National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Prince William Forest Park
Natural Resource Condition Assessment

National Capital Region

Natural Resource Report NPS/PRWI/NRR—2015/1051

ON THE COVER
Photograph of the South Fork of Quantico Creek in Prince William Forest Park.
Photograph courtesy of Tonya Watts, National Park Service

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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 and analyzed using methods based on established peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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.

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Executive Summary

Background

Prince William Forest Park (PRWI) is located in the southeast corner of Prince William County, Virginia and the northern edge of neighboring Stafford County, Virginia. The park preserves approximately 15,000 acres, at a transition between the rolling Piedmont Plateau and the low-lying Atlantic Coastal Plain. The two zones meet within the park at the “fall line,” where land level drops from the harder rocks of the Piedmont to the softer sedimentary rocks of the coastal plain, resulting in unique geological features such as waterfalls and rock outcroppings.

The 30 square-mile watershed of Quantico Creek is largely forested and protected as part of Prince William Forest Park and Marine Corps Base-Quantico. The South Fork Quantico Creek joins Quantico Creek proper near the eastern boundary of the park. The headwaters of South Fork Quantico Creek lie within Marine Corps Base-Quantico, and the 4 miles of creek downstream of PRWI are in private ownership. The remaining 17 square miles of watershed lie within the park. These streams receive more than 90% of the runoff from park lands.

The park is the largest example of a piedmont forest ecosystem in the national park system, and is a sanctuary for native plants and animals in the midst of a rapidly developing region. Prince William Forest Park contains several rare plant communities—a seepage swamp, remote stands of eastern hemlock, and several populations of the small-whorled pogonia (*Isotria medeoloides*), a federally threatened species. Because of the park’s location between two physiographic provinces, several of the plant species found in PRWI are at the edges of their natural ranges.

Natural Resource Condition Assessment

Assessment of natural resource condition within Prince William Forest Park was carried out using the Inventory and Monitoring Division’s National Park Service 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 Prince William Forest Park were in ***moderate condition*** based on very degraded air quality; moderate biological integrity; and good water resources and landscape dynamics.

Recommendations and Data Gaps

Degraded air quality is a problem throughout the eastern United States, and while the causes of degraded air quality largely are 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 climate change could increase ozone concentrations and change the amount of particle pollution.

Water resources within the park were in good condition overall, with 76% attainment of reference conditions. The majority of water resource indicators were in a very good condition. A higher overall attainment was, however, offset by very degraded conditions for total phosphorus and degraded conditions for the stream Physical Habitat Index. 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 identifying nutrient 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 on 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 continue to 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 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.

Landscape dynamics were in good condition overall, with 65% attainment of reference conditions. A higher overall attainment was offset predominantly by very degraded conditions for impervious surfaces and road density – largely in the buffer outside the park. Forest interior area and forest cover were both in moderate to very good condition.

Acknowledgements

Geoff Sanders, John Paul Schmit, Jim Pieper, Marian Norris, and NPS National Capital Region Inventory & Monitoring, 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, Nicole Lehmer, Jamie Testa, and Catherine Ward at the Integration and Application Network for assistance with document review.

NRCA Background Information

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

NRCAs 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:

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

- 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 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.

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

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

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

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

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

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.

Important NRCA success factors

Obtaining good input from the park and other NPS subjective matter experts in the project timeline.

Using study frameworks that accomodate 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.

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

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

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*

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

[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.

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

[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

Prince William Forest Park (PRWI) is located approximately 35 miles south of Washington, D.C. in Prince William County, Virginia. Totaling nearly 15,000 acres, the park is the largest protected area in the region and is the third largest national park in the state of Virginia. It is also the largest example of a Piedmont forest in the national park system, serving as a sanctuary for a diversity of plants and animals, which are threatened by increasing development in Northern Virginia.

Figure 2-1 Scenic drive at Prince William Forest Park. Photo: National Park Service.

The park is at a transition between the rolling Piedmont Plateau and the low-lying Atlantic Coastal Plain. These two zones meet within the park at the "fall line," where land level drops from the harder rocks of the Piedmont to the softer sedimentary rocks of the coastal plain, resulting in unique geological features such as waterfalls and rock outcroppings. Parts of the Quantico Creek watershed are also within the park, contributing to the beautiful natural landscape that the park preserves.

Figure 2-2 A cabin camp within Prince William Forest Park. Photo: National Park Service.

The forest canopy shelters the remains of a fascinating history: evidence of Native American hunting camps; portions of the Washington-Rochambeau Revolutionary Route National Historic Trail—the wagon road that General George Washington's Army traveled to the battle of Yorktown; remnants of a "poor house" that aided the poor and sickly from 1795-1925; over forty-five cemeteries and structural ruins of the white and African American families who farmed the land for hundreds of years; and miners digging for "fool's gold" at the Cabin Branch Pyrite Mine (NPS 2009). Evidence of habitation of park land dates back to 4500 B.C. and Native American villages were likely established in the area between A.D. 700 and 900. Though the land is sub-marginal for agriculture, farming has occurred in the area since A.D. 1100 with corn, wheat, cotton, and tobacco crops all grown at various times (NPS 2005).

Farming continued up until 1933, at which point the involvement of two government agencies set the stage for the creation of the modern park, then known as the Chopawamsic Recreational Demonstration Area (RDA). After its designation as an RDA, Civilian Conservation Corps (CCC) workers were assigned to the area to develop facilities that would permit recreational use, particularly organized group camping. The job of the CCC was to build five rustic cabin camps within the 11,000-acre area, thus providing the urban, social, and welfare organizations of Virginia, Maryland, and Washington, D.C. a place to experience outdoor camp life. By the time the recreation demonstration area was transferred to the Department of the Interior in 1936, most recreational developments were in place, and the lands were beginning to show signs of restoration through natural succession (NPS 2005). Prince William Forest Park was created as part of President Franklin D. Roosevelt's New Deal—a nationwide effort aimed at fighting the effects of the Great Depression. It was built as a new type of park, where low-income, inner-city children and families could escape the city and experience nature.

From 1942-1945, America's first centralized intelligence agency and forerunner to the CIA, the Office of Strategic Services (OSS), converted the Chopawamsic area into secret training zones. The OSS operated two training schools in the park for spies, teaching recruits to gather intelligence, decipher codes, and interpret covert radio transmissions. Many physical remnants exist from this time period, including the modified cabin camps; bunkers; and shooting, mortar, and demolition ranges (NPS 2013c). Today, four of the camps are listed on the National Register of Historic Places, along with the Cabin Branch Pyrite Mine. All of the camps' original 157 structures are used by groups and individuals for recreational or educational purposes (NPS 2005). Additionally, a new National Register nomination in 2010 identified the entire park north and west of 619 (excluding Chopawamsic) as a historic district with national themes.

Today, PRWI continues to be administered to preserve and interpret its significant natural and historic resources. The park is the largest example of a piedmont forest ecosystem in the national park system and is a sanctuary for native plants and animals in the midst of a rapidly developing region. Several species reach the limit of their natural range within the park, indicating that the park acts as a transitional zone between northern and southern climates, and between eastern and western physiographic provinces. The park is also home to numerous rare, threatened, and endangered species.

Park enabling legislation

Several laws and documents guide natural resource management for PRWI. Two examples are the National Park Service Organic Act of 1916 ("Organic Act," Ch. 1, 39 Stat 535) and Public Law 594 on the use of Recreation Demonstration Areas (1942). Other guidance documents include the NPS Management Policies (NPS 2006).

The Organic Act that established the National Park Service (NPS) on August 25, 1916 provides the primary mandate NPS has for natural resource protection within all national parks. 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."*

Prince William Forest Park is one of the parks that comprise the NPS National Capital Region. The park's legislative history is complex and sometimes confusing (NPS 2009). Unlike many units of the National Park System, Prince William Forest (Chopawamsic) has no single comprehensive enabling legislation. Rather, the establishment and operation of the park is influenced by numerous pieces of federal legislation and Executive Orders.

Emerging as a Recreational Demonstration Area (RDA) out of New Deal legislation in the 1930s, Prince William Forest (Chopawamsic) was transferred to the National Park Service by Executive Order 7496, dated November 14, 1936. Public Law 763, dated August 13, 1940, provided for the "operation of the recreational facilities within the Chopawamsic recreational demonstration project, near Dumfries, Virginia, by the Secretary of the Interior through the National Park Service." Public Law 2852 dated June 6, 1942 required that all RDA project areas be maintained for "public park recreational and conservation purposes." In 1948, Public Law 736 authorized "the transfer of certain federal lands within the Chopawamsic Park to the Secretary of the Navy, the addition of lands surplus to the Department of the Army to this park, the acquisition of additional lands needed to round out the boundaries of this park, [and] to change the name of said park to Prince William Forest Park." In addition, the Secretary of the Navy would guarantee the potability and undamaged source of water of the Quantico Creek east of Virginia Route 619. In 2002, Legislation HR 4546, Sec. 2835 was signed, authorizing the land exchange outlined in a 1998 Memorandum of Understanding between the park and Marine Corps Base-Quantico. The park regained land within the Chopawamsic watershed in the land exchange (NPS 2009).

Geographic setting

Park description

Prince William Forest Park (PRWI) is located in the southeast corner of Prince William County, Virginia and the northern edge of neighboring Stafford County, Virginia (Figure 2-3). VA Route 234 borders the park to the north, VA Route 619 to the south and west, and Interstate 95 (I-95) to the east. PRWI is approximately 56 km (35 mi) south of Washington, DC and 22 miles north of Fredericksburg, Virginia, near Dumfries and Triangle, Virginia.

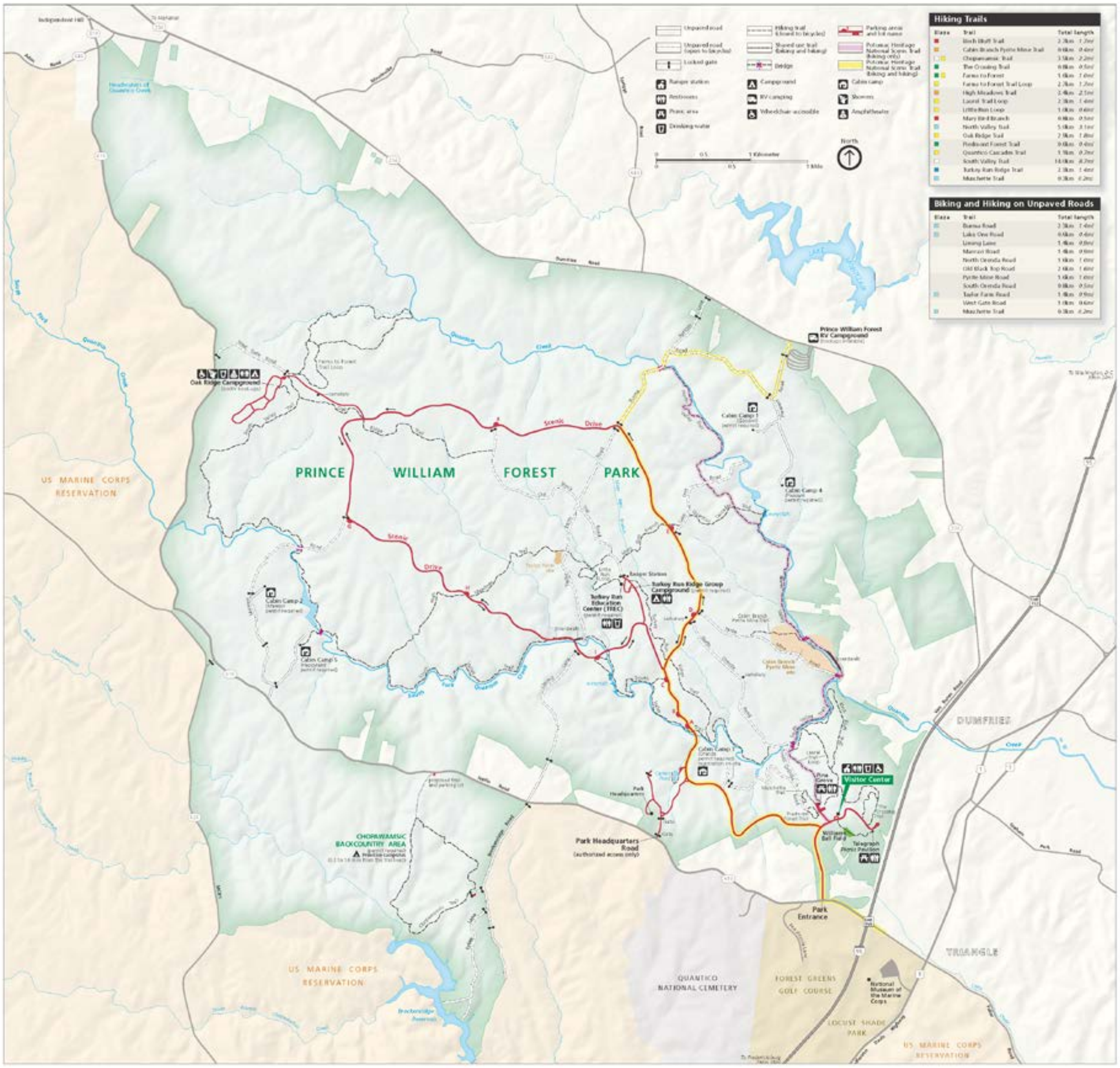

Figure 2-3 Prince William Forest Park Map. Source: National Park Service.

The park covers the Piedmont and the Coastal Plain physiographic provinces and straddles the southern and northern climates—making it a transition zone that supports many species to the outer limits of their ranges (Figure 2-4). The western two-thirds of the park are in the Piedmont province, while the eastern third is located in the Atlantic Coastal Plain. Marked differences in terrain combined with location in the transition zone between a northern and southern climate lead to ecosystem variations throughout the park.

Figure 2-4 Location of PRWI in Virginia, including physiographic provinces.

The “fall line,” or “fall zone” marks a transitional zone where the softer, less consolidated sedimentary rocks of the Atlantic Coastal Plain to the east intersect the harder, more resistant metamorphic rocks to the west, forming an area of ridges, waterfalls, and rapids. This zone covers more than 27km (17mi) of the Potomac River from Little Falls Dam, near Washington, DC, west to Seneca, Maryland.

The topography within the park consists of rolling hills and narrow ridge tops separated by steep-sloped valleys and ravines. The ridge tops are composed of resistant late Precambrian to early Paleozoic metamorphic rocks. Separating the ridge tips are areas where less resistant material, such as unconsolidated deposits, were easily eroded. Elevation in the park ranges from about 50 feet above sea level where Quantico Creek exits the park, to a 394-foot hilltop in the northwest portion of the park (Thornberry-Erlich 2009).

<u>Land use</u>

Prince William Forest Park lies within the Potomac River watershed, a tributary of the Chesapeake Bay (Figure 2-5). Land cover in the Potomac River watershed is about 58% forest, 32% agriculture, 5% water and wetlands, and 5% developed (ICPRB 2012) (Figure 2-6). 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).

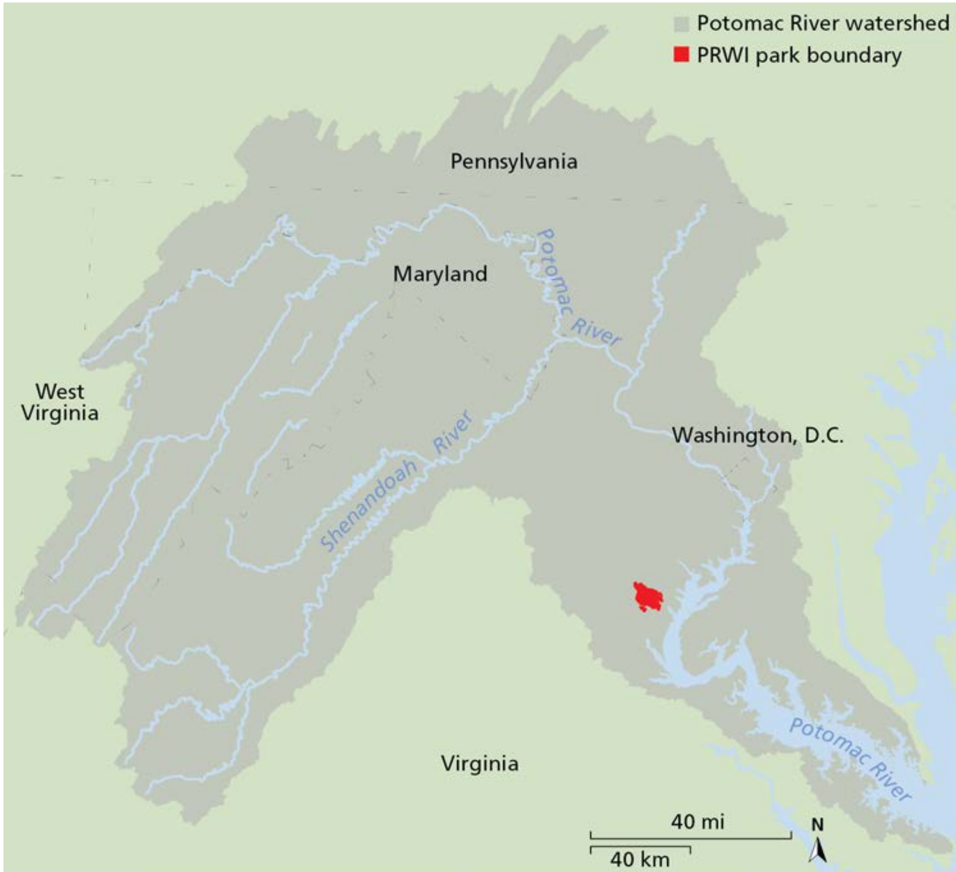

Figure 2-5 The Potomac River watershed.

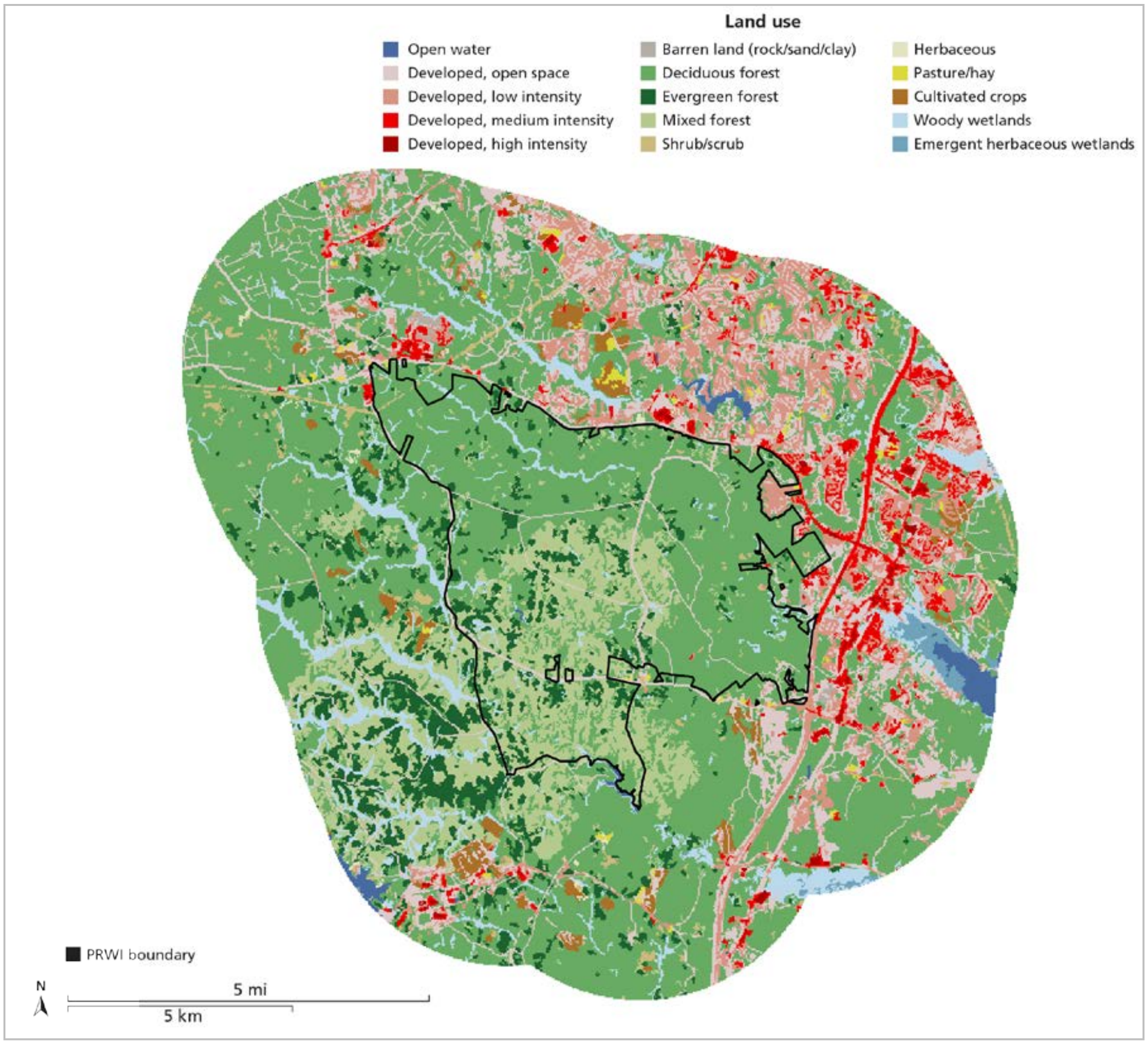

Figure 2-6 Adjacent land use within a 5x area buffer surrounding PRWI in 2011 (Jin et al. 2013; NPS 2011b).

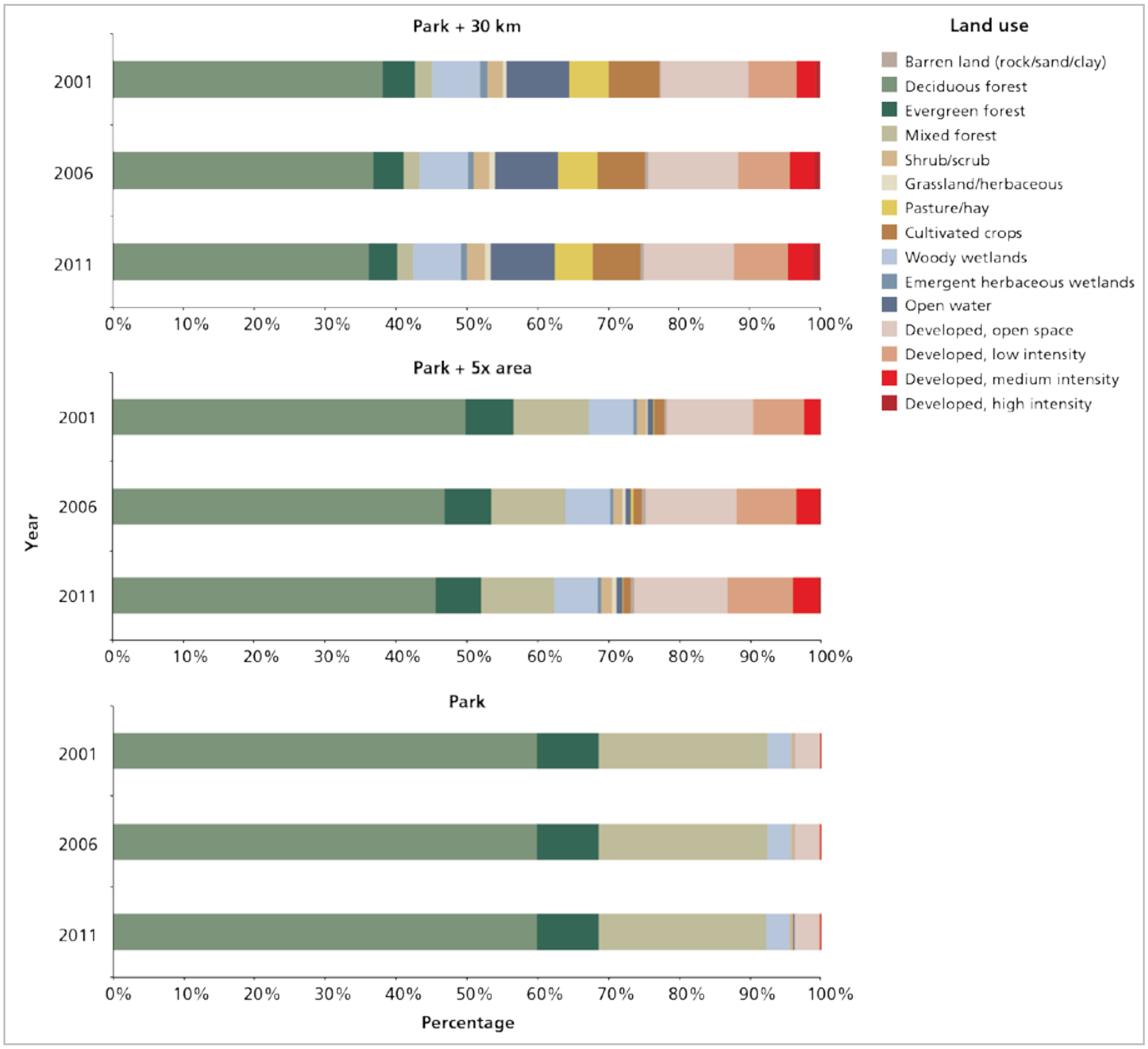

Figure 2-7 Changes in land use from 2001 to 2011 at three scales surrounding PRWI (Park, Park + 5x area, Park + 30km) (Jin et al. 2013; NPS 2011b).

Lands adjacent to the park are equally divided between private and public lands (Figure 2-7). Along the southern park boundary are U.S. Marine Corps Base-Quantico, Quantico National Cemetery, and private property along VA route 619 (NPS 1995). The park's northern boundary consists of lands predominately in private ownership, zoned as either residential or business (NPS 1995).

Two county parks, Locust Shade and Helwig, are located southeast and northwest of PRWI, respectively. These parks were developed for recreational purposes, and include an extensive trail system throughout the area. In addition, Locust Shade has a reservoir and marina for water-related recreation, as well as a driving range and miniature golf course (NPS 1995). Anne Moncure Wall Park, on the north side of Route 234 in Montclair, VA, is developed with sports fields, athletic courts, a playground and parking. Additionally, Prince William County is developing Fuller Heights Park in Triangle, VA. This park will include four lighted little league baseball fields, a multi-purpose field, as well as a trail, tot lot, and parking.

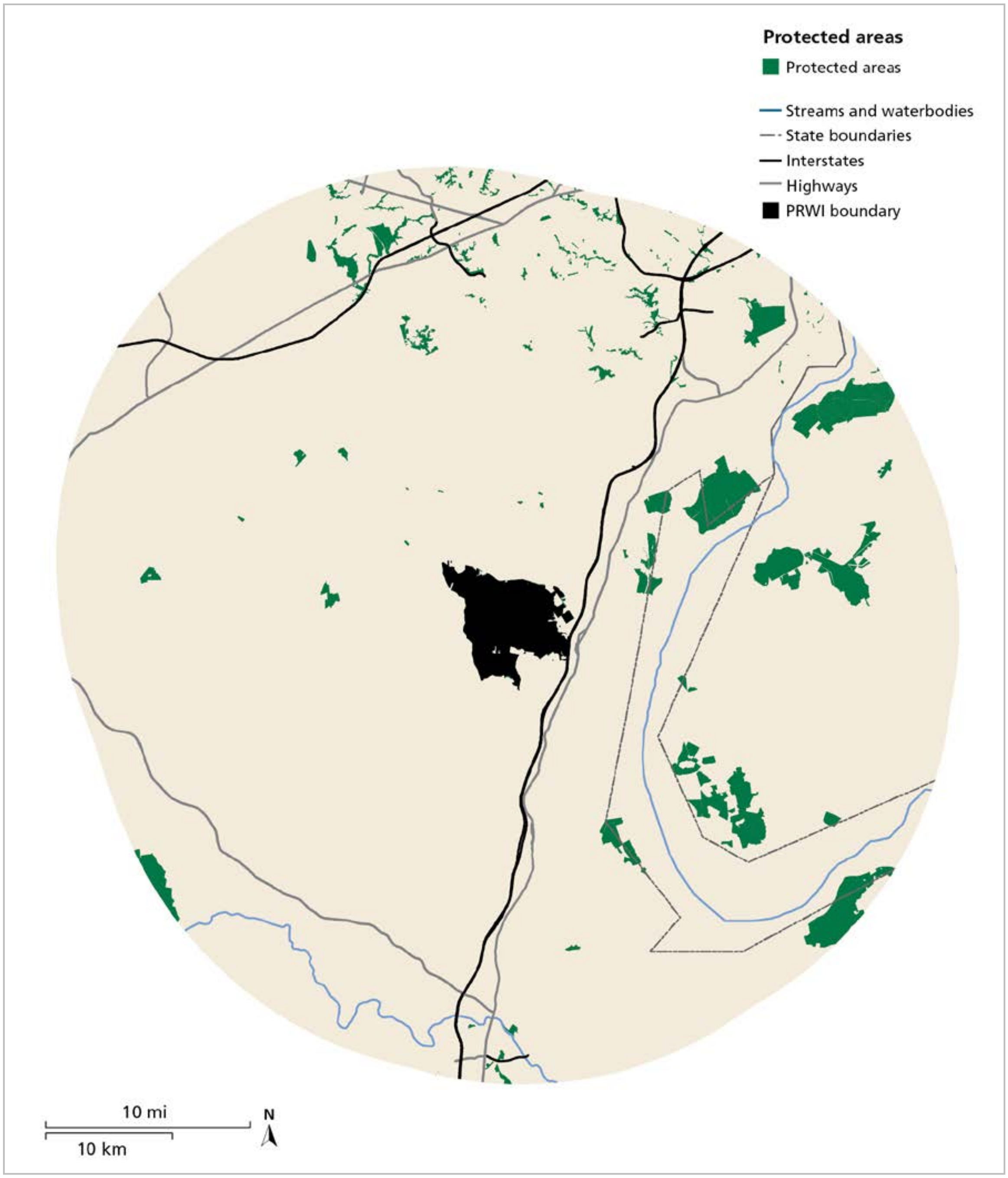

Figure 2-8 Protected areas around PRWI.

Population

Approximately 6.11 million people live in the Potomac River watershed (Figure 2-5). Almost three-quarters of the basin's population, approximately 5.36 million of these residents, live within the Washington, DC metropolitan area (Figure 2-8) (U.S. Census Bureau 2013a).

Prince William County's population has grown considerably in recent years, increasing 30% between 2000 (population of 280,813) and 2010 (population of 402,002) in comparison to a 13% increase in population statewide, making it the second-fastest-growing county, and third largest locality in Virginia (U.S. Census Bureau 2013) (Figure 2-10). Neighboring Stafford County has also experienced considerable population growth, with population increasing 39.4% between 2000 (population of 92,446) and 2010 (population of 128,961) (U.S. Census Bureau 2013).

The entrance to PRWI off of Interstate 95 at Route 619 is adjacent to U.S. Marine Corps Base-Quantico. The base supports a community of approximately 14,000 civilian and military personnel (NPS 2009).

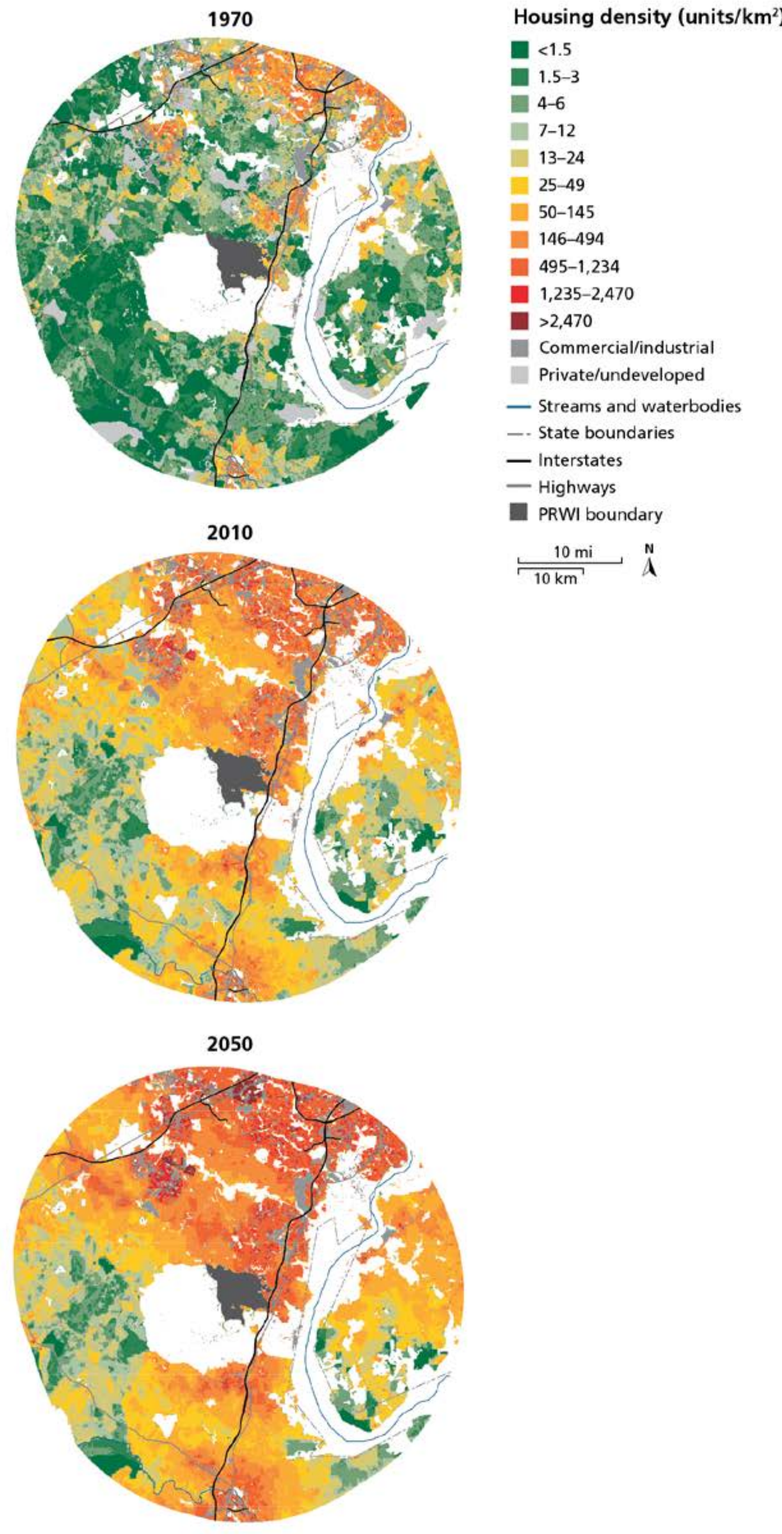

Figure 2-9 Housing density within a 30-km area surrounding PRWI in 1970, 2010, and 2050 (NPS 2011b, NPS 2014, U.S. Census Bureau 2011).

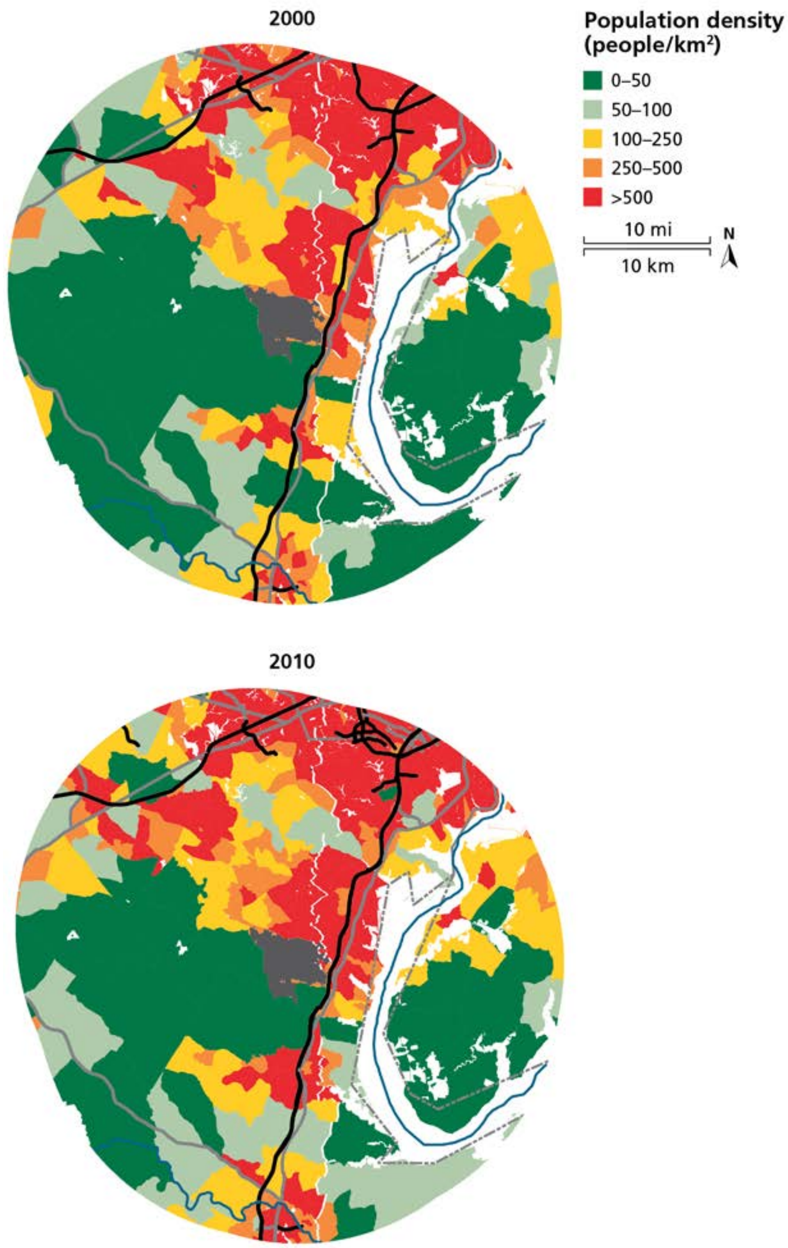

Figure 2-6 Population density within a 30 km buffer around park in 2000 and 2010 (NPS 2011b, U.S. Census Bureau 2011).

Climate

Prince William Forest Park and the surrounding areas experience all four seasons with an annual average temperature of 14.6°C (58.2°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 25.4°C (77.7°F) and occasional heavy thunderstorms. Heat waves during the summer are often accompanied by high humidity levels and corresponding ozone pollution (Davey et al. 2006). Winters are cold with an average temperature of 3.4°C (38.2°F) (National Weather Service 2013a). The average annual precipitation at PRWI is 1 meter (39.74 inches) (National Weather

Service 2013b), with an annual average total snowfall of 0.4 meters (15.4 inches) (National Weather Service 2013c). Precipitation is a common occurrence throughout the year but is generally more common in the summer (Davey et al. 2006).

There are 69 weather stations within 20km (12 mi) of PRWI, 44 of which have been identified as active (Davey et al. 2006). Recently, a weather station was added to the maintenance office at PRWI, but that data was not used within the current analysis (P. Petersen, personal communication).

Visitation statistics

In the past 5 years (2008-2012), recreation visits to PRWI have averaged 352,021 people per year (Figure 2-11) (NPS 2013b). Visitation to the park is highest from May to October, reflecting warmer spring weather, and the popularity of camping, hiking, and viewing fall foliage. June is the busiest month, followed by July and August. Visitation at the park is very dependent on the weather and fluctuates widely with day-to-day weather patterns (NPS 2009).

Park recreational opportunities include camping, fishing, hiking, biking, exercise, picnicking, and nature study/observation. The park has 59.5 km (37 miles) of trails, 40 km (25 miles) of streams, five ponds and lakes, four picnic areas, one 100-site family tent/RV campground, a group campground with seven sites, a concessionaire operated RV Campground with 76 sites, a designated backcountry area with six campsites, and five cabin camps with a total capacity of 890 persons (NPS 2009).

Most visitors to Prince William Forest Park are day visitors (Lawson et al. 2006). The most popular activities are hiking/walking, watching wildlife, driving for pleasure, picnicking, and biking. Hiking/walking, biking, and tent camping are the three most common primary activities (Lawson et al. 2006).

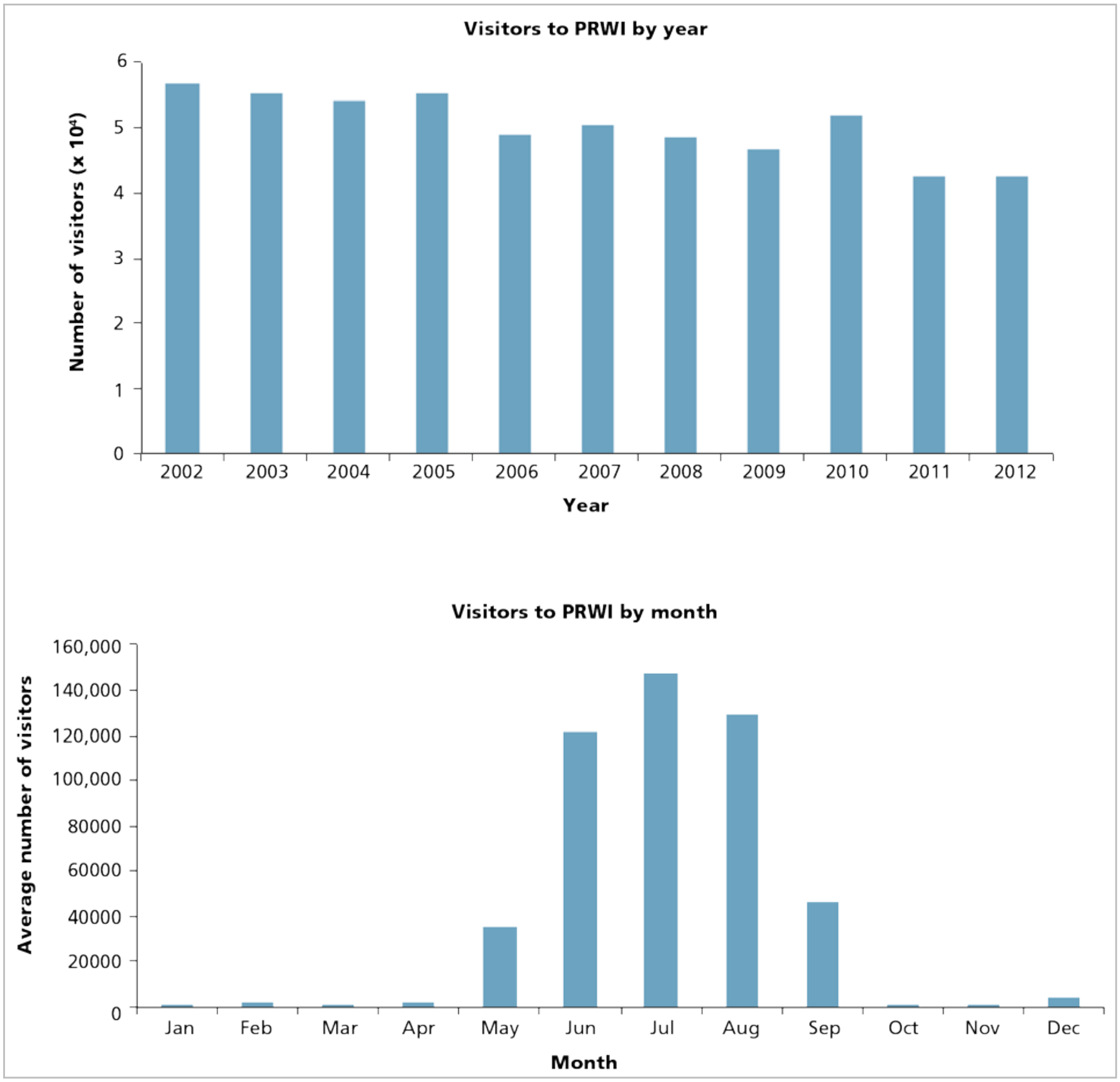

Figure 2-7 Visitors to PRWI over the past decade by year and by month (NPS 2013g).

Natural Resources

Prince William Forest Park preserves approximately 15,000 acres of Piedmont forest covering a major portion of the Quantico Creek watershed. The park represents one of the largest parcels of undