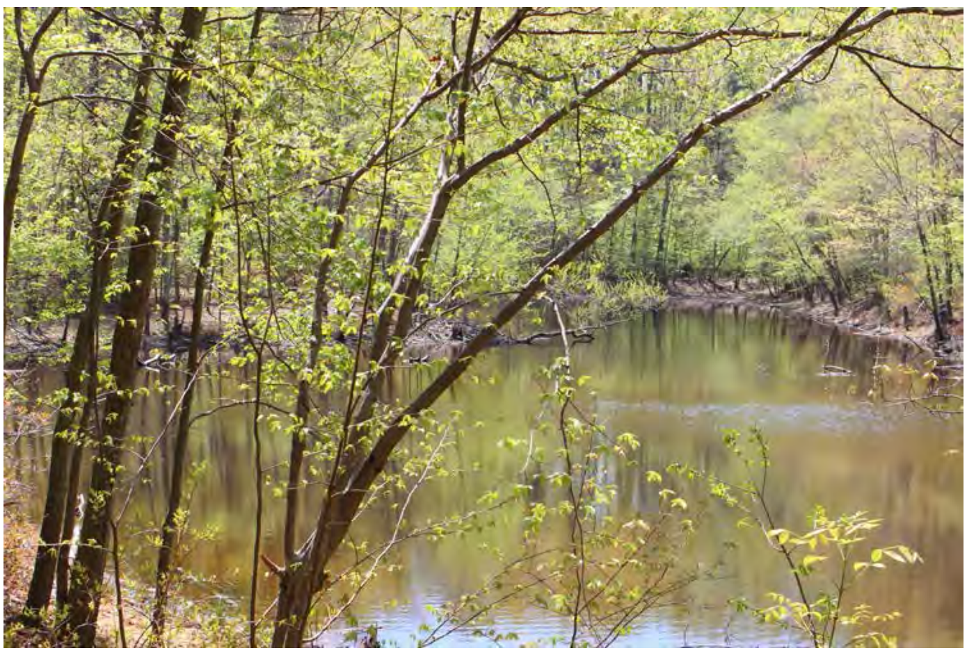


Figure 2-21 A pond within Wolf Trap National Park for the Performing Arts. Photo: NPS.

Additional species of fish recorded in the park include rosyside dace (*Clinostomus funduloides)*, creek chub (*Semotilus atromaculatus)*, fallfish (*Semotilus corporalis)*, river chub (*Nocomis micropogon)*, and central stoneroller (*Campostoma anomalum)*.

The redear sunfish (*Lepomis microlophus*) is an introduced species present in WOTR streams. The redear sunfish has been stocked in many small ponds throughout Virginia, but its current distribution is largely unknown (Raesly *et al.* 2004).

Integrated cultural and natural landscapes

A cultural landscape is a "geographic area, including both cultural and natural resources and the wildlife or domestic animals therein, associated with a historic event, activity, or person or exhibiting other cultural aesthetic values." (Cultural Resource Management Guidelines NPS-28). The National Park Service recognizes four descriptive types of cultural landscapes that are not mutually exclusive and are relevant to properties nationwide in both public and private ownership. These four types are historic sites, historic designed landscapes, historic vernacular landscapes, and ethnographic landscapes (Slaiby and Mitchell 2003).

Originally a working farm, WOTR retains elements of its historic landscape. This setting is a focal point of the Wolf Trap experience and includes fields, woodlands, a stock pond, a historic farmhouse and outbuildings, gardens, and meadows (NPS 2013a).

Soundscapes

The soundscape within a park comprises both natural ambient sounds and human-made sounds. Natural sounds include geophysical (e.g. wind, rain, running water) and biological sounds (e.g. insects, frogs, birds) (Pijanowski *et al.* 2011). This natural ambient environment enhances visitor experience of the natural park landscape (Miller 2008).

Two critical soundscapes exist within WOTR—the natural ambient sounds of the region, as well as human-made sounds occurring during performances. Despite sound walls, noise from the Dulles Toll Road can be heard throughout the park, but not at a level to drown out natural sounds. An agreement was signed with the Metropolitan Washington Airports Authority limiting the maximum traffic noise level within the park in the mid-1980's, in order to limit interference of traffic noise with performances at the Filene Center (NPS 2013b). There is potential for an increase in traffic noise over time from either an increase in vehicles or the opening of the Washington Metropolitan Area Transit Authority (Metro) Silver Line (NPS 2013b). Air traffic noise is also present in the park and can be disruptive.

Lightscapes

The natural darkness associated with the night sky is an important natural, scientific, and cultural resource valued by the National Park Service (NPS 2012b). The clarity of night skies is important to the visitor experience as well as being ecologically important (NPS 2013c). Wolf Trap's location in a highly urbanized area means that it is highly light-polluted by numerous sources outside of its boundaries. The park's primary mission of performing arts, most of which involve nighttime performances with several thousand visitors, requires the use of numerous light fixtures within the park, including large area lighting of about 15 acres of parking areas, roads, and pedestrian walkways. The difficulty of the park significantly reducing outdoor light sources and the inherent conflict with its legislated mission mean that Wolf Trap is unlikely to be able to have a significant dark sky goal. That said, the undeveloped forest areas of the park offer islands of relatively dark areas within the heavily lighted urban neighborhood. The intention of assessing lightscapes, despite the park having little management options to mediate, is primarily for educational and awareness purposes.

Resource issues overview

Internal park threats

Exotic species

Exotic species can outcompete and displace native species. Many invasive plants thrive on disturbances created within ecosystems, such as fragmentation, wildfires, or flooding. When native species are displaced by these disturbances, invasive species can more rapidly colonize the area, further facilitating competition for resources. Changes in habitat structure and composition of vegetation communities can affect nutrient cycling, water resources, and habitat quality for wildlife. Invasive wildlife creates similar community and ecosystem-level changes detrimental to native organisms.

Forest monitoring by NCRN I&M found the most frequently observed exotic vine species in WOTR are Japanese honeysuckle (*Lonicera japonica*), Oriental bittersweet (*Celastrus orbuclatus*), multiflora rose (*Rosa multiflora*), and mile-a-minute (*Polygonum perfoliatum*). On average, 4.17 exotic species per monitored plot have been found in the herb layer at WOTR. Exotic vine species can smother smaller trees, especially those nearest forest edges. The park is working continually to control and monitor exotic invasive plant species.

Table 2-1 Non-native species found or potentially found in WOTR (NPSpecies 2013).

Category	Common name (Scientific name)
Birds	Common pigeon (*Columbia livia*)
	Common Starling (*Sturnus vulgaris*)
	House sparrow (*Passer domesticus*)
Fish	Largemouth bass (*Micropterus salmoides*)
	Redear sunfish (*Lepomis microlophus*)
Plants	Amur bush honeysuckle (*Lonicera maackii*)
	Annual smartweed (*Polygonum sp.)*
	Asian bittersweet (*Celastrus orbiculatus*)
	Big chickweed (*Cerastium fontanum*)
	Bitter dock (*Rumex obstusifolius*)
	Bristled knotweed (*Persicaria longiseta*)
	Chicory (*Cichorium intybus*)
	Coltsfoot (*Tussilago farfara*)
	Common dayflower (*Commelina communis*)
	English plaintain (*Plantago lanceolata*)
	Fig buttercup (*Ficaria verna*)
	Garlic mustard (*Alliaria petiolata*)
	Indian strawberry (*Potentilla indica*)
	Japanese barberry (*Berberis thunbergii*)
	Japanese honeysuckle (*Lonicera japonica*)
	Japanese stiltgrass (*Microstegium vimineum*)
	Lady’s thumb (*Persicaria maculosa*)
	Mile-a-minute weed (*Persicaria perfoliata*)
	Mimosa tree (*Albizia julibrissin*)
	Moneywort (*Lysimachia nummularia*)
	Mugwort (*Artemisia vulgaris* L.)

Category	Common name (Scientific name)
	Mullein (*Verbascum* sp.) Multiflora rose (*Rosa multiflora*) Norway maple (*Acer platanoides*) Perennial ryegrass (*Lolium perenne*) Rough bluegrass (*Poa trivialis*) Sweet vernal grass (*Anthoxanthum ororatum*) Tall fescue (*Festuca arundinacea*) Toothed spurge (*Euphorbia dentata*) Tree of heaven (*Ailanthus altissima*) White clover (*Trifolium repens*)

Deer Overbrowse

Within the National Capital Region, white-tailed deer (*Odocoileus virginianus*) densities have risen rapidly in the past few decades due to a lack of natural predators, increased foraging area due to land fragmentation for suburban growth, and declines in hunting (Bates 2009). Because of increased urbanization and development around WOTR, white-tailed deer use the park as both habitat and as a greenway (Figure 2-22). Deer surveys within WOTR began in 2012.

Deer overbrowse alters the structure and composition of the vegetation by extirpating native plants, and facilitating the spread of invasive species (Allen and Flack 2001). Deer populations affect other forest species that depend on vegetation structure. Opening or removing the forest understory potentially alters the soil moisture content that amphibians depend on; deer can also trample ephemeral ponds used for amphibian breeding (Pauley et al. 2005). Alteration of the shrub layer can eliminate nesting habitat for bird species. Declines in regeneration of oaks and other mast-producing trees affect small mammal populations that depend on mast as a food source (Bates 2009). Deer have been linked to high numbers of ticks that may lead to increases in diseases such as Lyme's disease (Wilson et al. 1990, Deblinger et al. 1993). They can also carry and spread deer chronic wasting disease (Williams et al. 2002).

Figure 2-22. Deer overpopulation threatens the park’s ecology. Photo: NPS.

Water Quality

The type and density of land use in a watershed can affect downstream water quality and stream condition (Figure 2-23). While each land use type introduces issues to the natural stream system, more intense land use types, such as high-density residential, commercial, and industrial, can have high levels of impervious surface and contribute runoff and pollutants. Less intense land use types, such as open space and residential development are generally more pervious, have more vegetation, and therefore have less impact on water quality (Fairfax County 2013).

Heavy rains, runoff from neighboring housing subdivisions, pollutants, and trash have adversely impacted Wolf Trap Creek (NPS 2013b). Significant erosion of the stream bank has occurred within the park as a result of increased runoff and intermittent flooding, largely due to increasing urbanization within the watershed (NPS 2005). Runoff from the Dulles Toll Road may have detrimental effects to water quality (Pieper et al. 2012).

Figure 2-23. Wolf Trap Creek in the winter. Photo: NPS.

The Difficult Run Watershed Management Plan (DRWMP), adopted in 2007 by Fairfax County, projects population growth and land conversion from open space to residential use throughout the watershed. It is anticipated that this population growth will cause an increase from 18.4 to 20.6% in impervious acreage. In the Wolf Trap Creek catchment alone, the proposed storm water management upgrades and retrofits, as well as stream restoration initiatives, are expected to reduce total suspended solids, total nitrogen, and total phosphorus by 11.5%, 15.8%, and 22.7%, respectively. While the DRWMP may be altered throughout its 25-year implementation, it is expected to incorporate TMDL and storm water management actions according to larger watershed regulations for both the Potomac River and Chesapeake Bay.

Regional threats

Development/encroachment

Located within the District of Columbia metropolitan area, the once-rural landscape surrounding WOTR has changed significantly over the years. The Dulles Access Road (Toll Road), originally built in the early 1960s and expanded in 1984, runs along the southwest corner of the park. Roads and development fragment habitat, restricting or impeding the movement and migration of terrestrial and aquatic organisms.

Figure 2-24 A view of Tysons Corner from the Filene Center. Photo: NPS.

Local communities in and around the park, such as Tysons Corner, continue to grow, putting additional pressure on the park to provide recreational opportunities and open space for expanding populations (Figure 2-24) (NPS 2013b). Tysons Corner is the 12th largest employer in the United States and houses the largest concentration of office space in Northern Virginia. The 2014 Tysons Annual Report (an update from the Comprehensive Plan for Tysons of 2010) reported current capacity of Tysons Corner as 19,000 residents and 93,000 employees. This is projected to grow to 100,000 residents and 200,000 employees by 2050 (fairfaxcounty.gov). The metro Silver line, which now runs from East Falls Church beyond Dulles International Airport into Loudon County will transition Tysons Corner from an edge city to an urban downtown area in Fairfax County. Four Metrorail stops were completed in 2014, and commuter parking lots, residential and commercial buildings are underway. In addition, the plan includes a redesigned transportation system with circulator routes, community shuttles, feeder bus service, and vastly improved pedestrian and bicycle routes. Planners hope to achieve sustainable growth through restored streams, a green network of public parks, open spaces, trails, and green buildings.

However, despite environmental stewardship and stormwater management plans, including the use of low impact development techniques (i.e. porous pavement, rain gardens, green roofs) the increases in impervious surfaces, traffic, and population of the developed area puts Wolf Trap at risk of decreased water and air quality, increased light pollution, and habitat squeeze.

WOTR is a popular haven and venue in the densely populated Washington, D.C. area. With increased access to the area via the WMATA (Metro) silver line, visitor use within the park could increase dramatically, causing increased pressure on the natural resources within WOTR, but also providing an opportunity for increased education and experiences within the park. While the legislated purpose of WOTR is as a venue for live performances, visitor use, from hiking to picnicking, has the potential to place increasing demands on the protected areas within the park. There are two overlapping recreational trails within the park that provide opportunities for visitors to hike and bird watch—the 1.5 miles Wolf Trap TRACK Trail, and the 2.5 miles Wolf Trap Trail. Off trail traffic by visitors accessing areas not reached by the formal trail system could lead to the development of informal recreational trails. This could result in trail erosion, stream bank erosion, and impact vegetation communities and water quality.

Erosion

Humans have significantly modified the landscape surrounding WOTR and the geological processes of the area. Erosion inside and outside of the park increases the sediment carried by park streams, which affects aquatic and riparian ecosystems. Sediment loading can change channel morphology and increase the frequency of overbank flooding. Additionally, fine-grained sediments can transport particle bound contaminants (Thornberry-Ehrlich 2008).

From its southeast point of entry into the park, Wolf Trap Creek flows to the north, and halfway through its run, in the northeast section of the park, is joined by the Old Courthouse Branch Creek (Courthouse Creek). Significant erosion of the stream bank has occurred in several distinct areas as a result of increased runoff and intermittent flooding. Unconsolidated soils and sediments are exposed on slopes with sparse vegetation. Erosion of the landscape within the greater Difficult Run watershed leads to increased sediment loads throughout the park. Sediment loads and distribution can result in changes in channel morphology and increase the frequency of overbank flooding (Thornberry-Ehrlich 2008). These changes can result in a change, or loss of in-stream habitat.

Several projects to plant riparian buffers to stabilize the creek banks have been completed, including tree planting and placing rip-rap along creek banks. Erosion monitoring and control is an ongoing project within the park.

Air quality

NPS Management Policies state that mangers have a responsibility to protect national park air quality-related values from adverse air pollution impacts. Sources of pollution that affect air quality in WOTR are primarily outside the park's boundaries. Air pollution originates from several different types of sources—stationary sources, such as factories, power plants, and smelters; mobile sources such as cars, trains, and airplanes, and naturally occurring sources, such as windblown dust (U.S.

EPA 2011). The most commonly found air pollutants are particulate matter, ground level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. The East Coast of the United States has some of the worst air pollution in the country, characterized by low visibility, elevated ozone concentrations, and elevated rates of atmospheric nitrogen and sulfur deposition. Elevated ozone levels have been shown to cause premature defoliation in plants; high levels of nitrogen deposition acidify and fertilize soils and waters, thereby affecting nutrient cycling, vegetation composition, biodiversity, and eutrophication. Air pollution can be transported over long distances, making management difficult at the local scale.

Resource Stewardship

Management directives and planning guidance

Park purpose

As stated in the Foundation Document of the park, the purpose of Wolf Trap National Park for the Performing Arts is:

"*to provide opportunities to experience live performances, related educational programs, and associated recreation in a pastoral setting within the National Capital area.*" (NPS 2013a: 6).

Park significance

Significance statements express why Wolf Trap National Park for the Performing Arts resources and values are important enough to merit national park unit designation (NPS 2013a). Significance statements describe the distinctive nature of the park and inform management decisions, focusing efforts on preserving and protecting the most important resources and values of the park unit.

The following significance statements have been articulated for WOTR in the park's Foundation Document (NPS 2013b):

- **First and only national park for the performing arts.** Wolf Trap National Park for the Performing Arts is the first and only national park for the performing arts.

- **Home of the Filene Center.** Wolf Trap National Park for the Performing Arts is home to the Filene Center, a premier outdoor performing arts venue that has developed technical and operational capabilities which supports a high variety, density, and caliber of programming.

- **Collaborative partnership authorized by Congress.** The collaborative partnership between the Wolf Trap National Park for the Performing Arts and the Wolf Trap Foundation was authorized by Congress to aid the park in presentation of performing arts and related educational and cultural programming.

- **Bringing the performing arts to the public.** Wolf Trap National Park for the Performing Arts was the realization of the vision of Catherine Filene Shouse to bring a diversity of performing arts to the public in the National Capital area. Her donation of the land that became the park allowed the vision to become reality.

- **Cultural arts in an outdoor setting.** Wolf Trap National Park for the Performing Arts conserves a former agricultural site that allows visitors to experience cultural arts and compatible recreation in an outdoor setting.

Status of supporting science

Inventory and Monitoring program

The Inventory and Monitoring (I&M) Division of the NPS was formed in response to the Natural Resource Challenge of 1999. The goals of the I&M Division are to (NPS 2013a):

- Inventory the natural resources under National Park Service stewardship to determine their nature and status.
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments.
- Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.
- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision-making.
- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

In addition to conducting baseline inventories, I&M monitors vital signs that are indicators of ecosystem health. Vital signs include:

- physical, chemical, and biological elements and processes of park ecosystems;
- known or hypothesized effects of stressors; and/or
- elements that have important human values (Fancy *et al.* 2009).

WOTR is one of the 11 parks served by the National Capital Region Inventory & Monitoring Network (NCRN I&M). Numerous baseline inventories have been conducted at Wolf Trap and NRCN vital signs monitoring makes up a large portion of the natural resource data described in this report. The long-term monitoring of these vital signs is meant to serve as an ‘early warning system’ to detect declines in ecosystem integrity and species viability before irreversible loss has occurred (Fancy et al. 2009).

Research at the park

NCRN I&M has performed its own research and collaborated with a variety of outside researchers to fill gaps in knowledge and have a better understanding of park resources (Table 2-2). Collaborators have included various state and federal government agencies, the University of Maryland, the University of Delaware, and non-government organizations.

In 2013, the park initiated an All-Taxa Biodiversity Inventory (ATBI) with bee and wasp, butterfly and moth, and bird surveys. These surveys are being carried out with the help of volunteer 'citizen scientists' and in collaboration with the Audubon Society of Northern Virginia (birds), the USGS (bees and wasps), and independent researchers (butterflies and moths). A partial bibliography of research that has been completed at WOTR can be seen in Table 2-3.

Table 2-2 Status of NRCN I&M Inventories at Wolf Trap National Park for the Performing Arts.

Inventory	Description	Status
Air Quality Data	One of the 12-core natural resource inventories, the Air Quality Inventory provides actual measured or estimated concentrations of indicator air pollutants such as ozone, wet deposition species (NO_3, SO_4, NH_4, etc.), dry deposition species (NO_3, SO_4, HNO_3, NH_4, SO_2), and visibility (extinction for 20% cleanest days and 20% worst days for visibility).	Completed 2010
Air Quality Related Values	Air quality related values are resources sensitive to air quality, including vegetation, wildlife, water quality, and soils. This inventory identifies whether categories of these values are sensitive for a given park.	Completed 2011
Base Cartography Data	The Base Cartography inventory is one of 12 core inventories identified by the National Park Service as essential to effectively manage park natural resources. Base cartographic information from this inventory provides geographic information systems (GIS) data layers to National Park resource management staff, researchers, and research partners.	Completed 2010
Baseline Water Quality Inventory	This inventory documents and summarizes existing, readily available digital water quality data collected in the vicinity of national parks.	Completed 1996
Climate Inventory	One of the 12 natural resource inventories, the primary objective of the Climate Inventory is to obtain park-relevant baseline climate data useful to NPS biologists, hydrologists and resource managers.	Completed 2006
Geologic Resources Inventory	The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, and researchers with information that can help them make informed management decisions.	Completed 2008
Soil Resources	The Soil Resources Inventory (SRI) includes maps of the locations and extent of soils in a park; data about the physical, chemical, and biological properties of those soils; and information regarding the potential use and management of each soil. The SRI adheres to mapping and database standards of the National Cooperative Soil Survey (NCSS) and meets the geospatial requirements of the Soil Survey	Completed 2009

Inventory	Description	Status
	Geographic (SSURGO) database. SRI data are intended to serve as the official database for all agency applications regarding soil resources.	
Species Occurrence & Distribution	Bats, birds, fish, herpetofauna, paleontological resource, and vascular plants	Completed
Vegetation Mapping	The Vegetation Inventory Program (VIP) is an effort by the National Park Service (NPS) to classify, describe, and map detailed vegetation communities in more than 270 national park units across the United States. Stringent quality control procedures ensure the reliability of the vegetation data and encourage the use of resulting maps, reports, and databases at multiple scales.	Completed 2014

Table 2-3 A partial bibliography of research that has been completed at WOTR National Park for the Performing Arts.

Study topic	Reference
Air Quality	Kohut 2007; Lawrey 2011; Sullivan et al. 2011
Birds	Sinclair et al. 2004; Goodwin 2009, Ladin 2013
Climate	Davey et al. 2006;
Fish	Morgan 2013
Flora	Schmit et al. 2010; Parrish and Nortrup 2012; Schmit et al. 2012a; Schmit et al. 2012b;
Geology & Soils	Thornberry-Ehrlich 2008;
Herpetofauna	Pauley and Watson 2003;
Hydrology	Norris et al. 2011
Mammals	Johnson et al. 2008
Water Quality	Pieper et al. 2012;

Legislation

Public Law 101-636 (104 Stat. 4586, 104 Stat. 4587) November 28, 1990 An act to restructure repayment terms and conditions for loans made by the Secretary of the Interior to the Wolf Trap Foundation for the Performing Arts for the reconstruction of the Filene Center in Wolf Trap Farm Park in Fairfax, County, Virginia, and for other purposes.

Public Law 107-219 (116 Stat. 1330) August 21, 2002 an act to rename Wolf Trap Farm Park as “Wolf Trap National Park for the Performing Arts,” and for other purposes.

Public Law 97-310 (96 Stat. 1455) October 14, 1982 An act to provide financial assistance to the Wolf Trap Foundation for the Performing Arts for reconstruction of the Filene Center in Wolf Trap Farm Park, and for other purposes.

Legislation and Acts

- Archaeological and Historical Preservation Act – 1974
- Archaeological Resources Protection Act – 1979
- Comprehensive Environmental Response and Compensation and Liability Act (CERCLA) – 1984, as amended

- Department of Transportation Act – 1966
- Endangered Species Act – 1973
- Historic Sites Act – 1935
- National Environmental Policy Act – 1969
- National Historic Preservation Act – 1966, as amended
- National Parks Omnibus Management Act – 1998
- National Park Service Organic Act – 1916
- National Trust Act – 1949
- Redwood Act, Amending the NPS Organic Act – 1978
- Code of Federal Regulations
- Title 36, chapter 1, part 1, General Provisions
- Title 36, chapter 1, part 2, Resource Protection, Public Use and Recreation
- Title 36, chapter 1, part 4, Vehicles and Traffic Safety
- Title 36, chapter 1, part 5, Commercial and Private Operations

Executive Orders

- Executive Order 11514: "Protection and Enhancement of Environmental Quality"
- Executive Order 11593: "Protection and Enhancement of the Cultural Environment"
- Executive Order 11988: "Floodplain Management"
- Executive Order 11990: "Protection of Wetlands"
- Executive Order 12003: "Energy Policy and Conservation"
- Executive Order 12088: "Federal Compliance with Pollution Control Standards"
- Executive Order 12372: "Intergovernmental Review of Federal Programs"
- Executive Order 13112: "Invasive Species"
- Executive Order 13186: "Responsibilities of Federal Agencies to Protect Migratory Birds"
- Executive Order 13352: "Facilitation of Cooperative Conservation"
- Executive Order 13423: "Strengthening Federal Environmental, Energy, and Transportation Management"
- NPS *Management Policies 2006*

NPS Director's Orders

- Order 28: *Cultural Resource Management*
- Order 47: *Soundscape Preservation and Noise Management*

Study Scoping and Design

Preliminary scoping and park involvement

Preliminary scoping for the assessment of WOTR began in March 2013 with a meeting at Prince William Forest Park. In attendance were staff from WOTR and PRWI, the NPS National Capital Region Network (NCRN) Inventory and Monitoring (I&M) program, and the University of Maryland Center for Environmental Science Integration and Application Network (UMCES-IAN) (Figure 3-1). Project goals and reporting areas were made during the initial scoping meeting with the WOTR park staff. Park staff helped identify key indicators of environmental health for the park. Archived data for park resources from WOTR and NCRN I&M were organized into an electronic library comprised of management reports, hard data files, and geospatial data (GIS), which provided the primary sources for this assessment. Additional datasets were obtained from the NPS Air Resources Division (ARD) and the Interagency Monitoring of Protected Visual Environments (IMPROVE).

Figure 3-1 Participants at the preliminary scoping workshop for Wolf Trap National Park for the Performing Arts. From left to right: George Liffert, Pat Campbell, Simon Costanzo, Carol Pollio, Jane Thomas, Paul Petersen, Vidal Martinez, Bill Dennison, Megan Nortrup, Giselle Mora-Bourgeois, Geoff Sanders, Brianne Walsh, Eric Kelley, Phil Goetkin, and Chris Schuster.

Several follow-up meetings with staff from WOTR, NCRN I&M, and UMCES-IAN were used to identify and locate key resources for completing the assessment, to present work and calculations already completed, and to develop conclusions and recommendations based on the assessments findings.

Study design

Reporting areas

The focus of the reporting area for the NRCA was the land within the WOTR legislative boundary that is owned by the NPS. An area five times the total area of the park (evenly distributed around the entire park boundary) was examined for landscape dynamic metric analysis. Lands within 30 km (19 mi) of the park boundary were examined for context (Budde et al. 2009; Gross et al. 2009) but not included in the formal assessment.

Indicator framework

Recognizing the large amount of data included in this assessment compiled from the park's monitoring and stewardship activities, as well as other sources, the framework utilized for presenting assessment data in Chapter 4 was the vital signs categorization developed by NPS I&M (Fancy et al. 2008). Metrics included in the assessment were sorted into their respective vital signs categories so that they could be utilized in future studies (Figure 3-2). Fancy et al. (2008) identified a key challenge of large-scale monitoring programs to be the development of information products that integrate and translate large amounts of complex scientific data into highly aggregated metrics for communication to policy-makers and non-scientists. Aggregated indices were developed and are presented within the current natural resources assessment for Wolf Trap National Park for the Performing Arts.

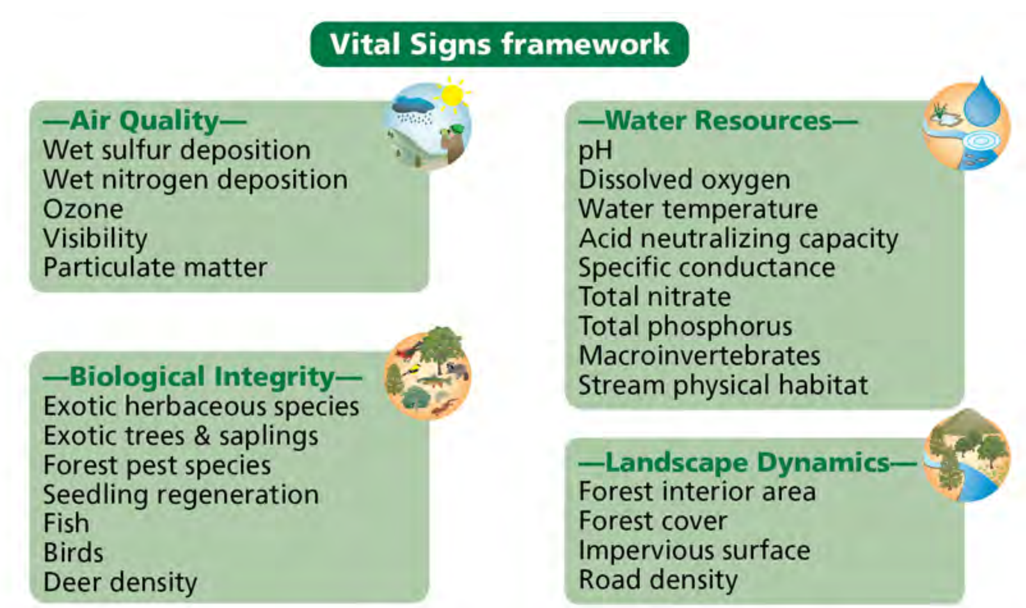


Figure 3-2 Vital signs framework used in the assessment of Wolf Trap National Park for the Performing Arts.

General approach and methods

The general approach taken to assess natural resource condition was to determine indicators appropriate to inform the current status of each metric, establish a reference condition for each indicator, and then assess the percentage attainment of reference condition. Details of approach, background, and justification are provided on a metric-by-metric basis in Chapter 4. Once attainment was calculated for each indicator, an unweighted mean was calculated to determine the condition for each vital sign category and then similarly to combine vital sign categories to calculate an overall park assessment.

Reference conditions

A natural resource condition assessment requires the establishment of criteria for defining desired, as well as current ecological conditions. The current assessment was based upon explicitly defined reference condition values. Reference conditions represent an agreed-upon value or range indicating that an ecosystem is moving away from a desired state and towards an undesirable ecosystem endpoint (Biggs 2004, Bennetts et al. 2007). Even with the definition of agreed-upon reference conditions, there is still the question of how best to use these reference condition values in a management context (Groffman et al. 2006). Recognizing these challenges, reference conditions can still be effectively used to track ecosystem change and define achievable management goals (Biggs 2004). As long as reference condition values are clearly defined and justified, they can be updated in the light of new research or management goals and can therefore provide an important focus for the discussion and implementation of ecosystem management (Jensen et al. 2000, Pantus and Dennison 2005).

Data synthesis

It is increasingly recognized that monitoring data collected for specific purposes, such as assessing the implementation of environmental regulations, does not necessarily allow for regional assessments of ecosystem condition (U.S. EPA 2000, 2002). As a result, one of the key challenges of large-scale monitoring programs is to develop integrated and synthetic data products that can translate a multitude of diverse data into a format that can be readily communicated to decision makers, policy developers, and the public (Fancy et al. 2008). These timely syntheses of ecosystem condition can provide feedback to managers and stakeholders, so that the effectiveness of management actions as well as future management goals can be determined at multiple scales (Dennison et al. 2007). One approach to synthesizing data is to develop multiple-metric indices to summarize the status of many aspects of a community and then draw inferences on the status of the supporting ecosystem (Karr 1981). Multi-metric indices improve on the use of just one measure, such as fish biomass or abundance, which often shows complex and variable responses to changes in environmental condition (Karr 1981). Multimetric indices are seen as providing greater insight into ecosystem condition than physical measurements alone (e.g., water quality), as biological communities provide an integrated summary of ecosystem condition over time (Roth et al. 1998, 2000, Harrison and Whitfield 2006).

Condition assessment calculations

A total of 24 vital sign metrics were used to determine the natural resource condition of WOTR. The approach for assessing resource condition within WOTR required establishment of a reference condition (i.e., reference condition) for each metric. Reference conditions ideally were ecologically based and derived from the scientific literature. However, when data were not available to support peer-reviewed ecological reference conditions, regulatory and management reference conditions were used.

Due to the wide range of data values for some of the metrics, medians were presented as the overall result instead of the mean. For the analysis of exotic herbaceous species, exotic trees & saplings, and forest pests, the mean was chosen for comparison against the reference condition.

Reference condition attainment of metrics was calculated based on the percentage of sites or samples that met or exceeded reference condition values set for each metric. A metric attainment score of 100% reflects that the metric met the reference condition identified to maintain natural resources at all sites and at all times. Conversely, a score of 0% indicates that no sites at any sampling time met the reference condition value. Once attainment was calculated for each metric, an unweighted mean was calculated to determine the condition of each vital sign. Attainment scores were categorized on a scale from very good to very degraded. Attainment scores for each metric are presented in Chapter 4.

The four vital sign scores were then averaged to produce a single assessment score for the entire park. Key findings, conclusions, and recommendations were also given for each vital sign and for the park as a whole in Chapter 5.

Natural resource conditions

Water resources

The main water resource of the park is Wolf Trap Creek, a permanent stream that winds around and through the park, and is joined by Courthouse Creek within the park (NPS 2007). Wolf Trap Creek forms part of the Difficult Run watershed, in the Potomac River basin. The park has a two-acre pond surrounded by forest that provides habitat for a variety of wildlife (NPS 2007). Several permanent springs and wetland areas are also located within Wolf Trap. The park's water resources are major contributors to both the scenic value of the park and its biological diversity (NPS 2007).

Nine metrics were used to assess stream water resources in WOTR: pH, dissolved oxygen (DO), water temperature, acid neutralizing capacity (ANC), specific conductance, total nitrate, total phosphorus, benthic index of biotic integrity (BIBI), and physical habitat index (PHI) (Table 4-1). Data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff. Water quality, BIBI and PHI monitoring sites are shown in Figure 4-1.

Table 4-1 Ecological monitoring framework data for stream Water Resources provided by agencies and specific sources included in the assessment of WOTR.

Water resource indicator	Source of data	Reference
pH	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Dissolved oxygen	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Water temperature	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Acid neutralizing capacity	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Specific conductance	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Total nitrate	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Total phosphorus	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Benthic Index of Biotic Integrity	NCRN I&M, MBSS	Norris and Sanders 2009, MBSS
Physical Habitat Index	NCRN I&M, MBSS	Norris and Sanders 2009, MBSS

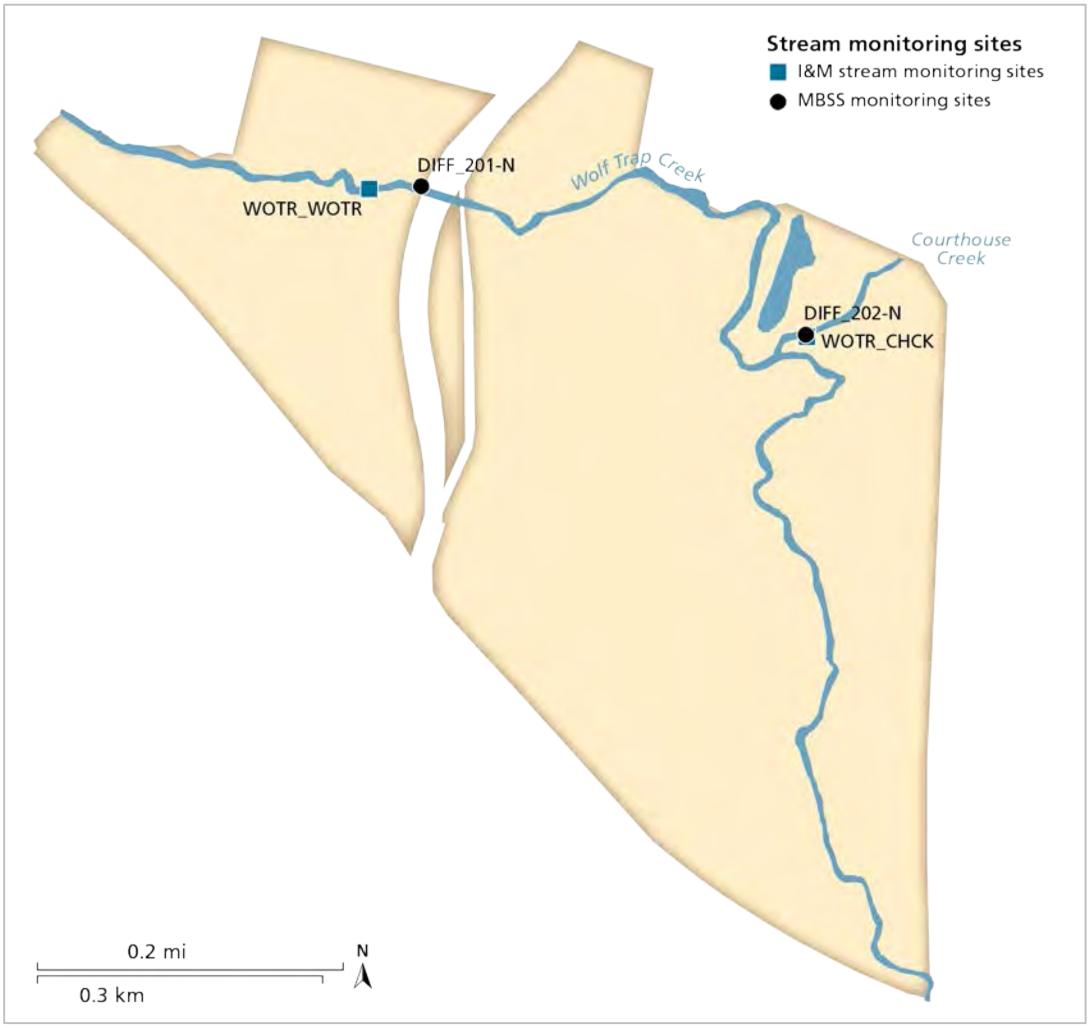


Figure 4-1 Stream sampling locations in WOTR used for long-term water quality monitoring (Norris et al. 2011), benthic macroinvertebrates and physical habitat index (MBSS) (Norris and Sanders 2009).

Reference conditions were established for each of the nine metrics (Table 4-2) and the data were compared to these reference conditions to obtain the percent attainment.

Wolf Trap scored high on attainment (good to very good) for pH (100%), water temperature (100%), ANC (99%), DO (93%) and total nitrate (72%) metrics. Specific conductance and total phosphorus scored low (very poor) on attainment (6% and 9% respectively), and were both in very degraded condition (Table 4-3).

Table 4-2 Water resource indicators, data availability, reference conditions, and condition assessment categories.

Water resource indicator	Number of sites	Number of samples	Period of observation	Reference condition	% attainment applied
pH	2	158	2005-2013	6.0≤pH ≤ 9.0	0-100% Scaled linearly
Dissolved oxygen (mg/L)	2	158	2005-2013	≥ 6.0	
Water temperature (°C)	2	159		≤ 32	
Acid neutralizing capacity (μeq/L)	2	157	2005-2013	≥ 200	
Specific conductance (μS/cm)	2	159	2005-2013	≤ 171	
Total nitrate (mg/L)	2	158	2005-2013	≤ 2	
Total phosphorus (mg/L)	2	121	2005-2013	≤ 0.037	
Benthic Index of Biotic Integrity	2	5	2004-2012	4.0-5.0 3.0-3.9 2.0-2.9 1.0-1.9	100% Scaled linearly 0%
Physical Habitat Index	2	4	2004-2012	81-100 66-80 51-65 0-50	75-100% (Scaled linearly) 50-75% (Scaled linearly) 25-50% (Scaled linearly) 0-25% (Scaled linearly)

Table 4-3 Summary of stream water resource condition assessment at WOTR.

Water resource indicator	WOTR result	% attainment of reference condition	Condition assessment	Overall water quality condition
pH	7.3	100	Very good	60% Good
Dissolved oxygen (mg/L)	8.80	93	Very good	
Water temperature (°C)	14.6	100	Very good	
Acid neutralizing capacity (μeq/L)	704	99	Very good	
Specific conductance (μS/cm)	281	6	Very degraded	
Total nitrate (mg/L)	1.80	72	Good	
Total phosphorus (mg/L)	0.1	9	Very degraded	
Benthic Index of Biotic Integrity	1.33	8	Very degraded	
Physical Habitat Index	65.4	49	Degraded	

Water pH

Description

The streams in and adjacent to WOTR are an important habitat for plants, invertebrates, fish, and amphibians, as well as an important water source for mammals and birds. Deposition of sulfate and nitrogen are a significant regional concern, and freshwater habitats may be impacted by acidification (Sadinski and Dunson 1992, NPS ARD 2010).

Data and methods

The data analyzed were collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010; Pieper et al. 2012) (Table 4-1). NCRN followed the sampling protocol specified in Norris et al. 2011. Measurements were taken monthly as instantaneous records. Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment.

A reference condition pH range of 6.0 - 9.0 was used for this assessment, which is the Virginia criteria for Class III warm waters—non-tidal coastal and piedmont zones (Virginia Water Control Board 2011). Both Courthouse Creek and Wolf Trap Creek are designated warm water streams. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-2).

Condition and trend

Condition of pH in WOTR was very good, with a median pH of 7.3 and 100% of data points attaining the reference condition of 6.0 - 9.0. Over the data range available, no significant trend was present (*p*-value > 0.01) (Figure 4-2).

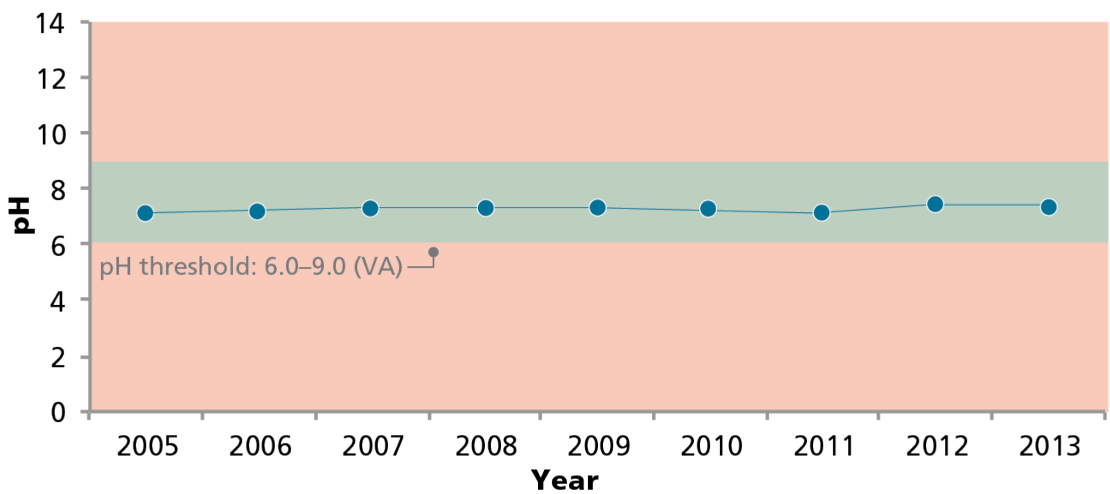


Figure 4-2 Annual median pH values for 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Dissolved oxygen

Description

Dissolved oxygen (DO) concentration in water is often used as an indicator to gauge the overall health of the aquatic environment. It is needed to maintain suitable habitat for the survival and growth of fish and many other aquatic organisms. Low DO is of great concern due to detrimental effects on aquatic life. Conditions that generally contribute to low DO levels include warm temperatures, low flows, water stagnation and shallow gradients (streams), organic matter inputs, and high respiration rates. Decay of excessive organic debris in the water column from aquatic plants, municipal or industrial discharges, or storm runoff can also cause DO concentrations to be undersaturated or depleted. Insufficient DO can lead to unsuitable conditions for aquatic life and its absence can result in the unpleasant odors associated with anaerobic decomposition. Minimum required DO concentration to support fish varies because the oxygen requirements of fish vary with a number of factors, including the species and age of the fish, prior acclimatization, temperature, and concentration of other substances in the water. For example, American shad (*Alosa sapidissima*) requires at least 5 mg/L of oxygen, while spot (*Leiostomus xanthurus*) can tolerate dissolve oxygen concentrations as low as 2 mg/L.

Data and methods

Data was collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper et al. 2012). NCRN followed the sampling protocol specified in Norris et al. 2011. Measurements were taken monthly as instantaneous records.

A reference condition of ≥5.0 mg/L was used for this assessment, which is the Virginia criteria for Class III warm waters—non-tidal coastal and piedmont zones (Virginia State Water Control Board 2011). Both Courthouse Creek and Wolf Trap Creek are designated warm water streams. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-2).

Condition and trend

Condition of dissolved oxygen in WOTR was very good, with a median DO of 8.8 mg/L and 93% of data points attaining reference condition of ≥5.0 mg/L. Over the data range available, no significant trend was present (p-value >0.01) (Figure 4-3).

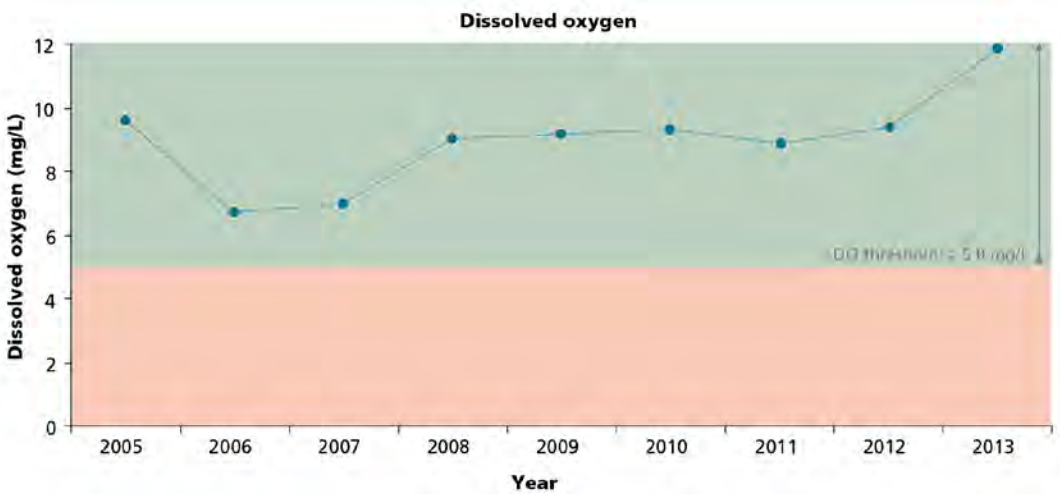


Figure 4-3 Annual median dissolved oxygen concentrations (mg/L) from 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Water temperature

Description

Aquatic organisms are dependent on certain temperature ranges for optimal health. Temperature affects many other parameters in water, including the amount of dissolved oxygen available, the types of plants and animals present, and the susceptibility of organisms to parasites, pollution, and disease. Causes of temperature changes in the water include weather conditions, shade, and discharges into the water from urban sources or groundwater inflows.

Data and methods

Data was collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper *et al.* 2012). NCRN followed the sampling protocol specified in Norris et al. 2011. Measurements were taken monthly as instantaneous records. Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment.

A reference condition of ≤ 32°C temperature was used for this assessment, which is the Virginia criteria for Class III warm waters—non-tidal coastal and piedmont zones (Virginia State Water Control Board 2011). Both Courthouse Creek and Wolf Trap Run are designated warm water streams. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-2).

Condition and trend

Current condition on water temperature in WOTR was very good, with a median temperature of 14.6°C and 100% of data points attaining reference condition between 2005 and 2013. When the seasonal median water temperatures were calculated, temperatures were highest in the summer months (median of 21.8°C), and lower in the spring, fall and winter months (15.7°C, 12.2°C, and 6.5°C respectively).

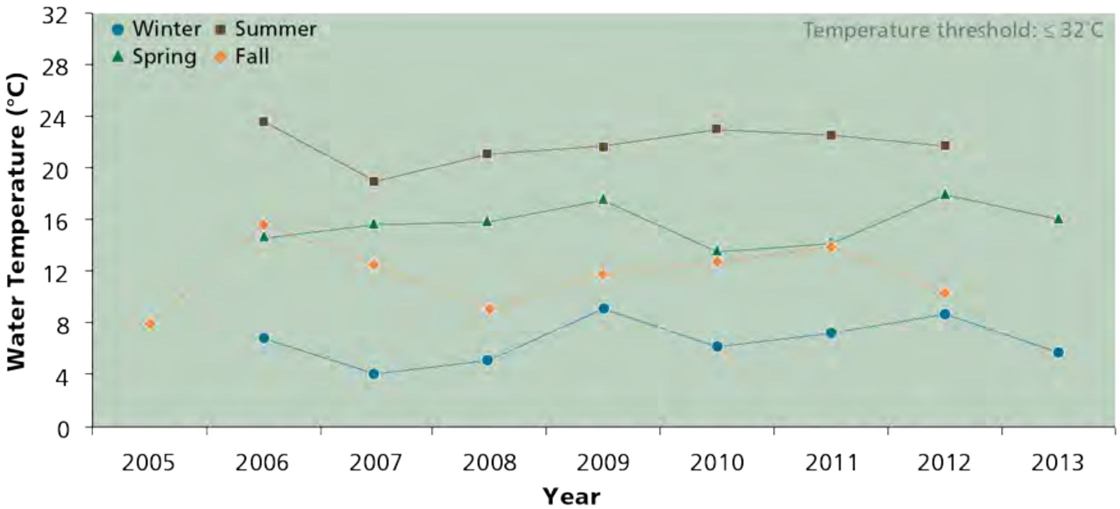


Figure 4-4 Seasonal median water temperature values (°C) from 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Acid neutralizing capacity

Description

Acid neutralizing capacity (ANC) is the prime indicator of a waterbody's susceptibility to acid inputs. ANC is a measure of the amount of carbonate and other compounds in the water that neutralize low (acidic) pH. Streams with higher ANC levels (better buffering capacity) are affected less by acid rain and other acid inputs than streams with lower ANC values (Welch et al. 1998).

Data and methods

The data analyzed were collected monthly at two sites between 2005 and 2013 by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper et al. 2012). NCRN followed the sampling protocol specified in Norris et al. (2011).

The Maryland Biological Stream Survey (MBSS) program developed the acid neutralizing capacity (ANC) reference condition after their first round of sampling (1995–1997). The MBSS data were used to detect stream degradation so as to identify streams in need of restoration and to identify ‘impaired waters’ candidates (Southerland et al. 2007). A total of 539 streams that received a fish or benthic index of biotic integrity (FIBI or BIBI) rating of poor (2) or very poor (1) were pooled and field observations and site-specific water chemistry data were used to determine stressors likely causing degradation.

The resulting ANC reference condition value linked to degraded streams was less than 200 µeq/L, which was used as the reference condition in this assessment (Southerland et al. 2007, Norris and Sanders 2009) where 1 mg/L [1 ppm] of $CaCO_3$ = 20 µeq/L. A less conservative reference condition of 50 µeq/L has also been suggested by some authors (Hendricks and Little 2003, Schindler 1988). Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment (Table 4-2). If a measurement was listed as “not detected,” it was assigned a fail result because the detection limit for ANC is higher than the reference condition.

Condition and trend

Current condition of ANC in WOTR was very good, with a mean ANC of 707 µeq/L and 99% of data points attaining reference condition of ≥ 200 µeq/L between 2005 and 2013. Over the data range available, no significant trend was present (*p*-value > 0.01) (Figure 4-5).

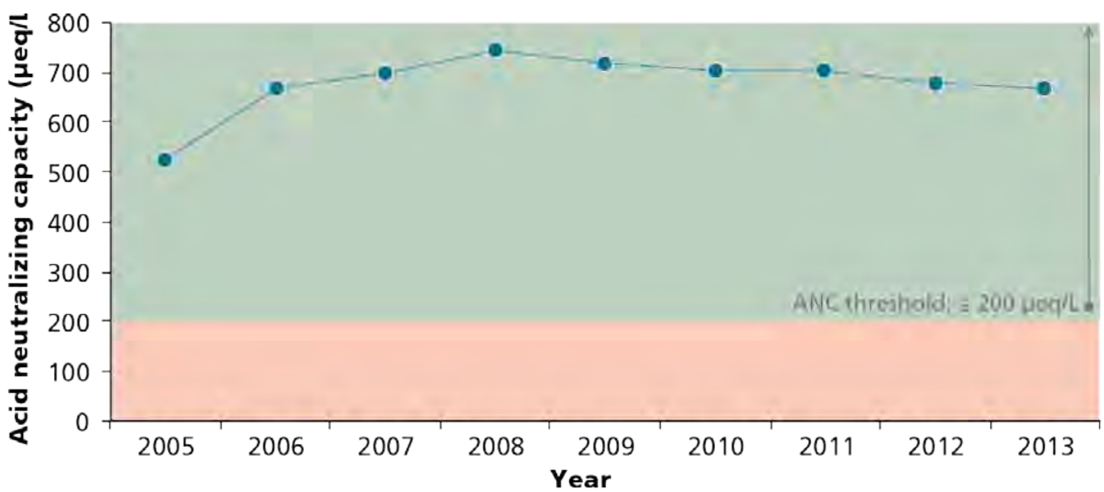


Figure 4-5 Median acid neutralizing capacity values (µeq/L) from 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Specific conductance

Description

Electrical conductivity is related to salinity and is a measure of water’s ability to conduct electricity, and therefore a measure of the water’s ionic activity and content. The higher the concentration of ionic (dissolved) constituents, the higher the conductivity (Radtke et al. 1998). As conductivity changes with temperature, conductivity can be normalized to a temperature of 25°C and reported as specific conductance to enable comparisons.

Common sources of pollution that can affect specific conductance are de-icing salts, dust-reducing compounds, agriculture (primarily from the liming of fields), and acid mine drainage associated with mining operations (USGS 1980, Stednick and Gilbert 1998, NPS 2002). Collectively, all substances in solution exert osmotic pressure on the organisms living in it, which in turn adapt to the condition imposed upon the water by its dissolved constituents. With excessive salts in solution, osmotic pressure becomes so high that water may be drawn from gills and other delicate external organs resulting in cell damage or death of the organism (USGS 1980, Stednick and Gilbert 1998, NPS 2002).

Data and methods

Data was collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper et al. 2012). NCRN followed the sampling protocol specified in Norris et al. 2011.

The reference condition for specific conductance was ≤ 171 µS/cm, above which conditions are said to be degraded (Morgan et al. 2007). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4-2).

Condition and trends

Condition of specific conductance in WOTR between 2005 and 2013 was very degraded, with a median conductance of 281.3 µS/cm and 6% of data points attaining the reference condition of ≤ 171 µS/cm). Over the data range available, no significant trend was present (*p*-value > 0.01) (Figure 4-6).

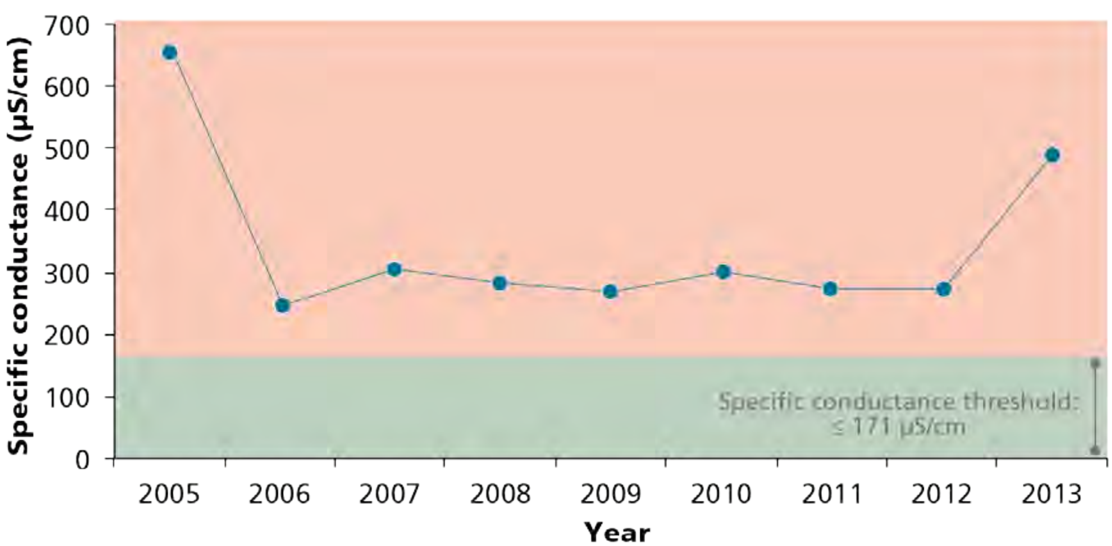


Figure 4-6 Annual median specific conductance values (µS/cm) from 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Total Nitrate

Description

Nitrate (NO_3) is a form of nitrogen which aquatic plants can absorb and incorporate into proteins, amino acids, nucleic acids, and other essential molecules. High concentrations of NO_3 can enhance the growth of algae and aquatic plants in a manner similar to enrichment in phosphorus and thus cause eutrophication of a water body. Nitrate is typically indicative of agricultural pollution. Nitrate in surface water may occur in dissolved or particulate form resulting from inorganic sources. Nitrate also travels freely through soil and therefore may pollute groundwater.

Data and methods

Data was collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper *et al.* 2012). NCRN followed the sampling protocol specified in Norris *et al.* 2011. It should be noted that the current methodology for measuring nitrate has been in use since July 2007. During the month of July 2007, a different method was used after an equipment malfunction. A third method was utilized prior to July 2007 (Norris and Pieper 2010).

Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment. If a measurement was listed as "not detected," it was assigned a pass result because the detection limit for nitrate is lower than the reference condition (J. Pieper, pers. comm.).

The Maryland Biological Stream Survey (MBSS) program developed the nitrate concentration reference condition after their first round of sampling as described for the ANC reference condition. The MBSS determined that a nitrate concentration of 2.0 mg NO_3/L (2 ppm) and above indicated stream degradation (Southerland *et al.* 2007, Norris and Sanders 2009) (Table 4-2). Each data point was compared against the reference condition to determine the percent attainment and condition.

Condition and trend

Condition of nitrate in WOTR was good, with a mean nitrate concentration of 1.8 mg/L and 72% of data points attaining reference condition of < 2.0 mg/L between 2005 and 2013. Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4-7).

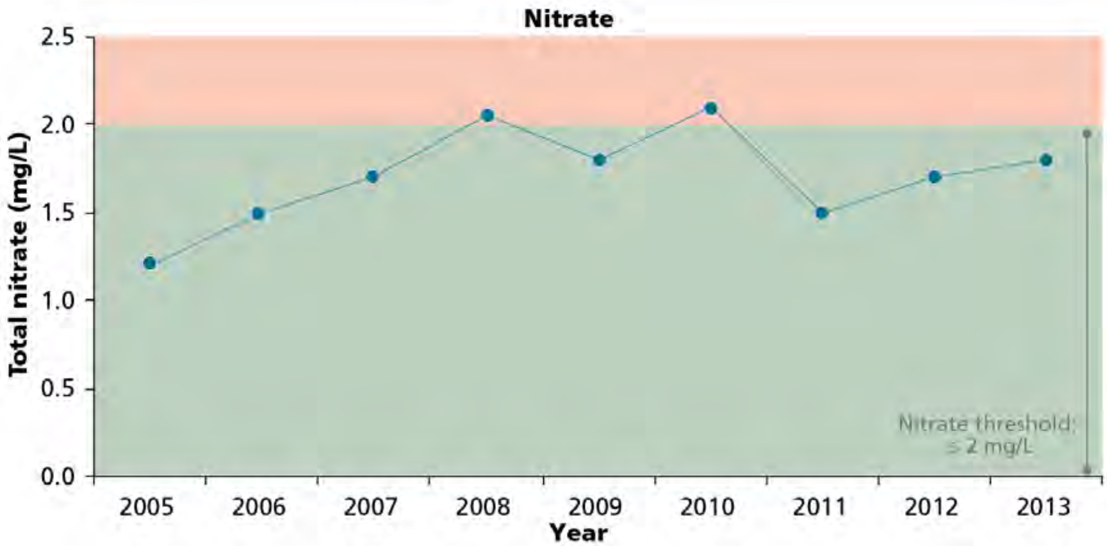


Figure 4-7 Annual median nitrate concentrations (mg/L) from 2005 to 2013 for two stream sampling locations in WOTR.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Total Phosphorus

Description

Phosphorus is an essential nutrient for plants to live and is frequently the limiting nutrient for plant growth in aquatic systems. A minor increase in phosphorus concentration can significantly affect water quality by changing the population and community dynamics of algae and diatoms leading to eutrophication (Allan 1995). The most common form of phosphorus pollution is in the form of phosphate (PO_4). Sources of phosphate pollution include sewage, septic tank leachate, fertilizer runoff, soil erosion, animal waste, and industrial discharge.

Data and methods

Data was collected monthly between 2005 and 2013 at two sites by National Capital Region Network (NCRN) Inventory & Monitoring staff (Norris and Pieper 2010, Pieper *et al.* 2012). NCRN followed the sampling protocol specified in Norris *et al.* 2011. No data was available for 2008. It should be noted that the current methodology for measuring total phosphorus has been in use since July 2007. During the month of July 2007, a different method was used after an equipment malfunction. A third method was utilized prior to July 2007 (Norris and Pieper 2010).

Measurements were taken monthly as instantaneous measurements. Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment. If a measurement was listed as “not detected,” it was assigned a pass result because the detection limit for phosphate is lower than the assessment reference condition (J. Pieper, pers. comm.)

The phosphate reference condition is based on the U.S. EPA Ecoregional Nutrient Criteria for total phosphorus. These criteria were developed to prevent eutrophication nationwide and are not regulatory (U.S. EPA 2000). The criteria are developed as baselines for specific geographic regions. Wolf Trap is located in Ecoregion IX or the Southeastern Temperate Forested Plains and Hills (Pieper *et al.* 2012). The ecoregional reference condition value for total phosphorus is 0.037 mg P/L (37 ppb) (U.S. EPA 2000) (Table 4-2). Each data point was compared against the reference condition to determine the percent attainment and condition.

Condition and trend

Current condition of total phosphorus at WOTR was very degraded, with a median total phosphate concentration of 0.08 mg/L and only 9% of data points attaining reference condition of 0.01 mg/L between 2005 and 2013. Over the data range available, no significant trend was present (*p*-value > 0.01) (Figure 4-8).

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

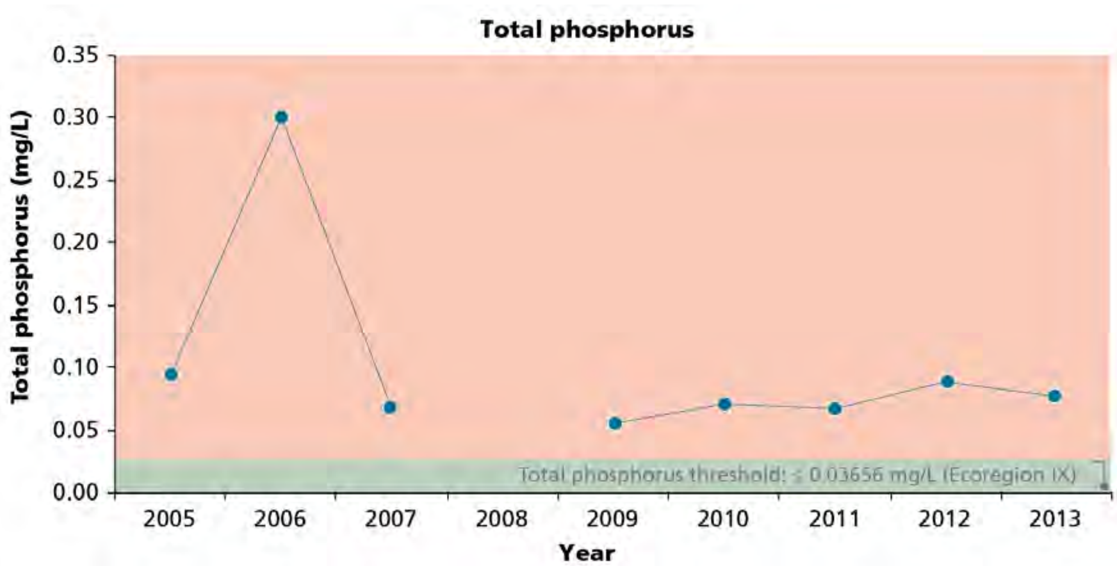


Figure 4-8 Annual median total phosphorus concentrations (mg/L) from 2005 to 2013 for two stream sampling locations in WOTR. Data was unavailable for 2008.

Benthic index of biotic integrity

Description

The Benthic Index of Biotic Integrity (BIBI) is one multi-metric index monitored by the Maryland Department of Natural Resources' Maryland Biological Stream Survey (MBSS). Taxonomic information at each site was used to calculate a Benthic Index of Biotic Integrity developed specifically for Maryland streams, but is applicable to nearby Virginia and West Virginia Sites (Hildebrand 2005). BIBI is an indicator of the health of the benthic macroinvertebrate communities in a stream.

Data and Methods

Data were collected at two sites between 2004 and 2012 by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Norris and Pieper 2010). NCRN followed the sampling protocol specified in Norris *et al.* 2011.

The reference conditions are based on the MBSS interpretation of the BIBI. The BIBI scores range from 1 to 5 and are calculated by comparing the site's benthic assemblage to the assemblage found at minimally impacted sites (Norris and Sanders 2009). A score of 3 indicates that a site is considered to be comparable to (i.e., not significantly different from) reference sites. Any sites with BIBIs less than 3 are in worse condition than reference sites (Southerland et al. 2007, Norris and Sanders 2009). BIBI values were ranked as follows: 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good), and these were the scale and categories used in this assessment (Southerland et al. 2007).

The range of BIBI scores from 1 to 5 were scaled linearly from 0 to 100% attainment. The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Table 4-2).

Condition and trend

Current condition of benthic macroinvertebrates in WOTR was very degraded, with a median BIBI of 1.33 based on five data points between 2004 and 2012 from two sites. This equates to 8% attainment of reference condition (very poor condition) (Figure 4-9). No trend analysis was possible with the current data set.

Table 4-4 Benthic Index of Biotic Integrity (BIBI) in WOTR.

Year	Site	Location	BIBI
2012	DIFF-202-N-2012	Courthouse Creek	2.67
2012	DIFF-201-N-2012	Wolf Trap Creek	2
2006	DIFF-201-N-2006	Wolf Trap Creek	1.33
2004	DIFF-201-N-2004	Wolf Trap Creek	1.33
2004	DIFF-202-N-2004	Courthouse Creek	1

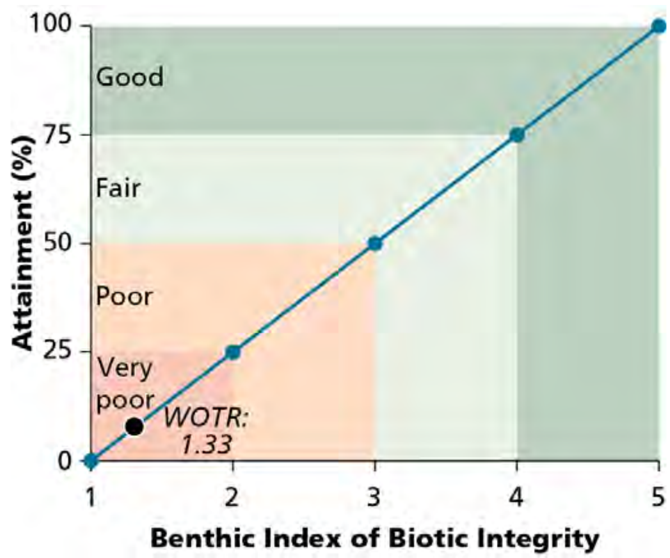


Figure 4-9 Application of percent attainment categories to the Benthic Index of Biotic Integrity (BIBI) categories. BIBI at WOTR was very degraded, with a median of 1.33, which equated to 8% of the reference condition.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Physical habitat index

Description

Physical habitat is an integral part of overall stream condition. Components of physical habitat include the diversity of flow conditions, the diversity and stability of substrates, the degree and extent of erosion, the amount of woody debris, and many other factors. These physical factors affect the biological potential of streams by providing the physical template upon which stream biological community structure is built (Paul et al. 2012).

Data and methods

Data for the Physical Habitat Index (PHI) were collected at 4 sites between 2004 and 2012. NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Habitat assessments are determined based on data from numerous metrics such as riffle quality, stream bank stability, woody debris, quality of streambed substrates, shading, and many more. Sites are given scores for each of the applicable categories and then those scores are adjusted to a percentile scale (Norris and Sanders 2009). Reported data are for one PHI assessment per site (per year when sites were visited in multiple years).

The PHI reference condition was developed by the Maryland Biological Stream Survey (MBSS) program after initial sampling as described for the ANC reference condition (see Section 4.1.4). The MBSS determined the scale for PHI values to be 0-50 (severely degraded), 51-65 (degraded), 66-80 (partially degraded), and 81-100 (minimally degraded), and these were the scale and categories used in this assessment (Paul et al. 2002, Southerland et al. 2005). Each of the four PHI value categories was assigned a percent attainment range.

The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment.

Condition and trend

Current condition of PHI in WOTR was degraded based on four data points between 2004 and 2012 from two sites, with a median PHI of 65.4 (Table 4-5), which equates to a 49% attainment of the reference condition (Figure 2-4). No trend analysis was possible with the current data set.

Table 4-5 Stream physical Habitat Index (PHI) in WOTR.

Year	Site	Location	PHI
2012	DIFF-202-N-2012	Courthouse Creek	66.65
2012	DIFF-201-N-2012	Wolf Trap Creek	68.98
2006	DIFF-201-N-2006	Wolf Trap Creek	57.5
2004	DIFF-201-N-2004	Wolf Trap Creek	64.16

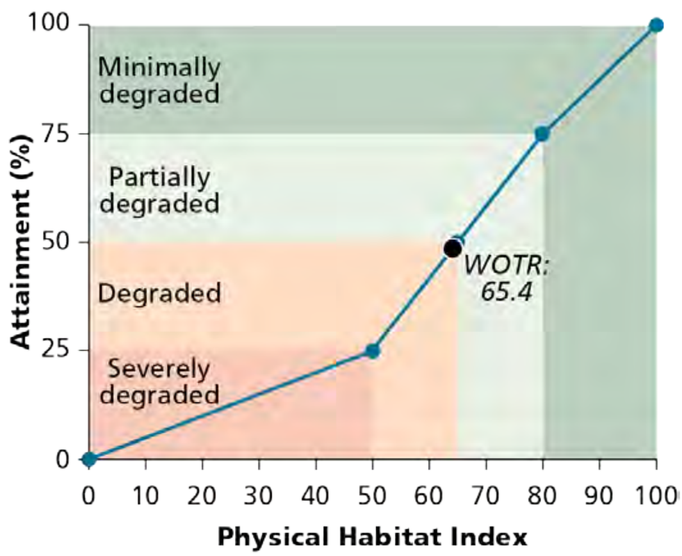


Figure 4-10 Application of the percent attainment categories to the Physical Habitat Index (PHI) value categories. PHI at WOTR was 65.4, which equated to 48.9% attainment of the reference condition.

Sources of expertise

- James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Biological integrity

Seven metrics were used to assess biological integrity in Wolf Trap—exotic herbaceous species, exotic trees and saplings, forest pests, seedlings and forest regeneration, fish index of biotic integrity (FIBI), bird community index (BCI), and deer density (Table 4-6). All data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff. Forest monitoring sites are shown in Figure 4-11, FIBI monitoring sites are shown in Figure 4-12, and bird community index sites are shown in Figure 4-13.

Table 4-6 Ecological monitoring framework data for Biological Integrity provided by agencies and specific sources included in the assessment of WOTR.

Biological integrity indicators	Source of data	Reference
Cover of exotic herbaceous species	NCRN I&M	Schmit et al. 2009, 2010, 2012
Area of exotic trees & saplings	NCRN I&M	Schmit et al. 2009, 2010, 2012
Presence of forest pest species	NCRN I&M	Schmit et al. 2009, 2010, 2012
Stocking index	NCRN I&M	Schmit et al. 2009, 2010, 2012
Fish index of biotic integrity	NCRN I&M	Norris and Sanders 2009, MBSS
Bird community index	NCRN I&M	O'Connell et al. 1998
Deer density	NPS NCR	Bates 2009

Figure 4-11 Forest monitoring sites in WOTR.

Figure 4-12 Fish index of biotic integrity (FIBI) monitoring sites in WOTR.

Figure 4-13 Bird monitoring sites in WOTR.

Reference conditions were established for each of the seven metrics and the data were compared to these reference conditions to obtain the percent attainment (Table 4-7). Single reference conditions were used for exotic plants, forest pests, native tree seedling regeneration, and deer, while multiple reference conditions were used for FIBI and BCI scores (Table 4-7).

Table 4-7 Biological integrity reference conditions for WOTR.

Biological integrity indicator	Number of sites	Number of samples	Period of observation	Reference condition	% attainment applied
Presence of exotic herbaceous species (% of plots with exotic species)	6	6	2010-2013	0% (absence)	0-100% Scaled linearly
Area of exotic trees & saplings (% of basal area)	6	12	2010-2013	< 5%	0-100% Scaled linearly
Presence of forest pest species (% trees infested)	6	6	2010-2013	< 1%	0-100% Scaled linearly
Stocking index	6	6	2010-2013	> 115	0-100% Scaled linearly
Fish index of biotic integrity	4	4	2004-2012	1.0-1.9 2.0-2.9 3.0-3.9 4.0-5.0	0-100% Scaled linearly
Bird Community Index (BCI)	6	13	2007-2014	20-40 40.1-52 52.1-60 60.1-77	0-25% (Scaled linearly) 25-50% (Scaled linearly) 50-75% (Scaled linearly) 75-100% (Scaled linearly)
Deer density	Park	2	2012-2013	< 8	0-100% (Scaled linearly)

Wolf Trap had variable results for biological integrity. The park scored in very good condition for area of exotic trees and saplings and forest pests (100% attainment); degraded condition for birds (28.9% attainment); and very degraded for exotic herbaceous species, seedlings and forest regeneration and deer density (17%, 0%, and 0% attainment respectively).

Table 4-8 Summary of biological integrity condition assessment at WOTR.

Metric	WOTR result	% attainment of reference condition	Condition assessment	Overall biological integrity condition
Presence of exotic herbaceous species (% of plots with exotic species)	11.2	17%	Very degraded	44% Moderate
Area of exotic trees & saplings (% of basal area)	0.3	100%	Very good	
Presence of forest pest species (% trees infested)	0%	100%	Very good	
Stocking index	0.5	0%	Very degraded	
Fish index of biotic integrity	3.50	64%	Fair	
Bird community index	42	28.9%	Low integrity	
Deer density	44	0%	Very degraded	

Exotic herbaceous species

Description

Invasive exotic plants are species that aggressively compete with and displace native plant communities. The result can be loss and destruction of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, reduced groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Although certain plant species were purposefully introduced in the United States for agriculture, erosion control (kudzu), or ornamental purposes (Japanese barberry, English ivy), many are now considered invasive threats. Exotic plant species are a ubiquitous and growing threat in the National Capital Region.

Exotic herbaceous plants make up the majority of exotic plant species found in the forests of parks of the National Capital Region, including Wolf Trap, and so pose the biggest problem to park management in terms of exotic plants (Schmit *et al.* 2010). According to Schmit *et al.* (2010), the most common exotic herbaceous species in forests are Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), and Oriental bittersweet (*Celastrus orbiculatus*).

Data and methods

Forest monitoring took place at six sites in WOTR from 2010-2013, but not all plots were measured every year (Schmit *et al.* 2009) (Figure 4-11). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

The cover of exotic herbaceous species in a plot was calculated from the percent cover of the single exotic species with the greatest cover. Results from each plot were assessed against the reference condition and the percentage of passing results was used as the percent attainment.

The Organic Act that established the National Park Service in 1916 and the U.S. Department of Interior NPS Management Policies (U.S. Dept. of Interior 2006) mandate the conservation of natural resources (see Park legislation). Because of the threat to the park posed by exotic herbaceous plants, the reference condition used for this assessment was that exotic herbaceous plants should be completely absent. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-7).

Condition and trend

Current condition for cover of exotic herbaceous species in WOTR was very degraded, with 11.2% cover and 17% of data points attaining reference condition (Figure 4-14). No trend analysis was possible with the current data set.

Figure 4-14 Exotic herbaceous species results by site for WOTR.

Sources of expertise

- John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Exotic trees & saplings

Description

Invasive exotic plants are non-native species that can reduce abundance and diversity of native plant communities (Vila *et al.* 2011). The result can be loss and destruction of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, reduced groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Exotic tree species, especially those that are invasive, are a ubiquitous and growing threat in the National Capital Region (NCRN 2008, 2010).

The only exotic tree species found in the monitoring plots thus far at WOTR is sweet cherry (*Prunus avium*), but other exotic tree species have been observed, including tree of heaven (*Ailanthus altissima)*, Norway maple (*Acer platanoides)*, and mimosa tree (*Albizia julibrissin)*.

Data and methods

Forest monitoring took place annually but not all plots were measured every year, and data was recorded for 2010-2013 (Schmit *et al.* 2009) (Figure 4-11). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed. The basal area of exotic trees and saplings in a plot was calculated as a percentage of total tree basal area. Results from each plot were assessed against the reference condition and the percentage of passing results was used as the percent attainment.

The reference condition used for this assessment was that the abundance of these invasive exotic plants should not exceed 5% of total basal area. Because 100% eradication is not a realistic goal, the reference condition is intended to suggest more than just simple presence of these exotic species but that the observed abundance has the potential to establish and spread, i.e., 5% cover may be considered as the point where the exotic plants are becoming established rather than just present. The Organic Act that established the National Park Service in 1916 and the U.S. Department of Interior NPS Management Policies (U.S. Dept. of Interior 2006) mandate the conservation of natural resources (see Section *2.1.1—Enabling legislation*). This reference condition is a guide to commence active management of an area by removal of these species. Each data point was compared against the reference condition to determine the percent attainment and condition. To determine the overall condition assessment for exotic trees and saplings in WOTR, the mean of all values was compared against the reference condition of ≤ 5%.

Condition and trend

Condition for basal cover of exotic trees and saplings in WOTR was very good, with a mean of 0.34% cover and 100% of data points attaining the reference condition of ≤ 5% of total basal area (Table 4-9, Figure 4-15). Despite having 100% attainment (attaining the reference condition of ≤ 5% of total basal area), one sampling plot, WOTR-0007, did have exotic trees present, the coverage was below the reference condition (Table 4-9). No trend analysis was possible with the current data set.

Table 4-9 Percent basal area of exotic trees and saplings. Site locations are shown in Figure 4-11.

Site	Year	Exotic trees	Exotic saplings
WOTR0004	2013	0	0
WOTR0009	2013	0	0
WOTR0001	2011	0	0
WOTR0003	2011	0	0
WOTR0007	2011	4.1	0
WOTR0008	2010	0	0

Sources of expertise

- John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

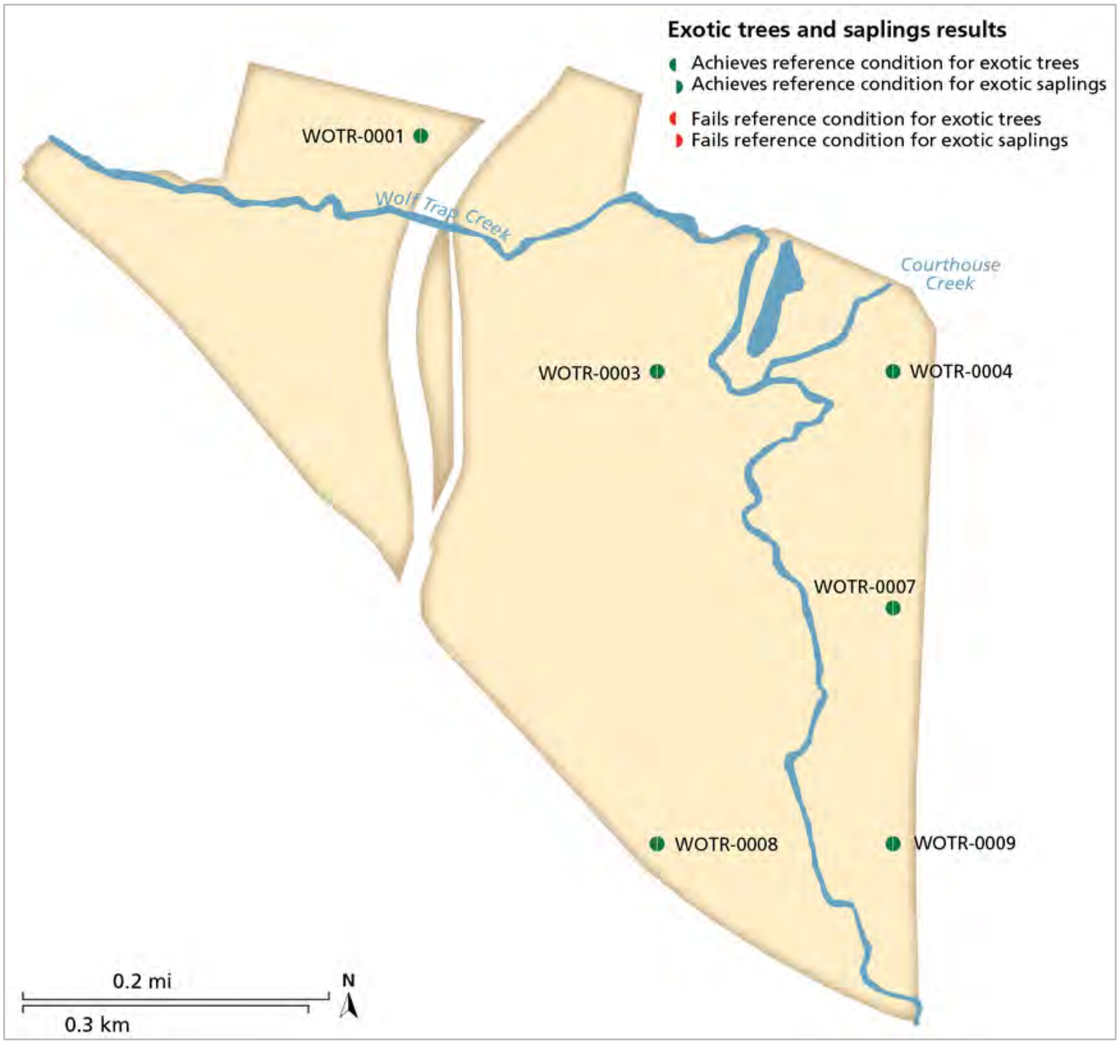


Figure 4-15 Exotic tree and sapling results by site for WOTR.

Forest Pests

Description

Defoliation caused by forest pests can stress and weaken trees leaving them more susceptible to secondary infections and infestations and other cumulative impacts. These impacts, both directly and indirectly caused by forest pest species, weaken and eventually kill some forest trees. This in turn has adverse effects on water quality, wildlife and habitat, rare plants, visitor use and experience, safety, the cultural landscape, and the wildland fire fuel load.

Several forest pest species are present within the Capital Region, however none have been established within WOTR. Fairfax County has sprayed for gypsy moths (*Lymantria dispar*) several times in the last few years on the park boundaries. Hemlock woolly adelgid (*Adelges tsugae*), an aphid-like insect originally from Asia that feeds on Eastern hemlock trees (*Tsuga canadensis*), is not present in the park as there are no hemlocks within the park. Additionally, during a nearby 2004 outbreak of Emerald Ash Borer, the US Forest Service removed several mature ash trees from areas surrounding the park. Several sentinel ash trees were placed within the park boundary, and monitored for several years, and none have shown signs of Emerald Ash Borer infestation.

Data and methods

Forest monitoring took place annually but not all plots were measured every year, and data was collected between 2010 and 2013 (Schmit *et al.* 2009) (Figure 4-11). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

The percentage of trees infested was calculated by dividing the number of trees afflicted by pests in each plot by the total number of trees in each plot. Results from each plot were assessed against the reference condition and the percentage of passing results was used as the percent attainment.

Due to the destructive nature and potential for forest damage from these pests, the reference condition used was established as any observation of these pests (i.e., > 1% of trees infested) being considered degraded. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-7).

Condition and trend

Current condition for insect pests was very good, with 0% of trees infested and 100% of data points attaining reference condition (Table 4-10, Figure 4-15). No trend analysis was possible with the current data set.

Table 4-10 Percent of trees with evidence of forest pest species.

Site	Year	% trees with pests
WOTR-0004	2013	0
WOTR-0009	2013	0
WOTR-0001	2011	0
WOTR-0003	2011	0
WOTR-0007	2011	0
WOTR-0008	2010	0

Sources of expertise

- John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Figure 4-16 Forest pest species results by site for WOTR.

Seedlings and forest regeneration

Description

Forests are the dominant natural vegetation in the parks of the National Capital Region Network. Many factors including dense white-tailed deer populations and fire suppression in forested regions can alter forest stand development and reduce wildlife habitat by reducing or eliminating young tree seedlings, shrubs, and herbaceous plants (Tierson et al. 1966, Jordan 1967, Marquis 1981, Tilghman 1989, Horsely *et al.* 2003, Coté *et al.* 2004, Nowacki and Abrams 2008). In response to regeneration concerns, scientists at the U.S. Forest Service developed a measure, called the 'stocking index' to determine if regeneration is sufficient (Marquis and Bjorkman 1982). The index takes into account the number and size of seedlings present.

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit *et al.* 2009) (Figure 4-11). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed. At each plot, seedlings and small saplings were counted and the height of each was determined. Based on these measurements, each plot was given a score, with older/larger seedlings and saplings receiving a higher score than smaller plants. Only seedlings ≥ 15 cm height and small saplings less than 2.5 cm diameter at breast height were used.

The stocking index reference condition used in this assessment was 115, above which a plot is considered to be adequately stocked at high densities of white-tailed deer. Each measurement was assessed against the reference condition and the percentage of passing results was used as the percent attainment (Table 4-7).

Condition and trend

Current condition for native tree seedling regeneration in WOTR was very degraded, with a mean stocking index value of 0.5 seedlings/ha and 0% of data points attaining reference condition of > 115 (Table 4-11; Figure 4-17). No trend analysis was possible with the current data set.

Table 4-11 Stocking index values.

Site	Year	Index
WOTR-0004	2013	1
WOTR-0009	2013	0
WOTR-0001	2011	0
WOTR-0003	2011	0
WOTR-0007	2011	0
WOTR-0008	2010	2

Sources of expertise

- John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Figure 4-17 Stocking index results by site for WOTR.

Fish

Description

The Fish Index of Biotic Integrity (FIBI) was proposed as a way of providing a more informative measure on anthropogenic influence on fish communities and ecological integrity than measurements of physiochemical metrics alone (Karr 1981). The metric was then adapted and validated for streams of Maryland using a reference condition approach, based on 1994-1997 data from a total of 1,098 sites.

Data and methods

Data were collected at four sites during 2004, 2006, and 2012. NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Sites were classified based on physical and chemical data and fish assemblages were compared to identified reference sites. Reported data are for one FIBI assessment per site.

FIBI values were ranked as follows: 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good), and these were the scale and categories used in this assessment (Southerland *et al.* 2007). The range of FIBI scores from 1 to 5 were scaled linearly from 0 to 100% attainment. The mean of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Table 4-7).

Condition and trends

Current condition of FIBI in WOTR was fair, with a mean FIBI of 3.50 and 62.5% attainment of reference condition (Table 4-12, Figure 4-18). No trend analysis was possible with the current data set.

Table 4-12 Fish Index of Biotic Integrity (FIBI) in PRWI. Monitoring sites are shown in Figure 4-12.

Year	Site	Location	FIBI
2012	DIFF-202-N-2012	Courthouse Creek	3.33
2012	DIFF-201-N-2012	Wolf Trap Creek	3.67
2006	DIFF-202-N-2006	Wolf Trap Creek	4.33
2004	DIFF-201-N-2004	Wolf Trap Creek	2.67

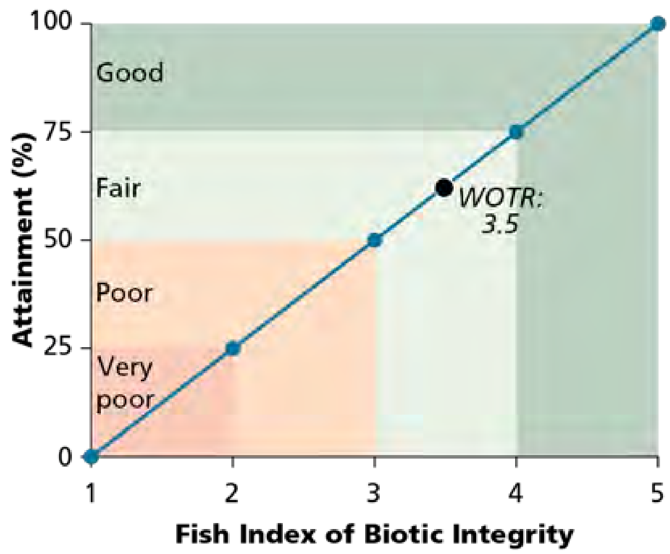


Figure 4-18 Application of the percent attainment categories to the Fish Index of Biotic Integrity (FIBI) value categories. FIBI at WOTR was 3.5, which equated to 75% attainment of the reference condition.

Sources of expertise

- Marian Norris, Water Resources Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Birds

Description

Birds exhibit numerous characteristics that make them appropriate as ecological indicators. They are conspicuous components of terrestrial ecosystems in the National Capital Region, they can integrate conditions across major habitat types, and many require specific habitat conditions (O'Connell *et al.* 1998).

Modeled after previously developed Indices of Biotic Integrity (IBIs), the Bird Community Index (BCI) was developed as a multi-resource indicator of biotic integrity in the central Appalachians (O'Connell *et al.* 1998).

Data and methods

Data was available for only 1 site between 2007 and 2013 (Figure 4-13). In 2014, 5 additional bird monitoring sites were added in WOTR. The data represented in the analysis are from 6 monitoring sites, however one site, WOTR-0008 was the only site monitored in all eight years (2007-2014). Point count data was used to assess the BCI using the O'Connell *et al.* (1998) scoring and guild assignments for the Appalachian bird conservation region (BCR) (Ladin and Shriver 2013). BCI scores were ranked as follows: highest integrity (60.1– 77.0), high integrity (52.1– 60.0), medium integrity (40.1–52.0), and low integrity (20.0–40.0). These were the scale and categories used in this assessment (O'Connell *et al.* 1998).

Each of the four BCI value categories were assigned a percent attainment range. Each BCI value was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Table 4-7).

Condition and trend

The 2014 BCI of six forest sites in WOTR showed medium integrity, with a median of 42.0 and a value of 28.9% attainment of reference condition (Table 4-13; Figure 4-19)

Because there was only one data point that monitored in multiple years for the entire park, a trend analysis was completed for site WOTR-008 to assess the trend in BCI in all years of the record (2007-2013) at that one site (Figure 4-20). Over the data range available, no significant trend was present (p-value > 0.01).

Table 4-13 Median bird Community Index (BCI) at six monitoring sites within WOTR. Note that in monitoring years 2007-2013, only one site in WOTR was sampled for Bird Community Index (WOTR-0008). Monitoring site location shown in Figure 4-23.

Year	Score
2014	51
2013	44
2012	42
2011	33
2010	41
2009	34

Year	Score
2008	39
2007	40

Sources of expertise

- John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

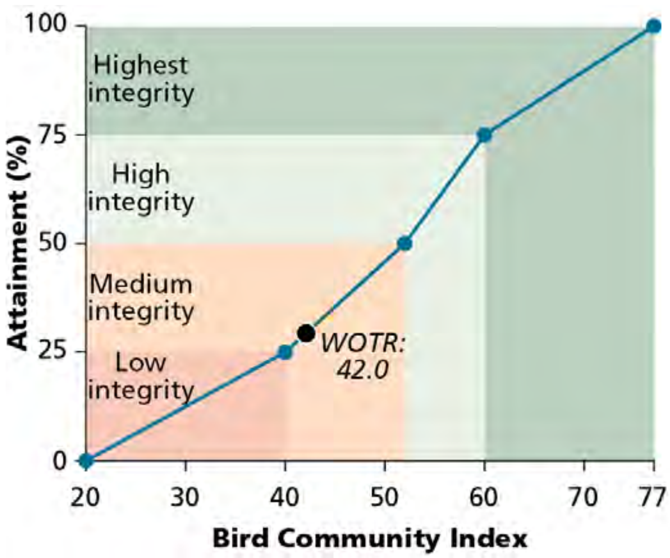


Figure 4-19 Application of the percent attainment categories to the Bird Community Index (BCI) value categories. BCI at WOTR was 42.0, which equated to 28.9% attainment of the reference condition.

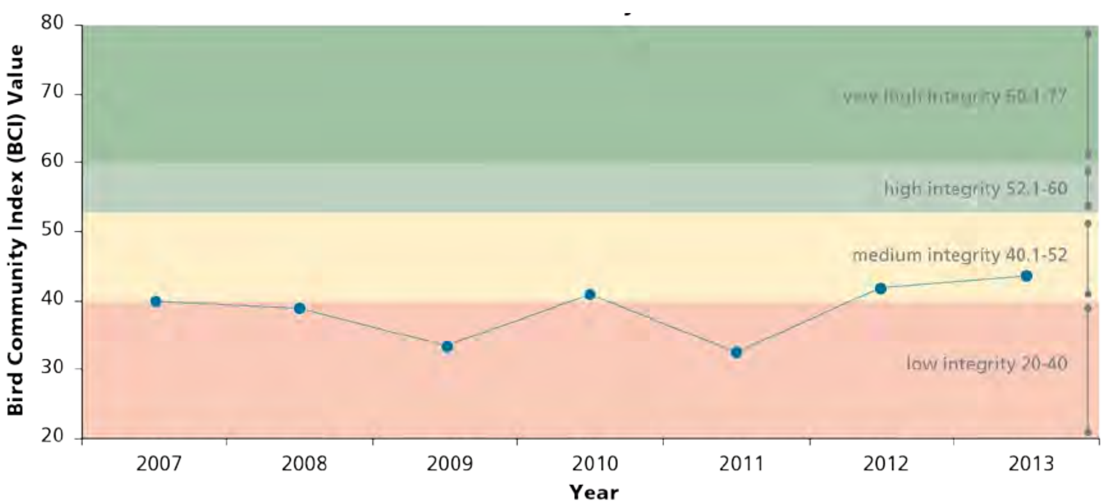


Figure 4-20 Bird community index (BCI) at site WOTR-008 between 2007 and 2013.

Deer density

Description

White-tailed deer (*Odocoileus virginianus*) are considered a significant stressor on forests of the National Capital Region. White-tailed deer densities throughout the eastern deciduous forest zone increased rapidly during the latter half of the 20th century and may now be at historically high levels. McCabe and McCabe (1997) estimate that pre-European deer densities in the eastern United States ranged between 3.1 and 4.2 deer/km^2 (8.0 and 10.9 deer/mi^2) in optimal habitats. Today, examples of deer populations exceeding 20 deer/km^2 (52 deer/mi^2) are commonplace (e.g., Knox 1997, Russell et al. 2001, Augustine and deCalesta 2003, Rossel Jr. et al. 2005, Griggs et al. 2006, McDonald Jr. et al. 2007).

The currently high population numbers for white-tailed deer regionally have been recognized since the 1980s as being of concern due to potentially large impacts upon regeneration of woody tree species as well as the occurrence and abundance of herbaceous species and consequent alterations to trophic interactions (deCalesta 1997, Waller and Alverson 1997, Côté et al. 2004). Besides directly impacting vegetative communities, deer overbrowsing can contribute to declines in breeding bird abundances by decreasing the structural diversity and density in the forest understory (McShea and Rappole 1997).

Data and methods

Deer population density was estimated at WOTR in 2012 and 2013 using the distance survey method (Bates 2006, 2009). Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The forest reference condition for white-tailed deer density (8.0 deer/km^2 [21 deer/mi^2]) is a well-established ecological reference condition (Horsley *et al.* 2003). Species richness and abundance of herbs and shrubs are consistently reduced as deer densities approach 8.0 deer/km^2 (21 deer/mi^2), although shown in some studies to change at densities as low as 3.7 deer/km^2 (9.6 deer/mi^2) (deCalesta 1997). One large manipulation study in central Massachusetts found deer densities of 10–17 deer/km^2 (26–44 deer/mi^2) inhibited the regeneration of understory species, while densities of 3–6 deer/km^2 (8–16 deer/mi^2) supported a diverse and abundant forest understory (Healy 1997). There are multiple sensitive species of songbirds that cannot be found in areas where deer grazing has removed the understory vegetation needed for nesting, foraging, and protection. Even though songbird species vary in how sensitive they are to increases in deer populations, these changes generally occur at deer densities greater than 8 deer/km^2 (21 deer/mi^2) (deCalesta 1997). Annual densities were compared against the reference condition to determine the percent attainment and condition.

Condition and trend

Current condition of deer population density in WOTR was very degraded, with 0% attainment of the reference condition (< 8.0 deer/km^2) for deer population density in 2012 and 2013. Population estimates for deer population in 2012 and 2013 exceeded the reference condition of < 8 deer/km^2 in both years, with a median deer population of 44 deer/km^2 for all years.

Sources of expertise

- Scott Bates, Wildlife Biologist, National Park Service, Center for Urban Ecology.

Landscape dynamics

Four metrics were used to assess landscape dynamics in WOTR—forest interior area, forest cover, impervious surface, and road density (measured at two different scales) (Table 4-14). Data from the 2006 National Land Cover database and the 2010 ESRI Streets layer were analyzed by National Capital Region Network (NRCN) Inventory & Monitoring (I&M) staff (ESRI 2010, NPS 2010a, NPS 201b, Fry et al. 2011, Jin et al. 2013).

The two spatial scales used for the analyses were: 1) within the park boundary and 2) within the park boundary plus and area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary. The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park.

Reference conditions were established for each metric (Table 4-15) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric. This resulted in an overall landscape dynamics condition attainment of 2%, or very degraded condition (Table 4-16).

Table 4-14 Ecological monitoring framework data for Landscape Dynamics provided by agencies and specific sources included in the assessment of WOTR.

Landscape dynamics indicator	Source of data	Reference
Forest interior area (within park)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Forest interior area (within park + 5x buffer)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Forest cover (within park)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Forest cover (within park + 5x buffer)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Impervious surface (within park)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Impervious surface (within park + 5x buffer)	NPS NPScape, National Land Cover Database 2011	NPS 2010a, Jin et al. 2013, NPS 2014a
Road density (within park)	NPS NPScape	NPS 2010b, NPS 2014b
Road density (within park +5x buffer)	NPS NPScape	NPS 2010b, NPS 2014b

Table 4-15 Landscape Dynamics reference conditions for WOTR.

Landscape dynamics indicator	Number of sites	Number of samples	Period of observation	Reference condition	% attainment applied
Forest interior area (within park)	Park	1	2011	% of total potential forest area translates to % attainment	0-100% Scaled linearly
Forest interior area (within park + 5x buffer)	Park	1	2011	% of total potential forest area translates to % attainment	
Forest cover (within park)	Park	1	2011	> 59%	
Forest cover (within park + 5x buffer)	Park	1	2011	> 59%	
Impervious surface (within park)	Park	1	2011	< 10%	
Impervious surface (within park + 5x buffer)	Park	1	2011	< 10%	
Road density (within park)	Park	1	2006	< 1.5 km/km^2	
Road density (within park + 5x buffer)	Park	1	2006	< 1.5 km/km^2	

Table 4-16 Summary of resource condition assessment of Landscape Dynamics in WOTR.

Landscape dynamics indicator	WOTR Result	% attainment	Condition assessment	Overall landscape dynamics condition
Forest interior area (within park)	10.4	10	Very degraded	2% Very degraded
Forest interior area (within park + 5x buffer)	3.7	4	Very degraded	
Forest cover (within park)	53.2	0	Very degraded	
Forest cover (within park + 5x buffer)	46.9	0	Very degraded	
Impervious surface (within park)	13.1	0	Very degraded	
Impervious surface (within park + 5x buffer)	13.1	0	Very degraded	
Road density (within park)	2.8	0	Very degraded	
Road density (within park + 5x buffer)	8.8	0	Very degraded	

Forest interior

Description

Forest interior habitat functions as the highest quality breeding habitat for forest interior dwelling species (FIDS) of birds. When a forest becomes fragmented, areas that once functioned as interior breeding habitat are converted to edge habitat and are often associated with a significant reduction in the number of young birds that are fledged in a year (Jones *et al.* 2000).

Data and methods

Forest interior area as percent of the park area (or buffered area) was calculated using the NPScape Phase 1 Landcover methods and script tools (NPS 2010) (Table 4-14) for forest morphology. The source data for this analysis was the 2011 National Land Cover Database (NLCD) (Jin *et al.* 2013) from which a Morphological Spatial Pattern Analysis (MSPA) dataset was generated using the GUIDOS software package (http://forest.jrc.ec.europa.eu/download/software/guidos) with the edge distance defined as 90 m (3 pixels). The number of acres of forest interior or 'core' area was extracted from the MSPA dataset for the park and the buffered areas.

The reference condition attainment was expressed as the number of acres of interior forest in the park as a percentage of the total potential acres of interior forest within the park (if the total forest area was one large circular patch). The data used in this assessment represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area 5 times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary. The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The percentage of potential forest interior area translated directly to the percent attainment and condition assessment.

Interior forest was defined as mature forested land cover ≥ 100 m (330 ft.) from non-forest land cover or from primary, secondary, or country roads (i.e., roads considered large enough to break the canopy) (Temple 1986).

Condition and trend

Forest interior area in WOTR at the scale of the park, and at the scale of the park plus the 5x buffer, was 10% and 4% of total area, respectively (Figure 4-21, Table 4-17). This indicated very degraded condition at the scale of the park, as well as at the 5x area scale. Note: forest interior area at an additional scale (park boundary plus a 30 km buffer is also shown Table 4-17 for reference but was not included in the current assessment. No trend analysis was possible with the current data set.

Table 4-17 Forest interior area (%) in WOTR.

Area	Interior area (%)
Park	10.4
Park + 5x area	3.7
Park + 30 km	5.7

Sources of expertise

- Mark Lehman, GIS Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service

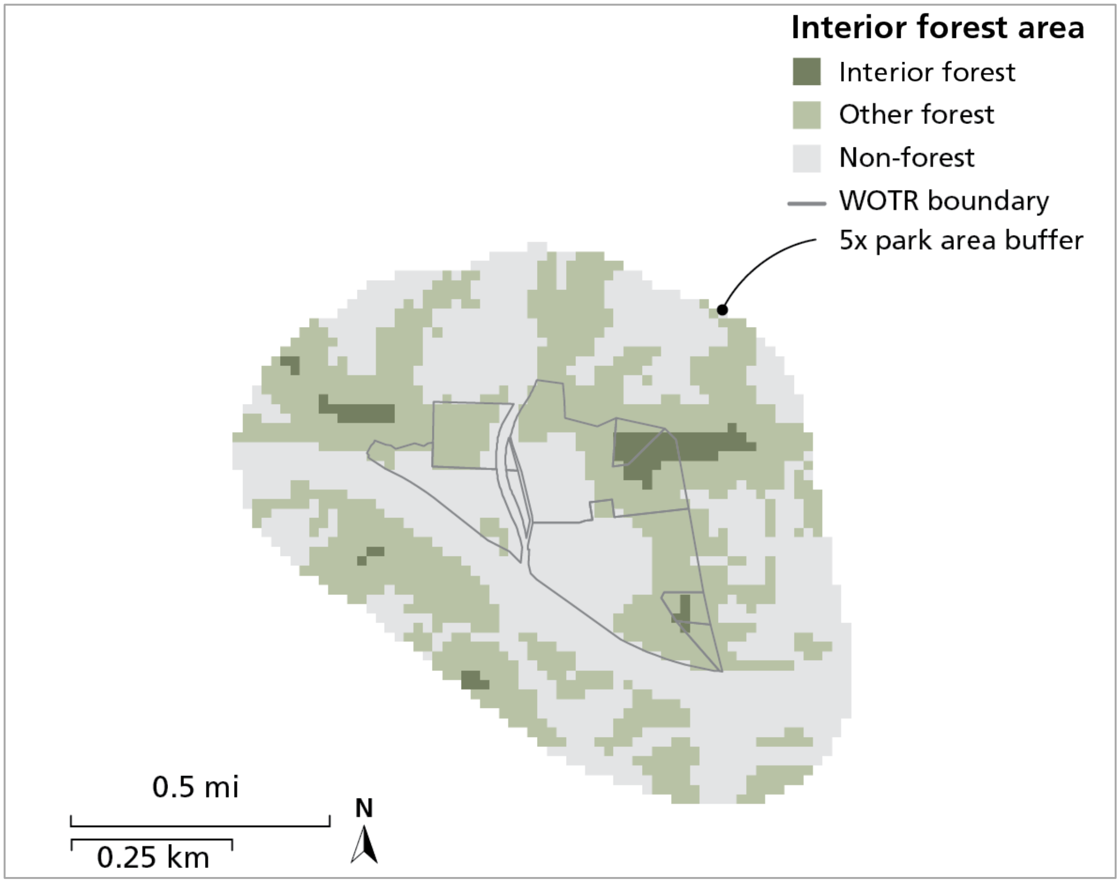


Figure 4-21 Extent of forest interior area within and around WOTR. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

Forest cover

Description

Forest is the dominant historical land use in the region surrounding WOTR and is still the dominant land use within the park itself (Figure 2-7). As intact and connected forest provides habitat, wildlife corridors, and ecosystem services, forest cover was chosen as a Landscape Dynamics metric.

Data and methods

Forest cover as a percent of the park area (or buffered area) was calculated using the NPScape Phase 1 Landcover methods and script tools (NPS 2010) (Table 4-14). The source data for this analysis was the 2011 National Land Cover Database (NLCD) (Jin *et al.* 2013). Three of the NLCD classifications were considered to be forested areas for this analysis: Deciduous Forest, Evergreen Forest, and Mixed Forest.

Modelling studies have found that in ecological systems, there is a 'tipping point' of forest cover below which a system becomes so fragmented that it no longer functions as a single system (Hargis et al. 1998). USGS digital land use data were used for forest cover in areas of North Carolina, West Virginia, and Alabama to determine the critical value of 59.28% (Gardner et al. 1987). Forest was chosen as it is a dominant vegetation type within the region, providing major structure to faunal and floral communities.

A forest cover reference condition of > 59% was used in this assessment and the data used represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4-22). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the result of the one-off calculation.

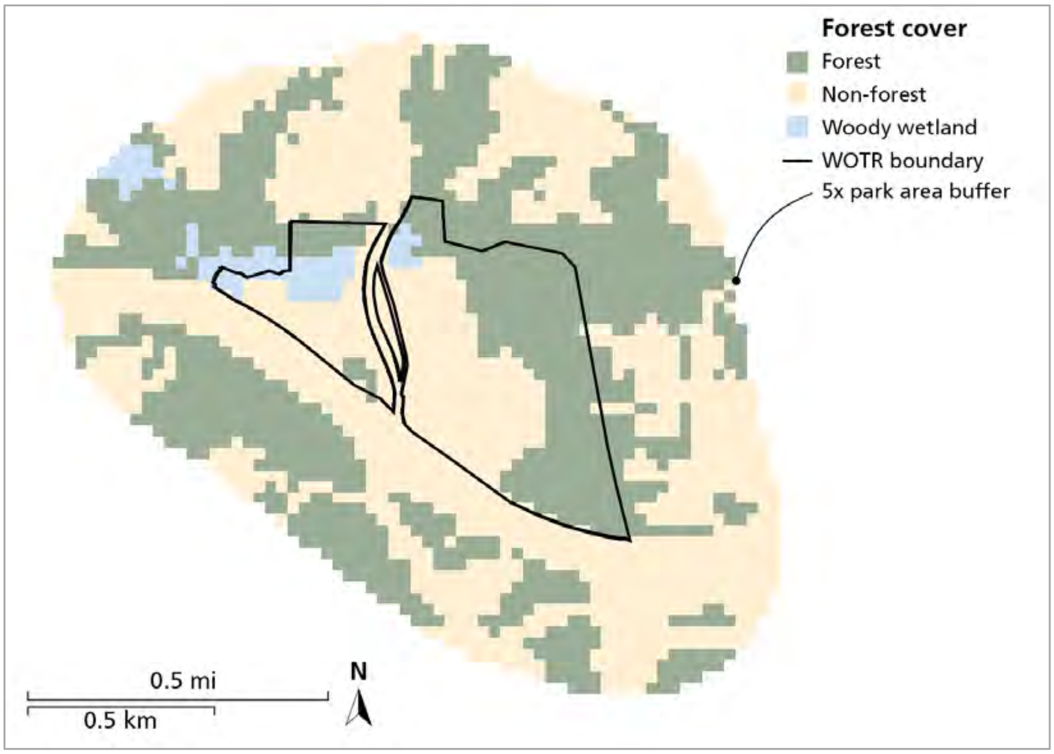


Figure 4-22. Extent of forest and non-forest landcover within and around WOTR. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

Condition and Trend

At the scale of the park, forest cover in WOTR was 53.2%, which is below the reference condition of 59%. This resulted in 0% attainment and a very degraded condition. When a buffer of five times the park was added, forest cover dropped to 46.9%, also below the reference condition of 59, resulting in 0% attainment of the reference condition and indicating very degraded condition. Note: forest cover at an additional scale (park boundary plus a 30 km buffer) is also shown in Table 4-18 for reference but was not included in the current assessment. No trend analysis was possible with the current data set.

Table 4-18 Forest cover in WOTR.

Area	Forest cover (%)
Park	53.2
Park + 5x	46.9
Park + 30km	27.9

Sources of expertise

- Mark Lehman, GIS Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Impervious surface

Description

Impervious surface is a representation of human impact on the landscape and directly correlates to land development (Conway 2007). It includes roads, parking lots, rooftops, and transport systems that decrease infiltration, water quality, and habitat while increasing runoff. Many ecosystem components such as wetlands, floral and faunal communities, and streambank structure show signs of impact above 10% impervious surface (Arnold and Gibbons 1996). Recent studies on stream macroinvertebrates continue to show shifts to more tolerant species and reductions in biodiversity at around this same reference condition (Lussier *et al.* 2008). Percent urban land is correlated to impervious surface and can provide a good approximation of watershed degradation due to increases of impervious surface.

Data and methods

A single mean impervious surface percentage was calculated for the park (and buffered areas) using ESRI zonal statistics on the 2011 National Land Cover Database impervious surface layer (NPS 2010b, Jin *et al.* 2013, NPS 2014b). Because of the research showing an impact threshold of 10% that was discussed above, the reference condition for total impervious surface was set to be less than 10%).

Data used in this assessment represent a one-off calculated at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4-23). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

Impervious surface in WOTR at the scale of the park and the scale of the park plus the 5x buffer was 13.09% and 13.11%, respectively. These were both above the reference condition of 10% impervious surface, resulting in 0% attainment and very degraded condition at both scales (Figure 4-23, Table 4-19) Note: impervious surface at an additional scale (park boundary plus a 30 km buffer) is also shown in Table 4-19 for reference but was not included in the current assessment. Areas adjacent to the park with the highest cover of impervious surface include the Washington, D.C. metropolitan area. No trend analysis was possible with the current data set.

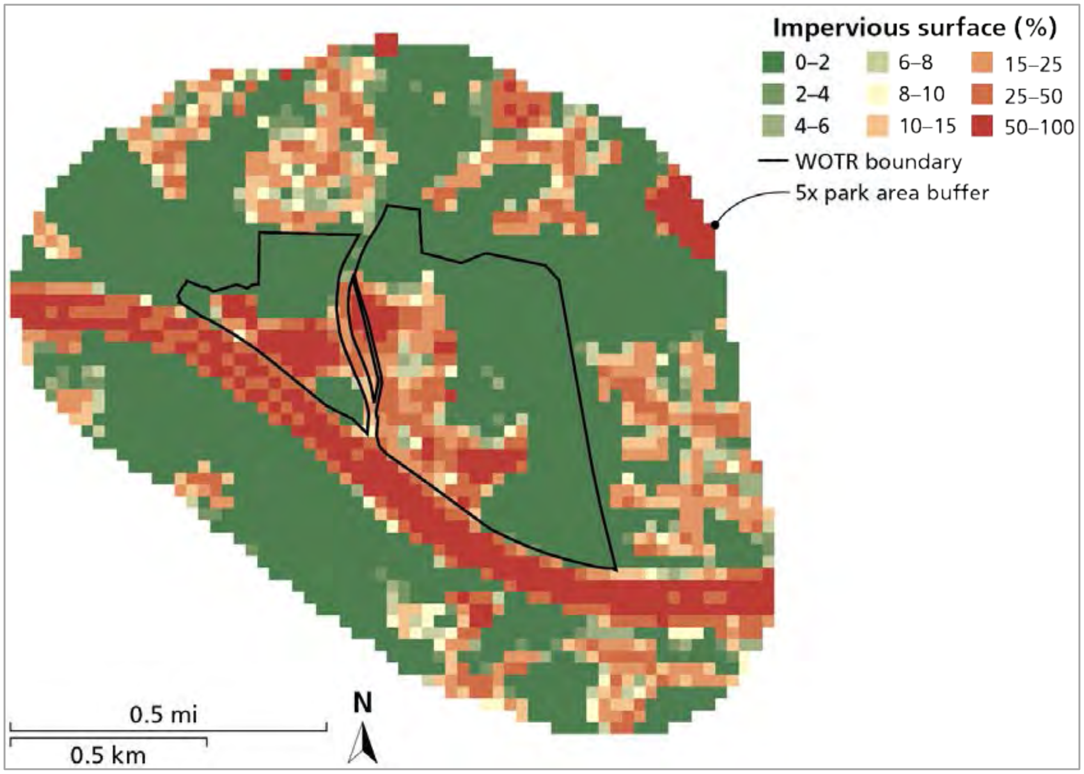


Figure 4-23 Percent impervious surface within and around WOTR. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

Table 4-19 Impervious surface (%) in WOTR.

Area	Impervious surface (%)
Park	13.1
Park + 5x area	13.1
Park + 30km	17.9

Sources of expertise

- Mark Lehman, GIS Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Road density

Description

Roads and other forest-dividing cuts such as utility corridors can act as barriers to wildlife movement and increase habitat fragmentation. High road density or the presence of a large roadway can decrease the quality of wildlife habitat by fragmenting it, and increases the risk of wildlife mortality by vehicle strike (Forman et al. 1995).

Data and methods

Road density (km of road per square km) and distance from roads were calculated using the NPScape Phase 2 Road Metrics Processing SOP (NPS 2010) for the park and buffered areas (Table 4-14). The 2010 ESRI Streets layer (ESRI 2010) was used as the source data. All of the features in this layer were included in this analysis with the exception of ferry routes.

Road densities higher than 1.5km/km^2 have been shown to impact turtle populations, while densities higher than 0.6 km/km^2 can impact natural populations of large vertebrates (Forman *et al.* 1995, Gibbs and Shriver 2002, Steen and Gibbs 2004). A road density reference condition of < 1.5km/km^2 was used in this assessment and data used in this assessment represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4-24; Figure 4-25). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

At the scale of the park, and at the scale of the park plus the 5x buffer road density in WOTR was 2.8 km/km^2, and 8.8 km/km^2, respectively. These both exceeded the reference condition of 1.5km/km^2, resulting in 0% attainment and very degraded condition at both scales. No trend analysis was possible with the current data set.

Table 4-20 Road density (km/km^2) in WOTR.

Area	Road density (km/km^2)
Park	2.8*
Park + 5x	8.8*
Park + 30km	7.1*

*Values outside of reference condition of < 1.5 km/km^2.

Sources of expertise

- Mark Lehman, GIS Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

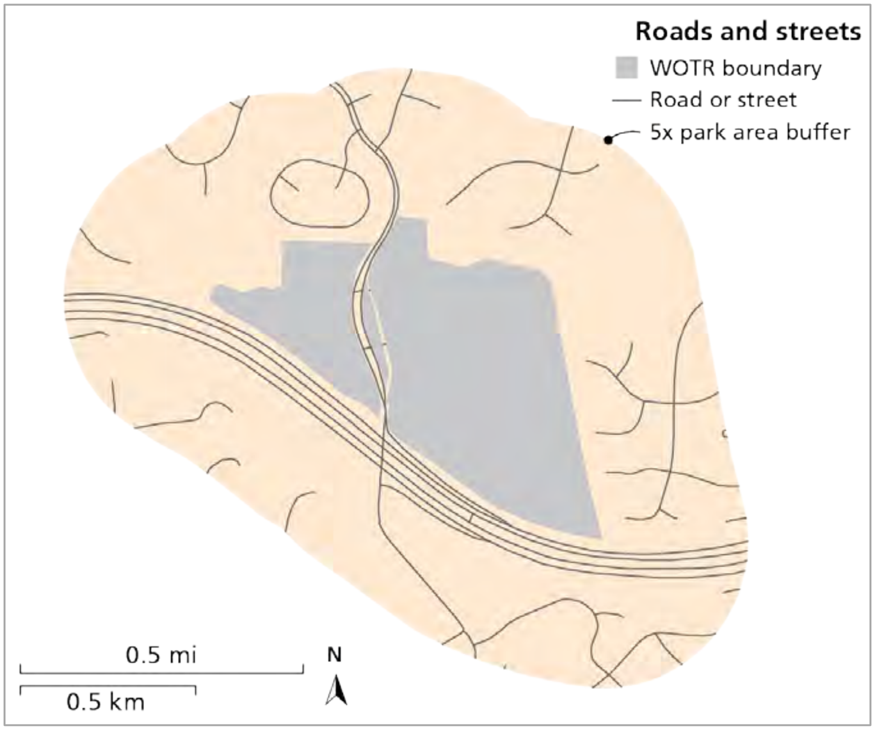


Figure 4-24 Map of the roads and streets in and around WOTR. This is the base map from which Figure 4-25 was generated.

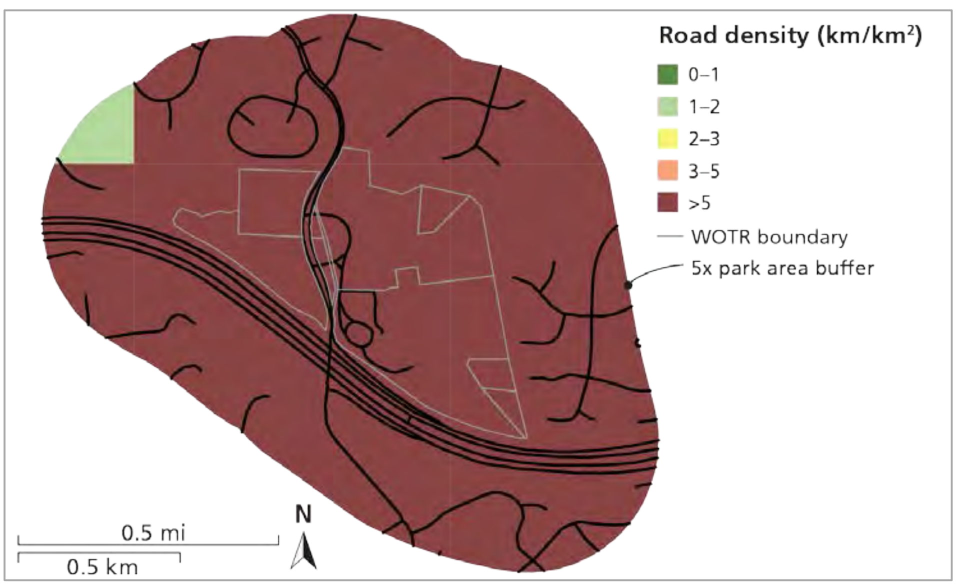


Figure 4-25 Road density within and around WOTR. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

Air resources

The Clean Air Act requires the U.S. EPA to set national air quality standards for specific pollutants that can negatively impact human health and the environment (U.S. EPA 2013). Six indicators of air quality have been assessed in this NRCA including wet sulfur and nitrogen deposition, ozone, visibility, particulate matter, and mercury deposition. Air quality can have detrimental effects on park vegetation and visitor experience. The intention of assessing air resources, despite the park having few management options to employ, is primarily for educational and awareness purposes.

Sulfur - Sulfur dioxide (SO_2) is one of a group of highly reactive gases known as "oxides of sulfur" or SOx. When deposited, SOx can cause terrestrial and aquatic ecosystems to become acidified; this can lead to changes in biodiversity or loss of fish or plant populations. Once in the atmosphere, SO_2 is highly mobile and can be transported distances greater than 500 km (311 miles) (Driscoll *et al*. 2001). Wet sulfate (SO_4^{2-}) deposition ("acid rain") is significant in the eastern part of the United States.

Nitrogen - Nitrogen deposition occurs as a result of both atmospheric deposition and nutrient fertilization of waters and soils. Impacts include such measurable effects as the disruption of nutrient cycling within ecosystems, changes to vegetation structure, loss of stream biodiversity, and the eutrophication of streams and coastal waters (Driscoll *et al.* 2001, Porter and Johnson 2007). Wet nitrogen deposition is significant in the eastern part of the United States.

Ozone – Ozone is a secondary atmospheric pollutant, meaning it is not directly emitted but rather is formed by a sunlight-driven chemical reaction on nitrogen oxides and volatile organic compounds emitted largely from burning fossil fuels (Haagen-Smit and Fox 1956). In humans, ozone can cause a number of health-related issues such as lung inflammation and reduced lung function, which can result in serious consequences. In 2010, the U.S. EPA proposed strengthening the primary ozone standard to a value in the range of 60-70 ppb to protect human health. After receiving public comment on their proposals, EPA deferred setting new standards until 2013.

EPA did establish a separate secondary standard to protect vegetation based on an ecologically relevant metric, the W126. Some plant species are more sensitive to ozone than humans. These sensitive plants can develop foliar injury from elevated ozone exposure levels especially when soil moisture levels are moderate to high. Under these conditions, plants have their stomata open, allowing gas exchange for photosynthesis, but also allowing ozone to enter.

Visibility - The presence of sulfates, organic matter, soot, nitrates, and soil dust can impair visibility. In the eastern U.S., the major cause of reduced visibility is sulfate particles formed from SO_2 emitted from coal combustion (National Research Council 1993). The Clean Air Act includes visibility as one of its national goals as an indicator of emissions (U.S. EPA 2004a).

Particulate matter - Fine particles less than 2.5µm diameter ($PM_{2.5}$) are emitted as smoke from power plants, gasoline and diesel engines, wood combustion, steel mills, and forest fires. Fine particles are also created when emissions of sulfur dioxide and nitrogen dioxide transform to sulfate and nitrate particles in the atmosphere. Because fine particles have multiple human health impacts, ground-level particulate matter is regulated under the Clean Air Act and the EPA set standard concentrations for airborne particulates (U.S. EPA 2004).

Mercury - Atmospheric mercury (Hg) comes from natural sources, including volcanic and geothermal activity, geological weathering, and anthropogenic sources such as burning of fossil fuels, processing of mineral ores, and incineration of certain waste products (UNEP 2008). Exposure to Hg can result in numerous health impacts for humans and other mammals (U.S. EPA 2001). Avian species' reproductive potential is negatively impacted by mercury. Mercury is also recorded to have a toxic effect on soil microflora, although no ecological depositional threshold is currently established (Meili *et al*. 2003).

Data and Methods

Five indicators were used to assess air quality in WOTR: wet sulfur deposition, wet nitrogen deposition, ozone (ppb and W126), visibility, and particulate matter. A sixth indicator (mercury deposition) was included for informational purposes but not included in the overall assessment. Data used for the assessment of current condition of wet sulfur and nitrogen deposition, ozone, and visibility were obtained from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2012a, b, c) (Table 4-21). These data were calculated by ARD on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The values for individual parks were taken from the interpolation at the park centroid, which is the location near the center of the park and within the park boundary (Figure 4-26). Data for the other two indicators (particulate matter and mercury deposition) were obtained from two nearby national monitoring sites (Table 4-21).

Table 4-21 Ecological monitoring framework data for Air Quality provided by agencies and specific sources included in the assessment of WOTR.

Indicator	Agency	Reference/source
Wet sulfur deposition	NPS ARD	NPS ARD 2012b; http://nadp.sws.uiuc.edu/data/animaps.aspx
Wet nitrogen deposition	NPS ARD	NPS ARD 2012b; http://nadp.sws.uiuc.edu/data/animaps.aspx
Ozone (ppb and W126)	NPS ARD	NPS ARD 2012a;
Visibility	NPS ARD	NPS ARD 2012c;
Particulate matter (PM 2.5)	IMPROVE	http://www.epa.gov/airdata
Mercury deposition	NADP-MDN	http://nadp.sws.uiuc.edu/data/mdndata.aspx

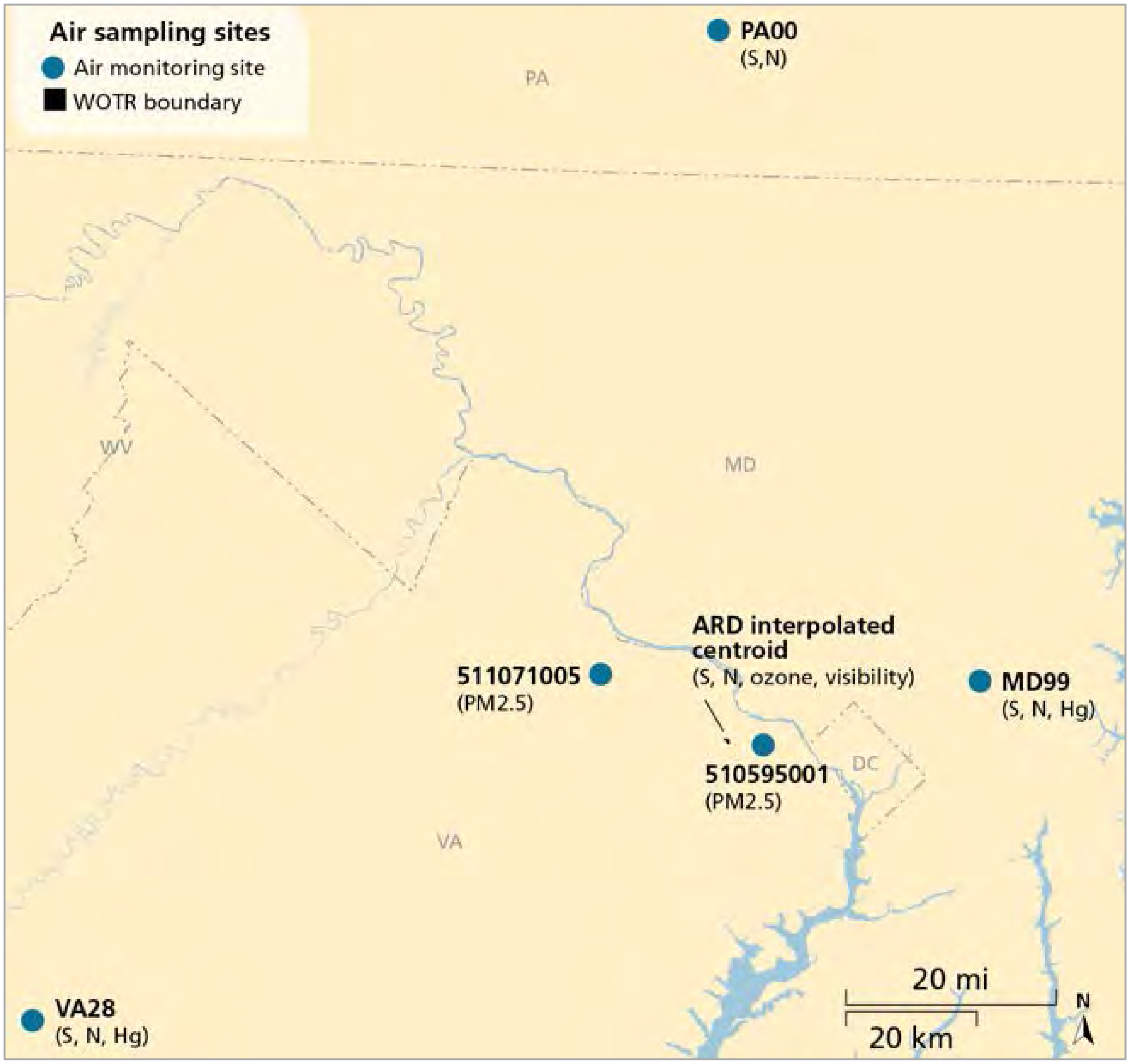


Figure 4-26 Regional air quality monitoring sites for wet deposition of sulfur and nitrogen, ozone, visibility, particulate matter, and mercury deposition. Wet deposition, ozone, and visibility data for 2006-2010 were interpolated by NPS ARD to estimate a mean concentration for WOTR.

Reference conditions were established for each of the five indicators (Table 4-22) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that indicator (Table 4-23). Multiple reference condition categories were used in accordance with the NPS ARD documentation (NPS ARD 2011) (Table 4-22).

Table 4-22 Air resource indicators, data availability, reference conditions, and condition assessment categories.

Air resource indicator	Number of sites	Number of samples	Period of observation	Reference condition	% attainment applied
Wet sulfur deposition (kg/ha/yr)	1^	N/A*	2006-2010	< 1 1-3 >3	100% 0-100% (scaled) 0%
Wet nitrogen deposition (kg/ha/yr)	1^	N/A*	2006-2010	< 1 1-3	100% 0-100% (scaled)

Air resource indicator	Number of sites	Number of samples	Period of observation	Reference condition	% attainment applied
				>3	0%
Ozone (ppb)	1^	N/A*	2006-2010	≤ 60 60.1-75.0 >75	100% 0-100% (scaled) 0%
Ozone (W126; ppm-hrs)	1^	N/A*	2006-2010	< 7 7-13 >13	100% 0-100% (scaled) 0%
Visibility (dv)	1^	N/A*	2006-2010	<2 2-8 >8	100% 0-100% (scaled) 0%
Particulate matter ($PM_{2.5}$; µg/m3)	2	1974	2002-2012	≤12 12.1-15.0 >15	100% 0-100% (scaled) 0%
Mercury deposition (ng/L)	2	701	2005-2011	N/A	N/A

^Interpolated value for park; * one interpolated value represents a five-year average of weekly measurements at multiple sites.

Condition and trend

Air quality in the region of WOTR scored 0% attainment (or condition of significant concern) for all air quality indicators, except particulate matter (48% attainment). This resulted in an overall air quality condition attainment of 8.0%, or very degraded condition (Table 4-23) (Figure 4-27).

Table 4-23 Summary of air quality condition assessment at WOTR.

Air quality indicator	WOTR Result	% attainment of reference condition	Condition assessment	Overall air quality condition
Wet sulfur deposition (kg/ha/yr)	4.9	0	Significant concern	8.0% Very degraded
Wet nitrogen deposition (kg/ha/yr)	4.4	0	Significant concern	
Ozone (ppb)	78.4	0	Significant concern	
Ozone (W126; ppm-hrs)	14.6	0	Significant concern	
Visibility (dv)	15.7	0	Significant concern	
Particulate matter ($PM_{2.5}$; µg/m3)	13.6	48	Moderate	
Mercury deposition (ng/L)	7.6	N/A	N/A	

To assess trends, data from the NPS ARD report were used where possible (NPS ARD 2011). Otherwise, monitoring sites closest to WOTR from the National Atmospheric Deposition Program (NADP) and Interagency Monitoring of Protected Visual Environments (IMPROVE) program were used (Figure 4-26). Inspection of available air quality data over time, presented in Figure 4-28 and Figure 4-29, does show improving trends on the eastern USA for wet sulfur deposition, particulate matter, mercury deposition, ozone, and the haze index. Wet nitrogen deposition does not follow this trend and is stable or increasing based on the data obtained from sites used for this assessment (Figure 4-28 B).

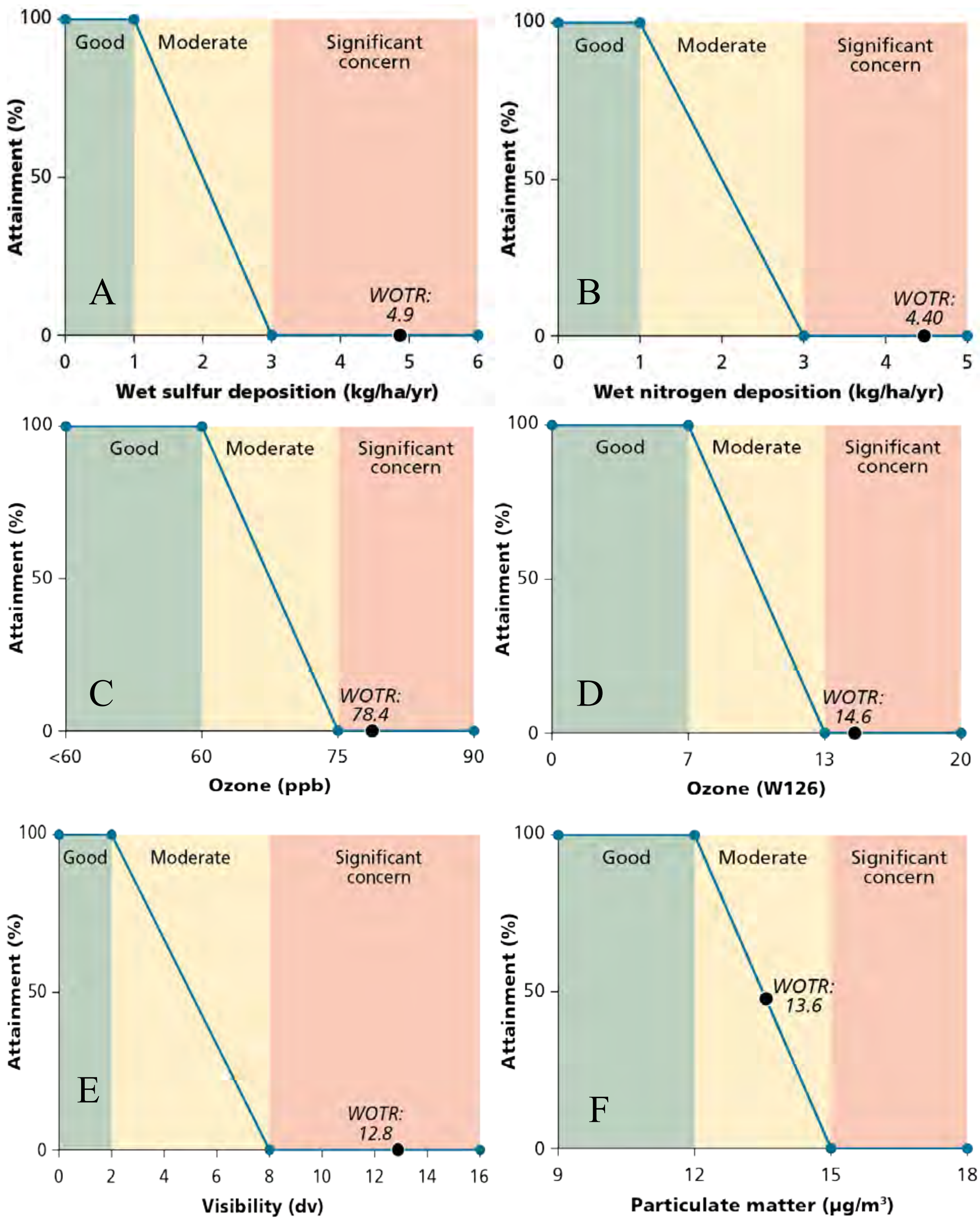


Figure 4-27 Application of the percent attainment categories to results for: A) wet sulfur deposition (kg/ha/yr); B) wet nitrogen deposition (kg/ha/yr); C) Ozone (ppb); D) Ozone (W126); E) Visibility (dv); F) Particulate matter ($\mu g/m^3$).

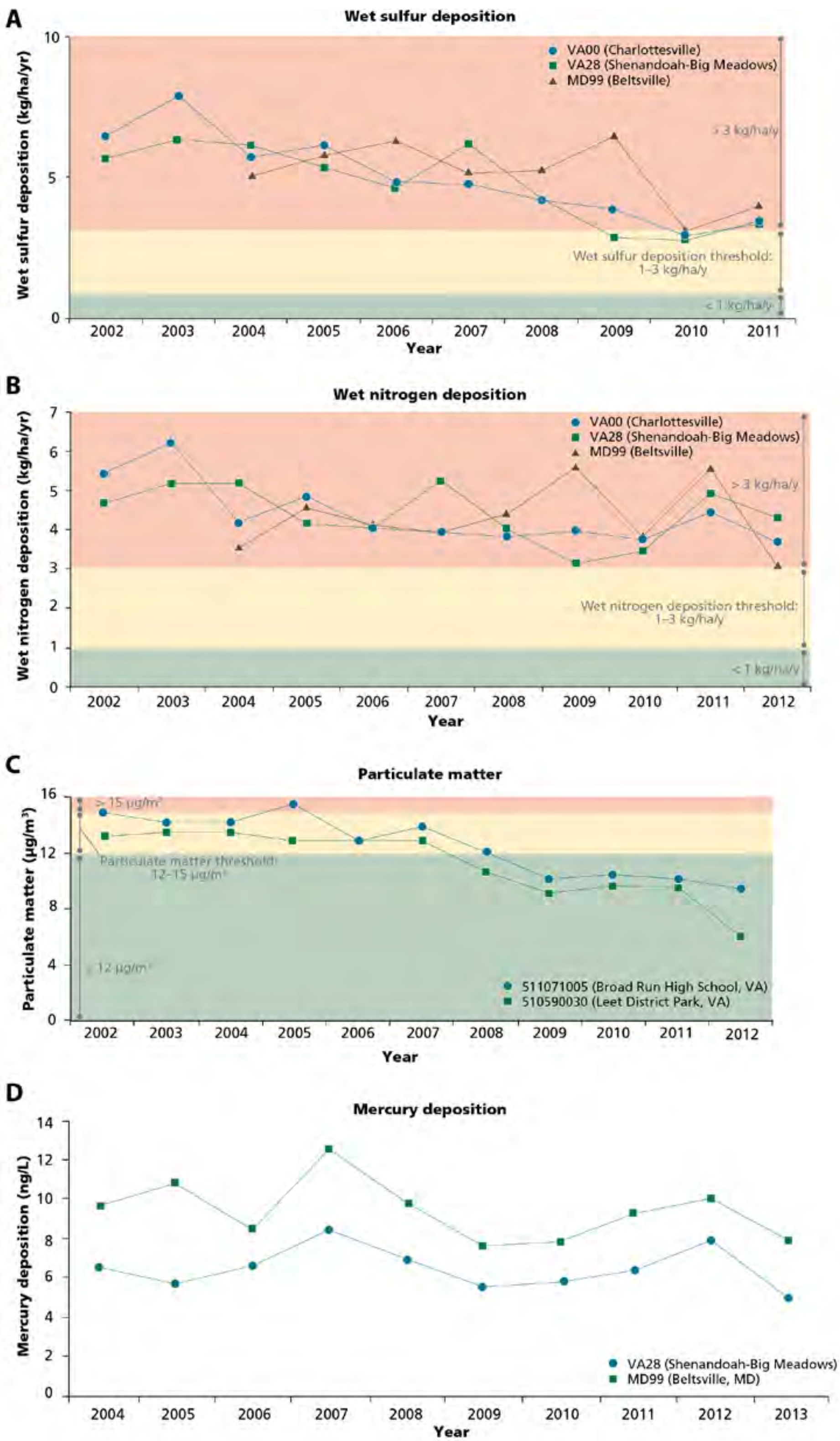


Figure 4-28 Trends observed over time in: A) wet sulfur deposition (kg/ha/yr); B) wet nitrogen deposition (kg/ha/yr); C) Particulate matter ($\mu g/m^3$); D) Mercury deposition (ng/L). No reference condition/reference condition is available for mercury deposition.

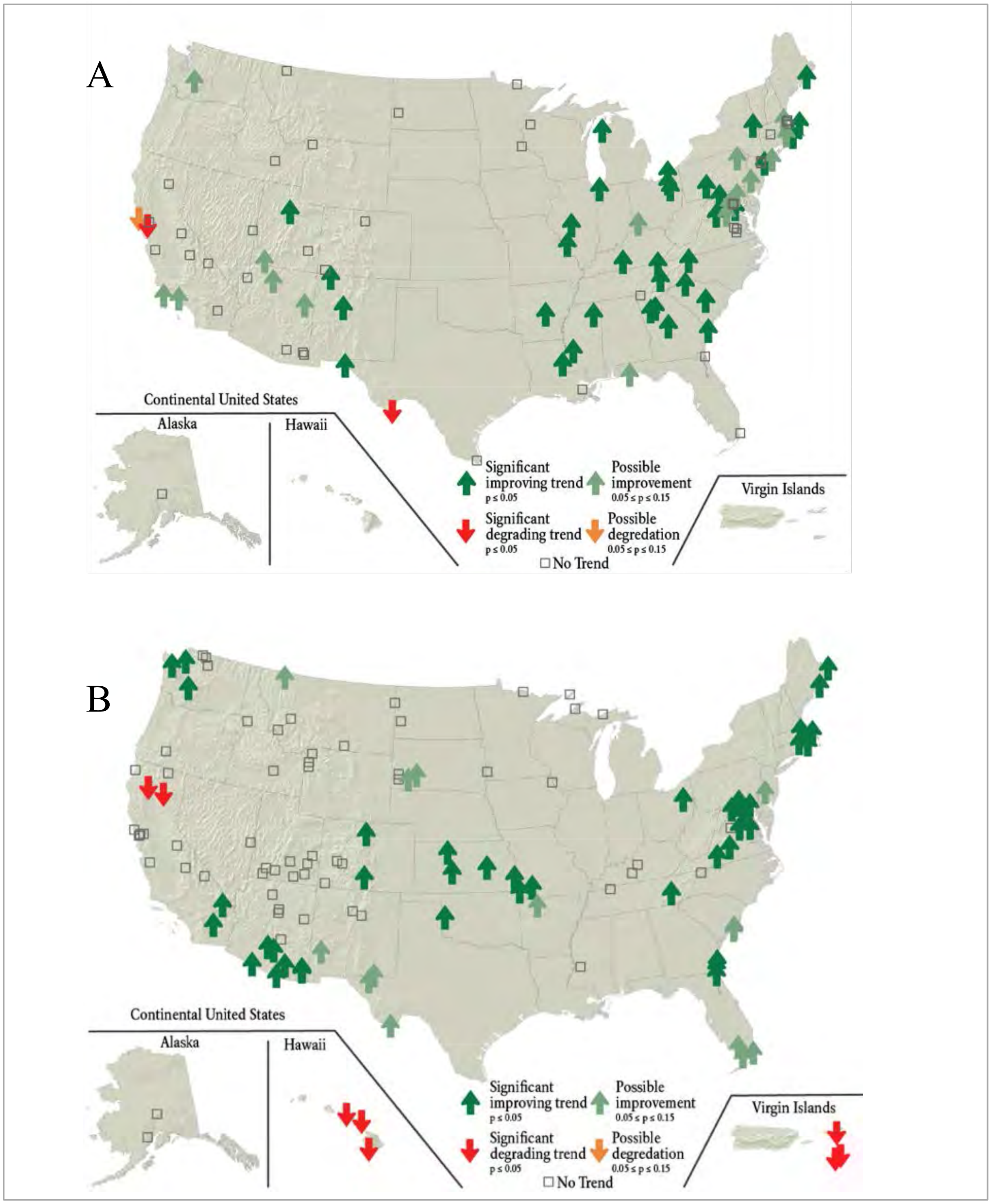


Figure 4-29 Trends in: A) Annual fourth-highest eight-hour ozone concentration (ppb/yr), 2000-2009 (NPS ARD); B) haze index (deciviews) on haziest days, 2000-2009 (NPS ARD).

Sources of expertise

- Air Resources Division, National Park Service http://www.nature.nps.gov/air/
- Drew Bingham, Geographer, NPS Air Resources Division.
- Ellen Porter, NPS Air Resources Division.
- Holly Salazer, NPS Air Resources Division Coordinator for the Northeast Region
- Interagency Monitoring of Protected Visual Environments (IMPROVE). http://vista.cira.colostate.edu/improve/
- National Atmospheric Deposition Program http://nadp.sws.uiuc.edu/
- National Atmospheric Deposition Program, Mercury Deposition Network. http://nadp.sws.uiuc.edu/MDN
- U.S. EPA PM Standards. http://www.epa.gov/airquality/particlepollution/

Summary and Discussion

Overall, natural resources in Wolf Trap National Park for the Performing Arts were classified as in ***degraded condition***, with 29% achievement of reference conditions (Table 5-1). The good and moderate condition of water resources and biological integrity, respectively, were largely offset by very degraded conditions for landscape dynamics and air resources. The very degraded condition for landscape dynamics was not unexpected for a small urban park with extensive landscape manipulation. Similarly, the status of air resources at WOTR are driven by external forces and cannot be expected to improve solely through management actions within the park. Despite these findings, it is widely recognized that WOTR adds critical green space in an increasingly urbanized northern Virginia, providing refuge for many species, serving as a migration rest stop for wildlife, and serving as a living biology classroom to the adjacent community.

Table 5-1 Natural resource condition assessment of WOTR.

Vital sign	Reference attainment	Condition
Water resources	60%	Good
Biological integrity	44%	Moderate
Landscape dynamics	2%	Very degraded
Air resources	10%	Very degraded
WOTR Overall	**29%**	**Degraded**

Water resources

Water resources within WOTR were in a ***good condition***, with 60% attainment of reference conditions. This is despite the majority of water inflows to the park originating from outside the park in developed/urban areas. This data comes from two stream water quality sites in the park.

Table 5-2 Summary of water resources in WOTR.

Metric	Condition
pH	Very good
Dissolved oxygen	Very good
Water temperature	Very good
Acid neutralizing capacity	Very good
Specific conductance	Very degraded
Total nitrate	Good
Total phosphorus	Very degraded
Benthic Index of Biological Integrity	Very degraded
Physical Habitat Index	Moderate
Water resources	**Good**

Table 5-3 Key findings, management implications, and recommended next steps for water resources in WOTR.

Key findings	Management implications	Recommended next steps
Very degraded condition for total phosphorus (Elevated phosphorus levels have been found in parks throughout the region and are thought to be largely due to underlying geology (Carruthers *et al.* 2009, Norris and Pieper 2010, Thomas *et al.* 2011a, b, c).)	• Affects stream flora and fauna • Reduces quality of visitor experience	• Minimize soil disturbance. • Implement best management practices such as riparian buffers and no-mow areas.
Very degraded condition for specific conductance	• Affects stream flora and fauna • Reduces quality of visitor experience	• Identify source (e.g. salting of roads outside and within WOTR) and conductance-sensitive organisms and locations for management initiatives. • Implement best management practices such as riparian buffers and no-mow areas.
Very degraded Benthic Index of Biological Integrity and moderate (degraded) Physical Habitat Index	• Affects stream flora and fauna • Reduces quality of visitor experience	• Implement stream restoration and manage volume and velocity of water entering the park (e.g. swales, riparian buffers and no-mow areas). • Prepare education materials for immediate neighbors. • Implement monitoring to identify sources and patterns of pollution affecting stream biota and develop management actions.

Table 5-4 Data gaps, justification, and research needs for water resources at WOTR.

Data gaps	Justification	Research needs
Amphibian data	• Unknown changes in toad population within the pond	• Amphibian survey.
Fish data for pond	• Unknown fish population	• Fish survey for pond.
Pond water quality	• Wildlife/habitat value	• Initiate water quality monitoring in pond.

Biological integrity

Biological integrity was in ***moderate condition***, with 44% attainment of reference conditions. Conditions for the seven biological integrity indicators ranged from very good (i.e. limited exotic trees and forest pest species) to very degraded (i.e. widespread coverage of exotic herbaceous species, poor stocking index, and high deer density).

Table 5-5 Summary of biological integrity in WOTR.

Metric	Condition
Cover of exotic herbaceous species	Very degraded
Area of exotic tree & saplings	Very good
Presence of forest pest species	Very good
Stocking index	Very degraded
Fish Index of Biological Integrity	Good
Bird Community Index	Degraded
Deer density	Very degraded
Biological Integrity	**Moderate**

Table 5-6 Key findings, management implications, and recommended next steps for biological integrity in WOTR.

Key findings	Management implications	Recommended next steps
Very degraded cover of exotic herbaceous species	• Displacement of native plant species, reduced food and habitat for native fauna	• Prioritize species and locations for implementing control measures. • Restore and maintain native species and communities. • Identify and map areas of exotic invasion that are not reflected in I&M forest monitoring (e.g. floodplain areas). Initiate monitoring of these areas.
Very degraded Stocking index	• Lack of forest regeneration and subsequent habitat	• Manage deer over-browse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park). • Implement planting initiatives.
Deer overpopulation may be impacting forest regeneration	• Increased herbivory reducing desired plant and bird species • More road collisions	• Expand deer monitoring program. • Develop a deer management plan.
Anecdotal: Increased observance of copperheads and northern water snakes likely due to increased accessibility via walking track construction	• Safety and public perception	• Increase education. • Rodent control near facilities.
Anecdotal: Increased raccoon presence	• Safety (excrement) and public disruption (presence during shows)	• Trash management. • Physical barriers.
Anecdotal: Reports of black bear presence in the park	• Safety and public perception	• Prepare unified staff response for public reporting. • Prepare education materials. • Trash management.

Table 5-7 Data gaps, justification, and research needs for biological integrity at WOTR.

Data gaps	Justification	Research needs
Comprehensive park species list	• Objective for the park is to have a diverse animal population and provide more diverse habitat and improved visitor experience	• Update invertebrate survey. • Update mammal survey. • All taxa inventory including butterflies, birds (ongoing) and bees (ongoing).
Current bat information	• Objective for the park is to have a diverse animal population and provide more diverse habitat and improved visitor experience • Last bat survey >10 years ago • Northern long-eared bat recently listed as threatened	• Update bat survey.

Landscape dynamics

Landscape dynamics was in ***very degraded condition***, with 2% attainment of reference conditions due to the cultural design of the park, regional development, and urban encroachment (Table 5-8). This condition will likely continue with new developments in the area (e.g. Tysons Corner) putting additional stress on the natural habitats of WOTR, while also adding pressure on the park to provide recreational opportunities and open space for growing populations.

Table 5-8 Summary of landscape dynamics in WOTR.

Metric	Condition
Forest interior area (within park)	Very degraded
Forest interior area (within park + 5x buffer)	Very degraded
Forest cover (within park)	Very degraded
Forest cover (within park + 5x buffer)	Very degraded
Impervious surface (within park)	Very degraded
Impervious surface (within park + 5x buffer)	Very degraded
Road density (within park)	Very degraded
Road density (within park + 5x buffer)	Very degraded
Landscape Dynamics	**Very degraded**

Table 5-9 Key findings, management implications, and recommended next steps for landscape dynamics in WOTR.

Key findings	Management implications	Recommended next steps
Very degraded forest interior area and forest cover – within and outside the park boundary	• Reduction in breeding habitat and reproductive success for forest interior bird species • Increased predation on forest birds	• Improve quality of existing forest habitat by managing for exotic species. • Reassess legitimacy of using forest interior as a reference condition given areal constraints.
Large areas of impervious surface – within and outside the park boundary	• Increased rainfall runoff volume and velocity (with pollutants)	• Change asphalt parking lots to porous yet durable surfaces (e.g. pervious pavers, grass). • Protect existing unpaved roads to grass parking areas to

Key findings	Management implications	Recommended next steps
		prevent erosion and perceived need for paving.
High road density	• Affects area of forest interior and disrupts habitat	• Difficult to manage. Potential traffic calming/reduction measures.

Table 5-10 Data gaps, justification, and research needs for landscape dynamics in WOTR.

Data gaps	Justification	Research needs
Impacts of climate change on park habitat	• Pressures of climate change will become more serious and widespread with time	• Risk assessment of likely impacts of climate change to park resources.

Air resources

Air quality conditions at WOTR were in a ***very degraded*** condition with 10% attainment of reference conditions (Table 5-11). Degraded air quality is a problem throughout the eastern United States, the causes of which (e.g. power generation) are largely out of the park's control. Specific implications to the habitats and species in the park are less well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts.

Despite a lack of sound and light pollution information, WOTR NPS staff recognize their proximity to development, associated traffic, and the ongoing expansion of the area's Metro transit system into the immediate Tysons Corner area. The opening of the Metro Silver Line in 2014 will increase access and transportation options to the park, while presenting additional challenges to the park's soundscape and infrastructure.

Table 5-11 Summary of air resources in WOTR.

Air resource indicator	Condition
Wet sulfur deposition	Very degraded
Wet nitrogen deposition	Very degraded
Ozone (ppb)	Very degraded
Ozone (W126)	Very degraded
Visibility	Very degraded
Particulate matter	Moderate
Overall Air Quality	**Very degraded**

Table 5-12 Key findings, management implications, and recommended next steps for air quality in WOTR.

Key findings	Management implications	Recommended next steps
Air quality is very degraded	Habitats and species in the park may be affected	• Monitor for local effects (e.g. ozone damage to vegetation).
Air quality is a regional problem	Habitats and species in the park may be affected	• Continue participation in Climate Friendly Parks program www.nps.gov/climatefriendlypark • Stay engaged with the wider community in terms of air quality education and activities.

Table 5-13 Data gaps, justification, and research needs for air quality in WOTR.

Data gaps	Justification	Research needs
Park-specific air quality data	• Air quality is measured and interpolated on regional and national scales • Need to implement park-specific management actions	• Use transport and deposition models. • Implementation of park-scale air quality monitoring would give better insights into park-level air quality condition and possible effects on park habitats and species. • Planting and monitoring a garden of ozone-sensitive plants.
Effects of poor air quality on park habitats and species	• Need to implement park-specific management actions	• Investigate effects of poor air quality on sensitive habitats and species within the park.
Ecological references for mercury wet deposition	• Mercury deposition is reported for WOTR but no reference exists for protection of species	• Adopt standards once NPS Air Resources Division establishes mercury wet deposition reference.
Lightscape information	• Night sky visibility is affected by primary park activities and neighboring influences	• Light study.
Soundscape information	• Potential increase in traffic noise over time, from either an increase in vehicles or the opening of the Washington Metropolitan Area Transit Authority's new Silver Line	• Noise/soundscape study.

Literature cited

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, New York, NY.

Allen, O., and S.R. Flack. 2001. Potomac Gorge Site Conservation Plan. National Park Service and the Nature Conservancy. Washington, D.C. and Arlington, Virginia. 146 pp. plus appendices.

Arnold Jr, C.L. and C.J. Gibbons. 1996. Impervious surface coverage. Journal of the American Planning Association 62(2): 243–269.

Audubon Society of Northern Virginia. 2013. Wolf Trap Farm Park Bird Inventory. Accessed September 30, 2013. Available at http://www.audubonva.org/index.php/why-we-count-birds-v15-208/wolf-trap-park-bird-inventory

Augustine, D.J. and D. deCalesta. 2003. Defining deer overabundance and threats to forest communities: from individual plants to landscape structure. Ecoscience 10: 472-486.

Bates, S.E. 2006. National Capital Region Network Inventory and Monitoring Program white-tailed deer density monitoring protocol version 1.1: Distance and pellet-group surveys.

Bates, S. E. 2009. National Capital Region Network 2008 deer monitoring report. Natural Resource Technical Report NPS/NCRN/NRTR—2009/274. National Park Service, Fort Collins, Colorado.

Bennetts, R.E., J.E. Gross, K. Cahill, C. McIntyre, B.B. Bingham, A. Hubbard, L. Cameron, and S.L. Carter. 2007. Linking monitoring to management and planning: assessment points as a generalized approach. The George Wright Forum 24: 59-79.

Biggs, H.C. 2004. Promoting ecological research in national parks—A South African perspective. Ecological Applications 14:1, 21-24.

Budde, P.J., B.J. Frakes, L. Nelson, and U. Glick. 2009. Technical guide for NPScape data and processing. Inventory and Monitoring Division, National Park Service, Fort Collins, CO.

Carruthers, T., S. Carter, L.N. Florkowski, J. Runde, and W.C. Dennison. 2009. Rock Creek Park natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2009/109. National Park Service, Natural Resource Program Center. Fort Collins, CO.

Chesapeake Bay Program. 2012. The Chesapeake Bay Watershed. Accessed 15 May 2013. http://www.chesapeakebay.net/discover/baywatershed

Conway, T.M. 2007. Impervious surface as an indicator of pH and specific conductance in the urbanizing coastal zone of New Jersey, USA. Journal of Environmental Management 85: 308–316.

Côté, S.D., T.P.Rooney, J.P. Tremblay, C. Dussault, and D.M. Waller. 2004. Ecological impacts of deer overabundance. Annual Review of Ecology, Evolution, and Systematics 35: 113-147.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31. Washington, DC.

Davey, C.A., K.T. Redmond, and D.B. Simeral. 2006. Weather and Climate Inventory, National Park Service, National Capital Region Network. Natural Resource Technical Report. NPS/NCRN/NRTR—2011/414. National Park Service, Fort Collins, Colorado.

Dawson, D.K., and M.G. Efford. 2014. Protocol for monitoring forest-nesting birds in National Park Service parks: Version 1.0 (December 2013). Natural Resource Report. NPS/NCRN/NRR—2014/749. National Park Service. Fort Collins, Colorado. Published Report 2206488.

Deblinger, R.D., M.L. Wilson, D.W. Rimmer, and A. Spielman. 1993. Reduced abundance of immature *Ixodes dammini* (Acari: *Ixodidae*) following incremental removal of deer. Journal of Medical Entomology 30(1): 144-150.

deCalesta, D.S. 1997. Deer ecosystem management. In: McShea, W.J. H.B. Underwood, and J.H. Rappole (eds). The science of overabundance: Deer ecology and population management. Springer, Netherlands.

Dennison, W.C., T.R. Lookingbill, T.J.B. Carruthers, J.M. Hawkey, and S.M. Carter. 2007. An eye-opening approach to developing and communicating integrated environmental assessments. Frontiers in Environmental Ecology 5(6): 307-314.

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. Bioscience 51: 180-198.

ESRI 2010. ESRI Data and Maps—U.S. and Canada Detailed Streets, TeleAtlas 2005.

Fairfax County. 2013a. 'Difficult Run Watershed Management Plan' Feb. 26, 2007. Accessed 4 December 2013. http://www.fairfaxcounty.gov/dpwes/watersheds/difficultrun.htm

Fairfax County. 2013b.'Demographics & Data: Fairfax County Virginia.' Accessed 4 December 2013. http://www.fairfaxcounty.gov/government/about/data/

Fairfax County. 2013c. 'Fairfax County Comprehensive Plan, 2013 Edition'. Accessed 23 January 2015. http://www.fairfaxcounty.gov/dpz/comprehensiveplan/area2/tysons1.pdf

Fancy, S.G., J.E. Gross, and S.L. Carter. 2008. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment: Electronically published May 29, 2008.

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in U.S. National Parks. Environmental Monitoring and Assessment 151: 161–174.

Forman, R.T.T., D.S. Friedman, D. Fitzhenry, J.D. Martin, A.S. Chen, and L.E. Alexander. 1995. Ecological effects of roads: Toward three summary indices and an overview for North America. In: Canters, K (ed). Habitat fragmentation and infrastructure. Ministry of Transport, Public Works and Water Management: Maastricht and The Hauge, Netherlands.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77: 858-864.

Gardner, R.H., B.T. Milne, M.G. Turner, and R.V. O'Neill. 1987. Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology 1: 19-28.

Gates, J.E., and J.B. Johnson. 2005. Bat inventory of the National Capital Region National Parks. Unpublished report prepared for the National Park Service, Washington, D.C.

Gibbs, J.P. and W.G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16: 1647-1652.

Goodwin, S. 2009. Patch, Landscape, and Soundscape Effects on the Forest Bird Communities in the National Parks of the National Capitol Region. University of Delaware. Thesis-2165170.

Griggs, J.A., J.H. Rock, C.R. Webster, and M.A. Jenkins. 2006. Vegetation legacy of a protected deer herd in Cades Cove, Great Smoky Mountains National Park. Natural Areas Journal 26: 126-136.

Groffman, P.M., J.S. Baron, T. Blett, A.J. Gold, I. Goodman, L.H. Gunderson, B.M. Levinson, M.A. Palmer, H.W. Paerl, G.D. Peterson, N. LeRoy Poff, D.W. Rejeski, J.F. Reynolds, M.G. Turner, K.C. Weathers, and J. Wiens. 2006. Ecological Reference conditions: The key to successful environmental management or an important concept with no practical application? Ecosystems 9: 1-13.

Gross, J.E., L.K. Svancara, and T. Philippi. 2009. A Guide to Interpreting NPScape Data and Analyses. NPS/IMD/NRTR—2009/IMD/XXX. National Park Service, Fort Collins, Colorado.

Haagen-Smit, A.J. and M.M. Fox. 1956. Ozone formation in photochemical oxidation of organic substances. Industrial and Engineering Chemistry 48: 1484-1487.

Hargis, C.D., J.A. Bissonette, and J.L. David. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. Landscape Ecology 13: 167-186.

Harrison, T.D. and Whitfield, A.K. 2006. Application of a multimetric fish index to assess the environmental condition of South African estuaries. Estuaries and Coasts 29, 1108-1120.

Healy, W.M. 1997. Influence of deer on the structure and composition of oak forests in central Massachusetts. In: McShea, W.J., H.B. Underwood, and J.H. Rappole (eds). The science of overabundance: Deer ecology and population management. Springer, Netherlands.

Hendricks, J. and J. Little. 2003. Reference conditions for regional vulnerability analysis. Regional vulnerability assessment program. National exposure research laboratory. U.S. EPA (E243-05). http://www.nrac.wvu.edu/classes/resm493Q/files/final_stressor_reference condition_table.pdf

Horsley, S.B., S.L. Stout, and D.S. deCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13: 98-118.

ICPRB. 2012. "General Facts & FAQs". Interstate Commission on the Potomac River Basin (ICPRB). Accessed May 15, 2013. Available at http://www.potomacriver.org/facts-a-faqs/faqs.

Jenkins, R.E. and N.M. Burkhead. 1994. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland.

Jensen, M.E., K. Reynolds, J. Andreasen, and I.A. Goodman. 2000. A knowledge-based approach to the assessment of watershed condition. Environmental Monitoring and Assessment 64:1, 271-283.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sensing of Environment, 132: 159 – 175.

Jones, C., J. McCann, and S. McConville. 2000. A guide to the conservation of forest interior dwelling birds in the Chesapeake Bay Critical Area. Report to the Critical Area Commission for the Chesapeake and Atlantic Coastal Bays. Accessed April 9, 2013. http://www.dnr.state.md.us/urc/docs/00009691.pdf

Jordan, J.S. 1967. Deer browsing in northern hardwoods after clearcutting: effect on height, density, and stocking of regeneration of commercial species. U.S. Forest Service Research Paper NE-57. 15pp.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6, 21-27.

Knox, W.M. 1997. Historical changes in the abundance and distribution of deer in Virginia. In: McShea, W.J., H.B. Underwood, and J.H. Rappole (eds). The science of overabundance: Deer ecology and population management. Springer, Netherlands.

Kohut, R. 2007. Assessing the risk of foliar injury from ozone on vegetation in parks in the U.S. National Park Service's Vital Signs Network. Environ Pollut.: 149(3) 348-357.

Ladin, Z.S. and W.G. Shriver. 2013. Avian monitoring in the National Capital Region Network: Summary report 2007–2011. Natural Resource Technical Report. NPS/NCRN/NRTR—2013/698. National Park Service. Fort Collins, CO. Published Report-2193341.

Lawrey, J.D. 2011. A lichen biomonitoring program to protect resources in the National Capital Region by detecting air quality effects. Natural Resource Technical Report NPS/NCRN/NRTR—2011/450. National Park Service, Fort Collins, Colorado.

Lussier, S.M., S.N. da Silva, M. Charpentier, J.F. Heltshe, S.M. Cormier, D.J. Klemm, M. Chintala, and S. Jayaraman. 2008. The influence of suburban land use on habitat and biotic integrity of coastal Rhode Island streams. Environmental Monitoring and Assessment 139: 119–136.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689-710.

Marquis, D.A. 1981. Effect of deer browsing on timber production in Allegheny hardwood forests of northwestern Pennsylvania. U.S. Forest Service Research Paper NE-475. 10pp.

Marquis, D.A. and J.C. Bjorkborn. 1982. Guidelines for evaluating regeneration before and after clearcutting Allegheny hardwoods. USDA Forest Service Research. Note NE-307.

Matthews, E., and J. Schmit. 2014. NCRN Forest Vegetation Monitoring Data 2006-2013. National Capital Region Network I&M Program. Washington, D.C. Generic Dataset 2217829.

McDonald, J.E. Jr., D.E. Clark, and W.A. Woytek. 2007. Reduction and maintenance of a white-tailed deer herd in central Massachusetts. Journal of Wildlife Management 71: 1585-1593.

McShea, W.J., and C. O'Brien. 2003. Small Mammal Survey of National Capital Region Parks-Final Report. National Zoological Park's Conservation and Research Center Front Royal, VA.

McShea, W.J. and J.H. Rappole. 2000. Managing the abundance and diversity of breeding bird populations through manipulation of deer populations. Conservation Biology 14: 1161-1170.

Meili, M., K. Bishop, L. Bringmark, K. Johanson, J. Muthe, H. Sverdrup, and W. de Vries. 2003. Critical levels of atmospheric pollution: Criteria and concepts for operational modeling of mercury in forest and lake ecosystems. The Science of the Total Environment 304: 83-106.

Miller, N.P. 2008. US National Parks and management of park soundscapes: A review. Applied Acoustics 69: 77-92.

Morgan, B. 2013. Biological Monitoring for Water Resources of National Capital Region Network Parks: 2012 Spring and Summer Stream Sampling Field Report. Published Report-2205524.

Morgan II, R.P., K.M. Kline, and S.F. Cushman. 2007. Relationships among nutrients, chloride and biological indices in urban Maryland streams. Urban Ecosystems 10: 153–166.

NADP/MDN (National Atmospheric Deposition Program/Mercury Deposition Network). 2012. http://nadp.isws.illinois.edu

NADP/NTN. 2013. National Atmospheric Deposition Program. http://nadp.sws.uiuc.edu/data/ntndata.aspx

National Park Service. 2011. NPScape NPS boundary-derived areas of analysis SOP: Park, 3km, and 30km areas of analysis. National Park Service, Natural Resource Program Center. Fort Collins, Colorado.

National Research Council. 1993. Protecting visibility in national parks and wilderness areas. Committee on Haze in National Parks and Wilderness Areas, National Academies Press. http://www.nap.edu/catalog/2097.html

National Weather Service. 2013a. "Dulles Average Monthly Temperature (since 1963)". Accessed 14 January 2014. Available at http://www.erh.noaa.gov/lwx/climate/iad/iadtemps.txt

National Weather Service. 2013b. "Dulles Monthly Precipitation (since 1963)". Accessed 14 January 2014. Available at http://www.erh.noaa.gov/lwx/climate/iad/iadprecip.txt

National Weather Service. 2013c. "Dulles Monthly Snowfall (since 1963)". Accessed 14 January 2014. Available at http://www.erh.noaa.gov/lwx/climate/iad/iadsnow.txt

Norris M.E. and G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Norris, M.E. and J.M. Pieper. 2010. National Capital Region Network 2009 water resources monitoring report. Natural Resources Data Series. Natural Resources Program Center, Fort Collins, Co.

Norris, M.E., J.M. Pieper, and T.M. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Nortrup M. 2011. National Capital Region Network Resource Brief: Birds, Wolf Trap National Park for the Performing Arts. National Capital Region Network, Inventory & Monitoring. Resource Brief-2188717. https://irma.nps.gov/App/Reference/Profile/2188717

Nowacki, G.J. and M.D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. Bioscience 58: 123-138.

NPS 2002. Draft recommendations for core water quality monitoring parameters and other key elements of the NPS Vital Signs Program water quality monitoring component, Freshwater Workgroup Subcommittee, June 14, 2002. National Park Service, Water Resources Division, Fort Collins, CO.

NPS 2010a. NPScape landcover measure—Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/252. Published Report 2165449. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS 2010b. NPScape landcover measure – Phase 2 North American Landcover metrics processing SOP: Landcover area per category and natural vs. converted landcover metrics. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS 2010c. NPScape roads measure—Phase 2 road metrics processing SOP: Road density and distance from roads. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS ARD (National Park Service, Air Resources Division). 2010. Air quality in national parks: 2009 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266. National Park Service, Denver, Colorado.

NPS ARD (National Park Service, Air Resources Division). 2011. Rating air quality conditions. National Park Service, Denver, CO. http://www.nature.nps.gov/air/planning/docs/20111122_Rating-AQ-Conditions.pdf

NPS ARD (National Park Service, Air Resources Division). 2012a. 2006-2010 5-year average ozone estimates. National Park Service. Denver, CO. http://www.nature.nps.gov/air/maps/airatlas/docs/Air_Atlas_Values_Tables/Ozone/NPS_AQC_Ozone_0610_web.pdf

NPS ARD (National Park Service, Air Resources Division). 2012b. 2006-2010 5-year average wet deposition estimates. National Park Service. Denver, CO. http://www.nature.nps.gov/air/maps/airatlas/docs/Air_Atlas_Values_Tables/Wet_Deposition/NPS_AQC_WetDep_0610_PRISM_web.pdf

NPS ARD (National Park Service, Air Resources Division). 2012c. 2006-2010 5-year average visibility estimates. National Park Service. Denver, CO. http://www.nature.nps.gov/air/maps/airatlas/docs/Air_Atlas_Values_Tables/Visibility/NPS_AQC_Vis_0610_web.pdf

NPS ARD (National Park Service, Air Resources Division). 2013. Air quality in national parks: trends (2000-2009) and conditions (2005-2009). Natural Resources Report NPS/NRSS/ARD/NRR—2013/683. National Park Service, Denver, Colorado.

NPS-28: Cultural Resource Management Guideline. Effective Date: June 11, 1998.

NPS 2002. Draft recommendations for core water quality monitoring parameters and other key elements of the NPS Vital Signs Program water quality monitoring component, Freshwater Workgroup Subcommittee, June 14, 2002. National Park Service, Water Resources Division, Fort Collins, CO.

NPS. 2005. Wolf Trap National Park for the Performing Arts, Environmental Assessment for Encore Circle Addition. Accessed 19 September 2013. http://parkplanning.nps.gov/document.cfm?parkID=201&projectID=17889&documentID=18213

NPS. 2007. Wolf Trap National Park for the Performing Arts, Environmental Assessment for Encore Circle Addition. Accessed January 21, 2014. http://parkplanning.nps.gov/projectHome.cfm?projectID=17889

NPS. 2010a. Invasive Exotic Plants- Resource Brief. Accessed 15 May 2013. http://science.nature.nps.gov/im/units/ncrn/index.cfm

NPS 2010b. NPScape landcover measure—Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/252. Published Report 2165449. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS 2010c. NPScape landcover measure – Phase 2 North American Landcover metrics processing SOP: Landcover area per category and natural vs. converted landcover metrics. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS 2010d. NPScape roads measure—Phase 2 road metrics processing SOP: Road density and distance from roads. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS. 2011. NPScape NPS boundary-derived areas of analysis SOP: Park, 3km, and 30km areas of analysis. National Park Service, Natural Resource Program Center. Fort Collins, Colorado.

NPS. 2012a. Compendium of Regulatory Provisions: Wolf Trap National Park for the Performing Arts. http://www.nps.gov/wotr/parkmgmt/upload/signed-2012-compendium.pdf

NPS. 2012b. Night Skies: Managing Landscapes. Accessed 4 December 2013. http://www.nature.nps.gov/night/management.cfm

NPS. 2012c. Sounds we protect. Accessed 9 December 2013. http://nature.nps.gov/sound/protect.cfm

NPS. 2013a. About the Inventory and Monitoring Program. Available at http://science.nature.nps.gov/im/about.cfm

NPS. 2013b. Foundation Document: Wolf Trap National Park for the Performing Arts.

NPS. 2013c. Night sky. Accessed 9 December 2013. http://nature.nps.gov/night/index.cfm

NPS. 2014a. NPScape Standard Operating Procedure: Housing Measure – Current and Projected Housing Density. Version [YYYY-MM-DD]. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado.

NPS. 2014a. NPScape Standard Operating Procedure: Land Cover Measure – Area per Category, Impervious Surface, Change Index, and Natural vs. Converted. Version [2014-01-24] National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado.

NPS. 2014b. NPS Stats—National Park Service Public Use Statistics Office. http://nature.nps.gov/stats

NPS. 2014b. NPScape Standard Operating Procedure: Roads Measure – Road Density, Distance from Roads, and Area without Roads. Version [2014-01-24] National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 1998. A Bird Community Index of Biotic Integrity for the Mid-Atlantic Highlands. Environmental Monitoring and Assessment 51: 145–156.

Pantus, F.J., and W.C. Dennison. 2005. Quantifying and evaluating ecosystem health: A case study from Moreton Bay, Australia. Environmental Management 36:5, 757-771.

Parrish, J. and M. Nortrup. 2012. National Capital Region Network Resource Brief: Native Grapes. National Capital Region Network, Inventory & Monitoring. Resource Brief-2188695.

Paul, M.J., J.B. Stribling, R. Klauda, P. Kazyak, M. Southerland, and N. Roth. 2003. A Physical Habitat Index for freshwater wadeable streams in Maryland. Report to the Maryland Department of Natural Resources, Annapolis, MD.

Pauley, T.K., M.B. Watson, and J.C. Mitchell. 2005. Final Report: Reptile and amphibian inventories in eight parks in the national capital region. Inventory and Monitoring Program, National Capital Region Network, Center for Urban Ecology, Washington D.C.

Pieper JM, M.E., Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report: water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Data Series. NPS/NCRN/NRDS—2012/381. National Park Service. Fort Collins, Colorado. Published Report-2190400.

Pijanowski, B.C., L.J. Villanueva-Rivera., S.L. Dumyahn., A. Farina, B.L. Krause, B.M. Napoletano, S.H. Gage, and N. Pieretti. 2011. Soundscape Ecology: The Science of Sound in the Landscape. *BioScience*, 61: 203–216. ISSN 0006-3568, electronic ISSN 1525-3244.

Porter, E. and S. Johnson. 2007. Translating science into policy: using ecosystem reference conditions to protect resources in Rocky Mountain National Park. Environmental Pollution 149: 268-280.

Radtke, D.B., Davis, J.V., and Wilde, F.D, 1998, Specific electrical conductance. In: Wilde, F.D., and D.B. Radtke (eds.). 1998. Field measurements, in national field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.3, 22 p.

Raesly, R.L., R.H. Hilderbrand, and P.F. Kazyak. 2004. Final Report: Inventory and Biological Monitoring of Fishes in National Parks of the National Capital Region. TIC #: NCRO D-54. BibKey ID: 580767.

Rossell, C.R. Jr., B. Gorsira, and S. Patch. 2005. Effects of white-tailed deer on vegetation structure and woody seedling composition in three forest types on the Piedmont Plateau. Forest Ecology and Management 210: 415-424.

Roth, N., M. Southerland, J. Chaillou, R. Klauda, P. Kazyak, S. Stranko, S.Weisberg, L. Hall Jr, and R. Morgan. 1998. Maryland biological stream survey: Development of a fish index of biotic integrity. Environmental Monitoring and Assessment 51: 89-106.

Roth, N.E., M.T. Southerland, J.C. Chaillou, P.F. Kazyak, and S.A Stanko. 2000. Refinement and validation of a fish index of biotic integrity for Maryland streams. Chesapeake Bay and Watershed Programs: Monitoring and non-tidal assessment CBWP-MANTA-EA-00.

Russell, L.F., D.B. Zippin, and N.L. Fowler. 2001. Effects of white-tailed deer (*Odocoileus virginianus*) on plants, plant populations, and communities: a review. American Midland Naturalist 146: 1-26.

Sadinski, W.J. and W.A. Dunson. 1992. A multilevel study of effects of low pH on amphibians of temporary ponds. Journal of Herpetology 26(4): 413–422.

Schindler, D.W. 1988. Effects of acid rain on fresh water ecosystems. Science 239: 149–157.

Schmit, J.P and P. Campbell. 2007. National Capital Region Network 2006 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2007/046. National Park Service, Fort Collins, CO.

Schmit, J.P., G. Sanders, M. Lehman, and T. Paradis. 2009. National Capital Region Network long-term forest monitoring protocol. Version 2.0. Natural Resource Report NPS/NCRN/NRR—2009/113. National Park Service, Fort Collins, CO.

Schmit, J.P., J. Parrish, and P.J. Campbell. 2012a. National Capital Region Network: 2006-2009 forest vegetation status report. Natural Resource Technical Report NPS/NCRN/NRTR—2012/570. National Park Service, Fort Collins, Colorado.

Schmit, J.P., J. Parrish, and P.J. Campbell. 2012b. National Capital Region Network: 2006-2009 forest pest, pathogen and exotic plan status report. Natural Resource Technical Report NPS/NCRN/NRTR—2012/650. National Park Service, Fort Collins, Colorado.

Schmit, J.P., P. Campbell, and J. Parrish. 2010. National Capital Region Network 2009 forest vegetation monitoring report. Natural Resource Technical Report NPS/NCRN/NRDS—2010/043. National Park Service, Fort Collins, Colorado.

Sinclair, J.A., M. Koenen, S. Hood., M. Milton, and C. Wright. 2004. Avian Inventory at Six National Capital Region National Parks: Final Report. National Park Service, Inventory and Monitoring Program, National Capital Region, Washington, D.C.

Slaiby, B.E. and N.J. Mitchell. 2003. A Handbook for Managers of Cultural Landscapes with Natural Resource Values. Woodstock, Vermont: Conservation Study Institute.

Southerland, M.T., L.A. Erb, G.M. Rogers, and P.F. Kazyak. 2005. Maryland Biological Stream Survey 2000—2004. Volume 7: Statewide and tributary basin results. Prepared for Maryland Department of Natural Resources.

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7: 751–767.

Stednick, J.D., and D.M. Gilbert. 1998. Water quality inventory protocol: riverine environments. NPS/NRWRD/NRTR—98/177, National Park Service, Servicewide Inventory and Monitoring Program, Fort Collins, CO.

Steen, D.A. and J.P Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. y 18: 1143-1148.

Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: National Capital Region Network (NCRN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/317. National Park Service, Denver, CO.

Temple, S.A. 1986. Predicting impacts of habitat fragmentation on forest birds: a comparison of two models. In: Verner, J., M.L. Morrison, and C.J. Ralph (eds). Wildlife 2000: Modelling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, WI.

Thomas, J.E., T. Carruthers, W.C., Dennison, M. Lehman, M. Nortrup, P. Campbell, E. Wenschhof, J. Calzarette, D. Cohen, L. Donaldson, and A. Landsman. 2011a. Antietam National Battlefield natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2011/413. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

Thomas, J.E., T. Carruthers, W.C., Dennison, M. Lehman, M. Nortrup, P. Campbell, and B. Gorsira. 2011b. Manassas National Battlefield natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2011/414. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

Thomas, J.E., T. Carruthers, W.C., Dennison, M. Lehman, M. Nortrup, P. Campbell, and A. Banasik. 2011c. Monocacy National Battlefield natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2011/415. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

Thornberry-Ehrlich, T. 2008. Wolf Trap National Park for the Performing Arts Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2008/041. National Park Service, Denver, Colorado.

Tierson, W.C., E.F. Patric, and D.F. Behrend. 1966. Influence of white-tailed deer on a northern hardwood forest. Journal of Forestry 64: 801–805.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management 53: 524–532.

U.S. Bureau of the Census, U.S. Department of Commerce. 2011. 2010 Census Summary File 1 Virginia/prepared by the U.S. Census Bureau. Available at http://www.census.gov/geo/maps-data/

U.S. Bureau of the Census, U.S. Department of Commerce. 2013a. District of Columbia QuickFacts. Accessed 15 May 2013. Available at http://quickfacts.census.gov/qfd/states/11000.html

U.S. Bureau of the Census. U.S. Department of Commerce. 2013b. Fairfax County QuickFacts. Accessed 15 May 2013. Available at http://quickfacts.census.gov/qfd/states/51/51059.html

U.S. Bureau of the Census, U.S. Department of Commerce. 2013c. Virginia QuickFacts. Accessed 15 May 2013. Available at http://quickfacts.census.gov/qfd/states/51000.html3U.S. Environmental Protection Agency (U.S. EPA). 2013. Air quality planning and standards. http://www.epa.gov/airquality

U.S. Department of Interior. National Park Service. 2006. Management policies 2006.

U.S. EPA. 2000. Ambient water quality criteria recommendations—rivers and streams in Nutrient Ecoregion XI. EPA 822-B-00-020. United States Environmental Protection Agency, Washington DC.

U.S. EPA. 2001. Water quality criterion for the protection of human health: methylmercury. U.S. Environmental Protection Agency, Washington D.C. EPA-823-R-01-001.

U.S. EPA. 2003. Guidance for estimating natural visibility conditions under the regional haze program. EPA-454/B-03-005.

U.S. EPA. 2004a. The Clean Air Act. Washington United States Environmental Protection Agency, Washington D.C. http://epa.senate.gov/envlaws/cleanair.pdf

U.S. EPA. 2004b. Air Quality Criteria for Particulate Matter Vol I of II. EPA/600/P-99/002aF

U.S. EPA. 2006. Provisional assessment of recent studies on health effects of particulate matter exposure. EPA/600/R-06/063.

U.S. EPA. 2009. Assessment of the impacts of global change on regional U.S. air quality: a synthesis of climate change impacts on ground-level ozone. An Interim Report of the U.S. EPA Global

Change Research Program. National Center for Environmental Assessment, Washington, DC. EPA/600/R-07/094F. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea

U.S. EPA. 2010. Our nation's air: status and trends through 2008. EPA-454/R-09-002. http://www.epa.gov/airtrends/2010

U.S. EPA. 2012. National recommended water quality criteria Current water quality criteria. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#hh

U.S. EPA. 2013. Air quality planning and standards. http://www.epa.gov/airquality

UNEP (United Nations Environment Programme) Chemicals Branch. 2008. The global atmospheric mercury assessment: sources, emissions and transport. UNEP—Chemicals, Geneva.

USDA (United States Department of Agriculture) Forest Service. 2009a. Gypsy moth in North America. http://www.fs.fed.us/ne/morgantown/4557/gmoth/

USDA (United States Department of Agriculture) Forest Service. 2009b. Hemlock woolly adelgid, Forest Health Protection, USDA Forest Service. http://na.fs.fed.us/fhp/hwa/

USGS (United States Geological Survey). 1980. Surfacewater. National handbook of recommended methods for water-data acquisition. U.S. Geological Survey.

USGS (United States Geological Survey). 2007-2014, National Hydrography Dataset available on the World Wide Web (http://nhd.usgs.gov), accessed December 5, 2014.

Vila, M., J.L. Espinar, M. Hejda, P.E. Hulme, V. Jarosik, J.L. Maron, J. Pergl, Y. Schaffner, Y. Sun, and P. Pysek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities, and ecosystems. Ecological Letters 14: 702-708.

Virginia State Water Control Board. 2011. Virginia Water Quality Standards. State of Virginia, editor. 9 VAC 25-260.

Waller, D.M., and W.S. Alverson. 1997. The white-tailed deer: a keystone herbivore. Wildlife Society Bulletin 25: 217-226.

Welch, E.B., J.M. Jacoby, and C.W. May. 1998. Stream Quality. In: Naiman R.J. and R.E. Bilby (eds.). River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York, NY.

Williams, E.S., M.W. Miller, T.J. Kreeger, R.H. Kahn, and E.T. Thorne. 2002. Chronic wasting disease of deer and elk: a review with recommendations for management. Journal of Wildlife Management 66:551—63.

Wilson, M.L., A.M. Ducey, T.S. Litwin, T.A. Gavin, and A. Spielman. 1990. Microgeographic distribution of immature *Ixodes dammini* ticks correlated with that of deer. Medical and Veterinary Entomology 4(2): 151-159.

Appendix A: Raw data

Table A-1. Particulate matter, PM2.5 (µg/m^3). Site locations are shown in Figure 4-26 and thresholds are shown in Table 4-22.

Site	Years	3-year mean
510595001	2000-2002	14.6
	2001-2003	14.1
	2002-2004	13.8
	2003-2005	14.0
	2004-2006	13.7
	2005-2007	13.7
	2006-2008	12.7
	2007-2009	11.7
511071005	2000-2002	13.8
	2001-2003	13.6
	2002-2004	13.6
	2003-2005	13.9
	2004-2006	13.6
	2005-2007	13.2
	2006-2008	12.2
	2007-2009	11.2
	2008-2010	10.3
	2009-2011	9.5
	2010-2012	9.46
110010042	2000-2002	14.6
	2001-2003	13.8
	2002-2004	14.0
	2003-2005	14.3
	2004-2006	14.4
	2005-2007	14.0
	2006-2008	12.7
	2007-2009	11.7
	2008-2010	10.8
	2009-2011	10.1
	2010-2012	9.7

Table A-2. Water quality data. Site locations are shown in Figure 4-1and thresholds are shown in Table 4-2 Water resource indicators, data availability, reference conditions, and condition assessment categories.

Site	Date	pH	DO (mg/L)	Temp (°C)	ANC (µeq/L)	Cond. (µS/cm)	NO_3 (mg/L)	TP (mg/L)
WOTR_CHCK	5/2/06	7.70	3.58	14.55	920	265	2	0.2414
WOTR_CHCK	6/15/06	7.6	8.17	17.95	736	251	1.5	1.0897
WOTR_CHCK	7/12/06	7.42	7.3	23.05	678	283.4	1.8	0.3002
WOTR_CHCK	8/7/06	7.24	5.79	24.5	478	160.4	1.3	0.2545
WOTR_CHCK	9/25/06	7.44	8	18.1	716	300.3	2.1	3.3279
WOTR_CHCK	10/19/06	7.555	8.315	15.65	660	204.05	1.5	0.2838
WOTR_CHCK	12/5/06	6.41	10.86	4.4	566	274.9	2.2	0.2741
WOTR_CHCK	1/10/07	7.42	11.82	4.05	554	250.2	0.98	0.2675
WOTR_CHCK	4/2/07	7.36	7.51	15.25	646	387.467	0.78	0.0457

Site	Date	pH	DO (mg/L)	Temp (°C)	ANC (µeq/L)	Cond. (µS/cm)	NO_3 (mg/L)	TP (mg/L)
WOTR_CHCK	5/9/07	7.54	8.473	15.567	714	323	2.59	0.326
WOTR_CHCK	6/7/07	7.41	6.46	17.55	778	304.15	1.85	0.0881
WOTR_CHCK	7/24/07	7.52	6.67	19.9	868	335.9	1.4	0.0424
WOTR_CHCK	8/22/07	6.72	7.39	18.9	562	199.2	0.8	0.0392
WOTR_CHCK	9/25/07	7.53	6.27	18.1	898	317.5	1.5	0.0555
WOTR_CHCK	10/23/07	7.29	5.55	16.8	792	231.4	1.6	0.0881
WOTR_CHCK	11/19/07	7.58	9.81	8.2	812	250.7	2.6	0.0620
WOTR_CHCK	12/17/07	7.32	12.29	3	560	414.4	2.1	0.0555
WOTR_CHCK	1/31/08	7.16	12.97	2.35	708	1382	3	
WOTR_CHCK	2/27/08	7.51	11.68	5.3	656	1876.5	2.9	0.0653
WOTR_CHCK	3/19/08	7.65	10.4	10.02	742	369.9	2.6	0.0359
WOTR_CHCK	4/23/08	7.46	8.73	15.6	738	261.45	2.1	0.0457
WOTR_CHCK	5/15/08	7.55	8.62	15.85	848	305.95	2.7	0.1142
WOTR_CHCK	6/23/08	7.54	7.32	21	702	306.68	2.7	0.1077
WOTR_CHCK	7/28/08	7.34	6.54	22.1	568	173.98	1.5	
WOTR_CHCK	8/26/08	7.88	7.87	20.1	*Not Reported	338.95	2	0.0326
WOTR_CHCK	9/23/08	7.47	7.18	18	762	309.95	2.3	0.0750
WOTR_CHCK	10/23/08	7.35	10.66	9.25	1048	311.7	1.9	0.0522
WOTR_CHCK	11/17/08	7.24	9.32	8.5	912	205.08	1.3	0.0620
WOTR_CHCK	1/22/09	6.82	*Not Reported	0.15	682	326.82	3.7	0.0718
WOTR_CHCK	3/30/09	7.5	11.24	9.83	720	467.68	1.8	0.0750
WOTR_CHCK	4/27/09	7.4	9.18	19.45	430	352.5	2.4	0.1403
WOTR_CHCK	5/27/09	7.46	9.2	16.1	654	227.95	2.3	0.0424
WOTR_CHCK	7/6/09	7.49	8.75	18.2	680	310.85	2.3	0.0555
WOTR_CHCK	7/29/09	7.48	7.4	22.1	712	281.3	1.7	0.1207
WOTR_CHCK	8/27/09	7.56	7.8	21.8	768	284.05	2	0.0489
WOTR_CHCK	9/24/09	7.49	8.4	20	816	329.35	2.7	0.1044
WOTR_CHCK	10/22/09	7.4	9.75	11.8	800	268.6	1.4	0.0979
WOTR_CHCK	11/19/09	7.56	9.85	12.1	960	296.55	2.5	0.0392
WOTR_CHCK	12/10/09	7.33	12.3	6.6	644	385.4	1.5	0.0522
WOTR_CHCK	1/21/10	7.42	13.7	3.8	658	685.2	2.5	0.0489
WOTR_CHCK	2/18/10	*Not Reported	*Not Reported	*Not Reported	*Not Reported	*Not Reported		0.0489
WOTR_CHCK	3/18/10	7.47	12.7	8.9	722	454.2	1.8	0.0946
WOTR_CHCK	4/15/10	7.59	12.2	11.4	708	380.4	2	0.0457
WOTR_CHCK	5/13/10	7.36	9.3	13.5	714	340	1.8	0.1860
WOTR_CHCK	6/17/10	7.41	8.3	20.4	756	334	2.2	0.0750
WOTR_CHCK	7/19/10	7.26	7.4	24	286	143.2	1.7	0.0294
WOTR_CHCK	8/19/10	7.16	7.7	21.7	568	216	2.1	0.0914
WOTR_CHCK	9/22/10	7.47	9	17.7	792	338.3	2.6	0.0359
WOTR_CHCK	10/20/10	7.06	9.79	12.85	222	301.4	2.8	0.0620
WOTR_CHCK	11/10/10	7.35	10.9	9.4	702	302	2.5	0.1501
WOTR_CHCK	12/9/10	7.44	14.2	0.5	2296	338.2	2.7	0.0979
WOTR_CHCK	1/13/11	7.4	15.5	5.9	640	935	2.9	0.0587
WOTR_CHCK	2/14/11	7.76	13.7	7.3	590	765	1.6	0.0816
WOTR_CHCK	4/13/11	7.06	9.8	12.1	704	163.7	1.2	0.1892
WOTR_CHCK	5/9/11	7.2	8.95	14.05	676	363.1	1.9	0.0914
WOTR_CHCK	6/15/11	7.22	8	17.5	762	330.7	1.5	0.0881

Site	Date	pH	DO (mg/L)	Temp (°C)	ANC (µeq/L)	Cond. (µS/cm)	NO_3 (mg/L)	TP (mg/L)
WOTR_CHCK	7/20/11	7.25	6.3	23.7	746	244.4	1.4	0.0228
WOTR_CHCK	8/18/11	7.32	6.8	21.6	762	287.2	1.2	0.0946
WOTR_CHCK	9/15/11	7.34	8.1	19.9	784	366.5	2.5	0.0489
WOTR_CHCK	10/20/11	7.04	7.85	15.7	596	183.25	1.2	0.0620
WOTR_CHCK	11/14/11	7.17	10.1	12.2	774	369.3	4.1	
WOTR_CHCK	12/8/11	6.96	10.25	7.8	600	215.15	1.7	
WOTR_CHCK	1/19/12	7.18	12.4	7.6	596	277.1	2.2	0.0424
WOTR_CHCK	2/13/12	7.23	11.1	8.6	630	523.5	2.2	0.0392
WOTR_CHCK	3/8/12	7.54	11.8	11.4	642	338.3	2.1	0.0555
WOTR_CHCK	4/17/12	7.77	9.4	17.7	762	339.1	1.9	0.0881
WOTR_CHCK	5/21/12	7.26	7.95	18.45	200	128.5	0.9	0.0620
WOTR_CHCK	6/18/12	7.45	7.9	18	730	287	1.9	0.0555
WOTR_CHCK	7/16/12	7.44	7.7	22.4	680	276.7	1.8	
WOTR_CHCK	8/16/12	7.62	8.2	21.1	674	295	1.1	0.0653
WOTR_CHCK	9/13/12	7.66	8.5	17	694	274.2	1.5	0.0359
WOTR_CHCK	10/10/12	7.47	9.4	13.8	712	257.5	1.9	0.0457
WOTR_CHCK	11/8/12	7.6	12.7	6.8	716	300.5	2.2	0.1142
WOTR_CHCK	12/13/12	7.72	13.1	6	730	289.5	1.2	0.0228
WOTR_CHCK	1/29/13	7.66	13.7	5.7	554	3226	1.9	0.0946
WOTR_CHCK	2/25/13	7.42	13.4	5.3	614	631.2	2.2	0.489
WOTR_CHCK	3/28/13	7.66	11.8	7.6	620	577	1.9	0.0620
WOTR_CHCK	4/23/13	7.75	11.2	12.4	758	324.5	1.07	
WOTR_CHCK	5/21/13	7.57	9	19.7	750	330.2	1.31	
WOTR_WOTR	11/1/05	7.08	10.43	11.6	*Present <QL	217.65	1.6	0.1501
WOTR_WOTR	12/5/05	7.17	8.72	4.35	526	1089.2	0.8	0.0392
WOTR_WOTR	1/10/06	*Not Reported	5.67	6.83	588	242.6	1.4	0.0653
WOTR_WOTR	2/16/06	6.86	11.49	5.7	468	633	1.1	0.0620
WOTR_WOTR	3/15/06	7.6	8.35	11.45	448	229.2		
WOTR_WOTR	4/6/06	6.9	3.78	12.4	744	305.1	1	0.1175
WOTR_WOTR	5/2/06	7.42	1.89	14.1	760	300.5	1.8	0.7863
WOTR_WOTR	6/15/06	6.8	5.84	17.7	768	366.3	1.2	1.2398
WOTR_WOTR	7/12/06	6.97	6.16	22.8	754	230	1.5	0.3263
WOTR_WOTR	8/7/06	7.18	6.2	24.1	352	153.7	1	1.5856
WOTR_WOTR	9/25/06	7.11	6.31	18	676	244.2	1.6	1.2594
WOTR_WOTR	10/19/06	7.25	7.1	15.65	520	173.27	1.3	2.7047
WOTR_WOTR	12/5/06	7.113	10.167	4.566	334	222.433	2	0.2251
WOTR_WOTR	1/11/07	7.17	11.61	4.116	518	194.7	2	0.1436
WOTR_WOTR	4/2/07	7.343	7.783	14.6	660	332.617	0.5	0.0457
WOTR_WOTR	5/9/07	7.073	6.267	15.6	698	250.083	2.09	0.0163
WOTR_WOTR	6/7/07	6.797	5.36	17.1	810	313.017	1.78	0.2643
WOTR_WOTR	7/24/07	6.45	5.09	18.2	704	380.5	1.1	
WOTR_WOTR	8/22/07	6.43	6.1	18.9	542	188.3	0.8	
WOTR_WOTR	9/25/07	6.27	4.98	17.5	726	460.9	1.7	
WOTR_WOTR	10/23/07	6.69	4.59	16.7	680	250.5	2	
WOTR_WOTR	11/19/07	7.29	7.33	8.3	706	216.4	2.3	
WOTR_WOTR	12/17/07	7.36	10	3.4	604	404.7	1.7	
WOTR_WOTR	1/31/08	6.88	12.11	2.8	722	769	2.5	
WOTR_WOTR	2/27/08	7.28	10.11	5.17	672	1190.83	2.4	

Site	Date	pH	DO (mg/L)	Temp (°C)	ANC (µeq/L)	Cond. (µS/cm)	NO_3 (mg/L)	TP (mg/L)
WOTR_WOTR	3/19/08	7.51	9.69	9.78	790	284.12	2.1	
WOTR_WOTR	4/23/08	7.29	9.6	15.68	776	179.35	2	
WOTR_WOTR	5/15/08	7.34	8.22	15.9	754	218.88	2.5	
WOTR_WOTR	6/23/08	7.22	7.61	21.13	712	235.3	1.7	
WOTR_WOTR	7/28/08	7.08	6.54	21.83	660	172.72	1.4	
WOTR_WOTR	8/26/08	7.14	7.64	20.07	*Not Reported	295.48	1.5	
WOTR_WOTR	9/23/08	7.06	8.36	18.3	742	264.7	1.7	
WOTR_WOTR	10/23/08	7.09	10.86	9.1	888	268.1	1.6	
WOTR_WOTR	11/17/08	6.99	9.28	8.2	968	186.42	1.4	
WOTR_WOTR	1/22/09	*Not Reported	*Not Reported	*Not Reported	*Not Reported	*Not Reported		
WOTR_WOTR	3/30/09	7.16	10.24	9.2	716	387.88	1.7	0.0489
WOTR_WOTR	4/27/09	7.31	9.38	18.7	776	269	3	0.0718
WOTR_WOTR	5/27/09	7.33	8.9	16.3	622	178.9	1.8	0.1044
WOTR_WOTR	7/6/09	7.24	9.1	18.35	756	245.5	1.8	0.0816
WOTR_WOTR	7/29/09	7.06	7.5	22.3	666	244	1.7	0.0555
WOTR_WOTR	8/27/09	7.07	7.9	21.6	736	232.9	1.8	0.0620
WOTR_WOTR	9/24/09	6.9	7.8	20.1	792	263.7	2	0.0555
WOTR_WOTR	10/22/09	7.02	10.4	11.6	824	212.8	1.7	0.0359
WOTR_WOTR	11/19/09	7.22	9.9	12	872	227.8	1.4	0.0424
WOTR_WOTR	12/10/09	7.24	12.3	6.3	548	257.85	1.3	0.1501
WOTR_WOTR	1/21/10	7.35	13.8	3.7	624	517.75	2.2	0.0816
WOTR_WOTR	2/18/10	*Not Reported	*Not Reported	*Not Reported	*Not Reported	*Not Reported		
WOTR_WOTR	3/18/10	7.34	12.53	8.7	730	328.5	1.3	0.0457
WOTR_WOTR	4/15/10	7.24	10.67	11.33	720	287.63	1.7	0.0783
WOTR_WOTR	5/13/10	7.19	8.55	13.5	680	281.3	1.8	0.0522
WOTR_WOTR	6/17/10	7.12	7.95	20.45	708	270.05	2	0.0620
WOTR_WOTR	7/19/10	7.15	7.25	24.35	286	123.15	1.2	0.0914
WOTR_WOTR	8/19/10	7.05	7.5	21.9	464	154.55	1.9	0.1109
WOTR_WOTR	9/22/10	6.93	7.95	17.7	694	298.35	2.8	0.1990
WOTR_WOTR	10/20/10	7.04	7.86	12.8	*Present <QL	241.2	3.5	0.0555
WOTR_WOTR	11/10/10	7.16	10.23	9.47	2632	241.83	2.1	0.0555
WOTR_WOTR	12/9/10	*Not Reported	*Not Reported	*Not Reported	*Not Reported	*Not Reported		
WOTR_WOTR	1/13/11	*Not Reported	*Not Reported	*Not Reported	*Not Reported	*Not Reported		
WOTR_WOTR	2/14/11	7.34	13.35	7.2	608	572.2	1.5	0.1175
WOTR_WOTR	4/13/11	7.14	9.43	12.5	776	166.85	1.3	0.1468
WOTR_WOTR	5/9/11	7.06	8.85	14.3	730	282.35	1.9	0.0457
WOTR_WOTR	6/15/11	7.02	7.85	17.6	702	268.25	1.1	0.0620
WOTR_WOTR	7/20/11	7.1	6.6	23.65	692	264.75	1.3	0.0685
WOTR_WOTR	8/18/11	6.93	6.8	21.45	612	234.65	1.4	0.0587
WOTR_WOTR	9/15/11	7.13	7.3	20	752	276.25	1.8	0.1240
WOTR_WOTR	10/20/11	7.09	7.95	15.65	608	245.8	1.2	0.1044
WOTR_WOTR	11/14/11	7.16	10.9	12.3	764	289.1	1.6	0.0489
WOTR_WOTR	12/8/11	6.89	10.55	7.7	530	133.95	1.4	0.2545
WOTR_WOTR	1/19/12	7.41	11.2	6.2	626	220.2	2.1	0.0359
WOTR_WOTR	2/13/12	7.84	11.2	8.9	670	500.2	2	0.1533

Site	Date	pH	DO (mg/L)	Temp (°C)	ANC (μeq/L)	Cond. (μS/cm)	NO_3 (mg/L)	TP (mg/L)
WOTR_WOTR	3/8/12	7.26	12.03	11.3	616	251.5	1.9	0.0620
WOTR_WOTR	4/17/12	7.43	10.67	17.47	744	271.27	1.5	0.0392
WOTR_WOTR	5/21/12	7.35	8.37	18.2	604	143.97	1.3	0.1958
WOTR_WOTR	6/18/12	7.37	8.27	18	728	239.47	1.8	0.1533
WOTR_WOTR	7/16/12	7.17	7.13	22.63	640	234.33	1.3	0.0522
WOTR_WOTR	8/16/12	7.15	6.2	21.07	718	272.7	1.3	0.1240
WOTR_WOTR	9/13/12	7.14	7.7	16.75	640	298.9	1.5	0.1305
WOTR_WOTR	10/10/12	7.18	8.37	14.03	678	220.93	1.6	0.0750
WOTR_WOTR	11/8/12	7.77	12.23	6.77	682	247.4	0.2	0.1990
WOTR_WOTR	12/13/12	7.43	13.17	5.9	730	244.3	1.5	0.1109
WOTR_WOTR	1/29/13	7.22	13.85	4.8	558	2152.5	1.9	0.1566
WOTR_WOTR	2/25/13	7.32	13.85	5.9	654	466.75	1.9	0.0522
WOTR_WOTR	3/28/13	7.44	11.9	7.9	678	519.55	1.7	0.1305
WOTR_WOTR	4/23/13	7.33	10.9	12.1	744	258.5	0.928	
WOTR_WOTR	5/21/13	7.35	9.1	20	842	257.5	1.14	

Table A-3 Deer density (deer/km^2) in WOTR.

Year	Density
2012	48
2013	40
Median	44

Appendix B: Expanded Executive Summary

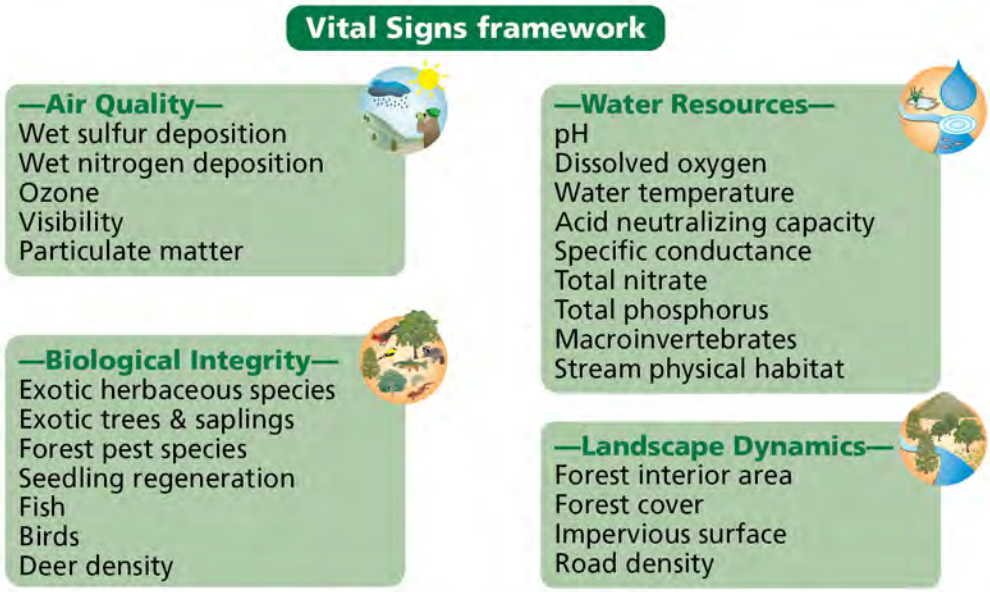
Background and context

Wolf Trap National Park for the Performing Arts is a 117-acre park located approximately 18 miles west of Washington, D.C. in Vienna, Virginia. Established in 1966, the park was designated as the first national park for the performing arts. The park provides a natural sanctuary for native bird, plants, and animal species in a developing region. Less than half of Wolf Trap's land is developed, leaving approximately 65 acres of woodland, streams, and wetland with a variety of plants, animals, birds, and wildflowers. The natural areas within WOTR add critical green space in a dense suburban area, offer a migration stop for wildlife, and serve as a living biology classroom to the surrounding community. WOTR consists of a diversity of natural resources including streams, ponds, wetlands, and two acres of upland forests. The park encourages education through two miles of hiking trails, as well as several demonstration gardens. WOTR also supports sustainable vegetable gardens, and several extensive native plant gardens.

Multiple regional and local stressors challenge the natural resources within WOTR. Air pollution from power plants, industry, and vehicle emissions result in reduced air quality through large regions of the central eastern seaboard of North America. The park is therefore subjected to high ozone and atmospheric deposition, potentially impacting flora, fauna, and park visitors. WOTR is one of the largest green spaces near Tysons Corner, Virginia, and will likely see increased visitation with increased nearby development. Watershed-wide urbanization and development result in challenges to water quality. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion.

Approach

Assessment of natural resource condition within WOTR was carried out using the National Park Service Inventory and Monitoring Program Vital Signs ecological monitoring framework. Twenty-five metrics were analyzed in four categories: Air Quality, Water Resources, Biological Integrity, and Landscape Dynamics. Within each vital sign, indicators were identified that would inform the assessment and data was sourced for these indicators. The assessment of condition was based on the comparison of available data collected between 2002 and 2014 to ecological thresholds. Reference conditions were established for each indicator, and the percentage attainment of reference condition was calculated. Once attainment was calculated for each indicator, an unweighted mean was calculated to determine the condition for each vital sign category and the similarly to combine vital sign categories to calculate an overall park assessment. Based on these key findings, management recommendations were developed and data gaps were identified.



Features of Wolf Trap National Park for the Performing Arts

Wolf Trap National Park for the Performing Arts (WOTR) consists of 117 acres, about half of which is designed landscape. The park is located in Fairfax County, Virginia near the town of Vienna. It is bordered by residential neighborhoods on its east, west, and north, and by VA Route 267 to the south and southwest. Additionally, Trap Road, a minor arterial road maintained by the Vienna Department of Transportation runs through the park. The park is located approximately 2.4 miles northwest of Tysons Corner, VA, and eighteen miles west of Washington, D.C. The park consists of a diversity of natural resources including streams, ponds, and two acres of upland forests; making up a large area of green space in an otherwise urbanized region.

The landscape of the park consists of wooded rolling hills, a stream valley, and flat to gently sloping areas. Wolf Trap lies within the Piedmont Physiographic Province and varied hydrological influences acting on the underlying geology have built a complex topography at the park. The overall elevation varies by about 100 feet. The highest hills in the park are in the southeast corner and the lowest points are in the flood plain in the northwest corner. Topographic and elevation differences like these ones, along with seasonal flooding, support a diversity of habitats ranging from year-round wetlands to dry, steep, forested slopes.

The park is part of the Difficult Run watershed, the largest watershed in Fairfax County, Virginia. Two streams, Courthouse Creek and Wolf Trap Creek, meet within the WOTR boundary and flow through the park, eventually draining into Difficult Run.

Threats to Wolf Trap National Park for the Performing Arts:

Degraded air quality is a problem throughout the eastern United States, and while the causes of degraded air quality are largely out of the park’s control, the specific implications to the habitats and species in the park are not well known.

Wolf Trap National Park for the Performing Arts is one of the largest green spaces near Tysons Corner, VA and will likely see increased pressures as Tysons Corner and Fairfax County continue to develop. Increasing urbanization of the Difficult Run watershed has led to adverse effects of runoff, pollutants, trash, and erosion on Wolf Trap Creek. Erosion inside and outside of the park increases the sediment carried by park streams, which affects aquatic and riparian ecosystems.

On average, National Capital Region Network Inventory & Monitoring forest data shows 4.17 exotic species per monitored plot in the herb layer at WOTR. Exotic and invasive plants compete with native species, while insect and other pests cause damage to forest trees. Several pests and disease threaten forest resources, among them the gypsy moth (*Lymantria dispar).* Excessive numbers of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings. On a regional scale, degraded air quality associated with vehicular traffic affects aquatic habitats and sensitive species.

Key findings, recommendations, and data gaps

Overall, the natural resources of Wolf Trap National Park for the Performing Arts were in *degraded condition.*

The vital signs framework showed that air quality condition was generally very degraded, water resources condition was generally good, biological integrity condition was variable but moderate overall, and landscape dynamics condition was generally very degraded.

Vital sign	Reference attainment	Condition
Water resources	61%	Good
Biological integrity	50%	Moderate
Landscapes dynamics	2%	Very degraded
Air resources	10%	Very degraded
WOTR Overall	**31%**	**Degraded**

Air Quality

Air quality was in a very degraded condition. Degraded air quality is a problem throughout the eastern United States, and while the causes of degraded air quality are out of the park's control, the specific implications to the habitats and species in the park are less well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts.

The close connection between climate and air quality is reflected in the impacts of climate change on air pollution levels. In particular, the U.S. EPA has concluded that climate change could increase ozone concentrations and change amounts of particle pollution.

Air Quality. Key findings, management implications, and recommended next steps for air quality in Wolf Trap National Park.

Key findings	Management implications	Recommended next steps
Air quality is very degraded and is a regional problem	• Impacts of poor air quality on park largely unknown. • Habitats and species in the park may be affected. • Nearby parks (e.g. Shenandoah NP) have clear ecological impacts of poor air quality (i.e. acid rain impacts).	• Investigate effects of poor air quality on sensitive habitats (e.g. ozone damage to vegetation). • Stay engaged with the wider community in terms of air quality education and activities. • Support regional air quality initiatives.

Air Quality. Data gaps, justification, and research needs for air quality in Wolf Trap.

Data gaps	Justification	Research needs
Park-specific air quality data	• Air quality is measured and interpolated on regional and national scales. • Need to implement park-specific management actions.	• Use transport and deposition models to analyze and estimate park specific air quality data and trends.

Data gaps	Justification	Research needs
		• Implementation of park-scale air quality monitoring would give better insights into park-level air quality condition and possible effects on park habitats and species. • Planting and monitoring a garden of ozone-sensitive plants
Effects of poor air quality on park habitats and species	• Need to implement park-specific management actions	• Investigate effects of poor air quality on sensitive habitats and species within the park
Ecological references for mercury wet deposition	• Mercury deposition is reported for WOTR but no reference exists for protection of species.	• Adopt standards once NPS Air Resources Division establishes mercury wet deposition reference.
Lightscape information	• Extent of impacts to night sky visibility unknown	• Perform a light study
Soundscape information	• Potential increase in traffic noise over time, from either an increase in vehicles or the opening of the Washington Metropolitan Area Transit Authority's new Silver Line	• Perform a noise/soundscape study

Water Resources

Stream water resources were in good condition overall, with 61% attainment of reference conditions. However, total phosphorus was in a very degraded condition, which is similar to results found in parks throughout the region. Specific conductance and the Benthic Index of Biotic Integrity (BIBI) are currently in very degraded conditions while the Physical Habitat Index is in moderate (degraded) condition. The majority of water inflows to the park originate from outside the park in developed/urban areas. Data gaps and research recommendations revolve around maintaining good water quality by identification of nutrients sources and sensitive organisms.

Water temperature increase is one of the most immediate threats from climate change, and this would result in the loss of fish and other organisms that depend upon cooler water.

Water Quality. Key findings, management implications, and recommended next steps for air quality in Wolf Trap.

Key findings	Management implications	Recommended next steps
Very degraded condition for total phosphorus (Elevated phosphorus levels have been found in parks throughout the region and thought to be largely due to underlying geology (Carruthers *et al.* 2009, Norris and Pieper 2010, Thomas *et al.* 2011a, b, c).)	• Affects stream flora and fauna	• Minimize soil disturbance • Implement best management practices such as riparian buffers and no-mow areas.
Very degraded condition for specific conductance	• Affects stream flora and fauna • Reduces quality of visitor experience	• Identify source (e.g. salting of roads outside and within WOTR) and conductance-

Key findings	Management implications	Recommended next steps
		sensitive organisms and locations for management initiatives. • Implement best management practices such as riparian buffers and no-mow areas.
Very degraded Benthic Index of Biological Integrity and moderate (degraded) Physical Habitat Index	• Affects stream flora and fauna • Reduces quality of visitor experience	• Implement stream restoration and manage volume and velocity of water entering the park (e.g. swales, riparian buffers and no-mow areas). • Prepare education materials for immediate neighbors. • Implement monitoring to identify sources and patterns of nutrients and stream habitat degradation and then develop management options.

Water Quality. Data gaps, justification, and research needs for air quality in Wolf Trap.

Data gaps	Justification	Research needs
Amphibian data	• Unknown changes in toad population within the pond	• Amphibian monitoring
Fish data for pond	• Unknown fish population	• Fish survey for pond
Pond water quality	• Wildlife/habitat value	• Initiate water quality monitoring site within pond.

Biological integrity

Biological integrity was in a moderate condition overall, although results for individual metrics were variable. Deer density and the stocking index were both in very degraded condition. Studies show a relationship between high deer density and poor forest regeneration, therefor deer management should continue to be a top priority. Other monitoring recommendations include exotic species monitoring and education, and continuing to monitor pests and diseases. Data gaps and research needs include a method for analyzing non-forest bird species and models of the effects of climate change and other stressors on the region’s forests.

How climate change may affect the park’s resources and habitats should be an ongoing research focus, in particular how it might affect the introduction and spread of exotic species and forest pests and diseases.

Biological Integrity. Key findings, management implications, and recommended next steps for air quality in Wolf Trap.

Key findings	Management implications	Recommended next steps
Very high cover of exotic herbaceous species	• Displacement of native plant species, reduced food and habitat for native fauna	• Prioritize species and locations for implementing control measures • Restore and maintain native species and communities • Identify and map areas of exotic invasion that are not reflected in NCRN I&M forest monitoring (e.g. floodplain areas).
Very degraded Stocking Index	• Lack of forest regeneration and subsequent habitat	• Manage deer over-browse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park) • Implement planting initiatives
Degraded Bird Community Index	• Decrease in visitor experience, soundscape, and seed distribution	• Improve bird habitat
Anecdotal: Increased observance of copperheads and northern water snakes likely due to increased accessibility via walking track construction	• Safety and public perception	• Increase education • Rodent control near facilities
Anecdotal: Increased raccoon presence	• Safety (excrement) and public disruption (presence during shows)	• Trash management • Physical barriers
Anecdotal: Reports of black bear presence in the park	• Safety and public perception	• Prepare unified staff response for public reporting • Prepare education materials • Trash management

Biological Integrity. Data gaps, justification, and research needs for air quality in Wolf Trap.

Data gaps	Justification	Research needs
Comprehensive park species list	• Objective for the park is to have a diverse animal population and provide more diverse habitat and improved visitor experience	• Update invertebrate survey • Update mammal survey • All taxa inventory including butterflies, birds (ongoing) and bees (ongoing)
Current bat information	• Objective for the park is to have a diverse animal population and provide more diverse habitat and improved visitor experience • Last bat survey >10 years ago	• Update bat survey

Landscape dynamics

Landscape dynamics were in very degraded condition overall, with 2% attainment of reference conditions due to the cultural design of the park, regional development, and urban encroachment. Forest interior area, forest cover, and impervious surface (at both spatial scales) were all in very degraded condition, as was road density within the park. This condition will likely continue with new developments in the area (e.g. Tysons Corner) putting additional stress on the natural habitats of Wolf Trap, while also adding pressure on the park to provide recreational opportunities and open space for growing populations.

Research needs for the park mostly relate to its function as habitat corridor in the region. How climate change may affect the park's resources and habitats should be an ongoing research focus.

Landscape Dynamics. Key findings, management implications, and recommended next steps for air quality in Wolf Trap.

Key findings	Management implications	Recommended next steps
Very degraded forest interior area and forest cover – within and outside the park boundary	• Reduction in breeding habitat and reproductive success for forest interior bird species • Increased predation on forest interior birds	• Reassess legitimacy of using forest interior as a reference condition given areal constraints
Large areas of impervious surface – within and outside the park boundary	• Increased rainfall runoff volume and velocity (with pollutants)	• Change asphalt parking lots to porous yet durable surfaces (e.g. pervious pavers, grass) • Protect existing unpaved roads to grass parking areas to prevent erosion and perceived need for paving.
High road density	• Disrupts forest interior areas	• Difficult to manage. Potential traffic calming/reduction measures

Landscape Dynamics. Data gaps, justification, and research needs for air quality in Wolf Trap.

Data gaps	Justification	Research needs
Impacts of climate change on park habitat	• Pressures of climate change will become more serious and widespread with time	• Risk assessment of likely impacts of climate change to park resources

Appendix C. Natural Resource Condition Assessment Brief

Wolf Trap National Park for the Performing Arts
Natural Resource Condition Assessment Brief

National Park Service
U.S. Department of the Interior

Natural Resource Condition Assessments (NRCAs) evaluate the current condition of a subset of natural resources and resource indicators in a national park. This brief summarizes the findings of the 2015 NRCA for Wolf Trap National Park for the Performing Arts.

Wolf Trap National Park for the Performing Arts (WOTR) is a 117 acre park located approximately 18 miles west of Washington, D.C. in Vienna, Virginia. Established in 1966, the park was designated as the first national park for the performing arts. The park provides a natural sanctuary for native bird, plants, and animal species in a developing region. Less than half of Wolf Trap's land is developed, leaving approximately 65 acres of woodland, streams, and wetland with a variety of plants, animals, birds, and wildflowers. The natural areas within WOTR add critical green space in a dense suburb, offer a migration stop for wildlife, and serve as a living biology classroom to the surrounding community. The park encourages education through two miles of hiking trails, as well as several demonstration gardens. WOTR also supports sustainable vegetable gardens, and several extensive native plant gardens.

The land within WOTR consists of a diversity of natural resources including streams, ponds, wetlands, and two acres of upland forests; making up a large area of green space in an otherwise urbanized region. Multiple regional and local stressors challenge the natural resources within WOTR. Air pollution from power plants, industry, and vehicle emissions result in reduced air quality through large regions of the central eastern seaboard of North America. The park is therefore subjected to high ozone and atmospheric deposition, potentially impacting flora, fauna, and park visitors. WOTR is one of the largest green spaces near Tysons Corner, Virginia, and will likely see increased visitation with increased nearby development. Watershed-wide urbanization and development result in challenges to water quality. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion.

An impressive, modern performing arts complex occupies land that early English settlers once described as menaced by wolves. Photo © Thomas Paradis, National Park Service.

Wolf Trap National Park for the Performing Arts Resources and Threats

Natural resources	Threats to park natural resources
Native plant communities	Poor air quality
Native pollinator meadows	Invasive exotic species
Managed landscapes	Deer overpopulation
Sustainable visitor use	Urban development
Wildlife habitat	Adjacent land use
Pond	Nutrient runoff
	Stream bank erosion
	Global climate change

Features of, and threats to natural resources in Wolf Trap National Park for the Performing Arts.

Natural resource condition in Wolf Trap National Park for the Performing Arts.

A total of 25 vital sign indicators were used to determine the natural resource condition of WOTR. We established reference conditions for each indicator and calculated their percentage attainment of reference condition. A score for each vital sign category (air quality, biological integrity, water resources, and landscape dynamics) was calculated by averaging indicator scores in that category. We then averaged vital sign categories to calculate an overall park assessment. Based on key vital sign findings, management recommendations were developed and data gaps were identified.

KEY FINDINGS AND RECOMMENDATIONS

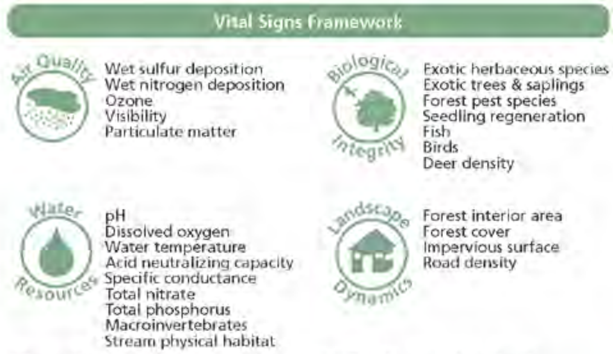
Overall, the natural resources of Wolf Trap National Park for the Performing Arts were in degraded condition.

The Vital Signs framework showed that air quality condition was generally very degraded, water resources condition was good, biological integrity condition was variable but moderate overall, and landscape dynamics condition was very degraded.

Air Quality Air quality was in a very degraded condition. Degraded air quality is a problem throughout the eastern United States, and while the causes of degraded air quality are largely out of the park's control, the specific implications to the habitats and species in the park are less well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts. The close connection between climate and air quality is reflected in the impacts of climate change on air pollution levels. In particular, the U.S. EPA has concluded that climate change could increase ozone concentrations and change the amount of particle pollution.

Water Resources Stream water resources were in good condition overall, with 60% attainment of reference conditions. However, total phosphorus was in a very degraded condition, which is similar to results found in parks throughout the region. Specific conductance and the Benthic Index of Biotic Integrity (BIBI) are currently in very degraded conditions while the Physical Habitat Index is in moderate (degraded) condition. The majority of water inflows to the park originate from outside the park in developed/urban areas. Data gaps and research recommendations revolve around maintaining good water quality by identification of nutrients sources and sensitive organisms. Water temperature increase is one of the most immediate threats from climate change, and this would result in the loss of fish and other organisms that depend upon cooler water.

Biological Integrity Biological integrity was in a moderate condition overall, although results for individual metrics were variable. Deer density and seedling regeneration were both in very degraded condition. Studies show a relationship between high deer density and poor forest regeneration and as such, deer management should continue to be a top priority. Other monitoring recommendations include exotic species monitoring and education, and continuing to monitor pests and diseases. Data gaps and research needs include a method for analyzing non-forest bird species and models of the effects of climate change and other stressors on the region's forests.



The vital signs framework used to assess Wolf Trap National Park for the Performing Arts.

Vital Sign	Reference condition attainment	Current condition
Air Quality	10%	Very degraded
Water Resources	60%	Good
Biological Integrity	50%	Moderate
Landscape Dynamics	2%	Very degraded
WOTR	**31%**	**Degraded**

The overall reference condition attainment and current condition of each of the four vital signs within Wolf Trap National Park for the Performing Arts.

Landscape Dynamics Landscape dynamics were in very degraded condition overall, with 2% attainment of reference conditions due to the cultural design of the park, regional development, and urban encroachment. Forest interior area, forest cover, and impervious surface (at both spatial scales) were all in very degraded condition, as was road density within the park. This condition will likely continue with new developments in the area (e.g. Tysons Corner) putting additional stress on the natural habitats of Wolf Trap, while also adding pressure on the park to provide recreational opportunities and open space for growing populations. Research needs for the park mostly relate to its function as habitat corridor in the region. How climate change may affect the park's resources and habitats should be an ongoing research focus.

CONCLUSIONS

Natural resources in Wolf Trap National Park for the Performing Arts are in degraded condition overall and are under threat from surrounding land use, regionally poor air quality, and overpopulation of deer. Climate change is predicted to negatively affect many of the natural resources of the park, including increasing ozone levels and particle pollution, raising the water temperature of streams, changing forest composition, and affecting exotic species and forest pests and disease.

This brief is excerpted from: Walsh, B.M., S.D. Costanzo, W.C. Dennison J.P. Campbell, M. Lehman, M. Nortrup, B. Chittenden, P. Goetkin, C. Schuster. 2015. Natural Resource Condition Assessment for Wolf Trap National Park For the Performing Arts. Natural Resource Report NPS/WOTR/NRR—2015/1030. National Park Service, Fort Collins, Colorado.

For more information, please visit the Park's Visitor Center or call (703) 255-1800.
Wolf Trap National Park for the Performing Arts
National Park Service
www.nps.gov/wotr

Developed in collaboration with:

National Capital Region Network
Inventory & Monitoring Program
National Park Service
science.nature.nps.gov/im/units/ncrn/

Integration & Application Network (IAN)
University of Maryland Center for Environmental Science
www.ian.umces.edu

ian.umces.edu
Innovation for a better future

NPS 627/129718, September 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov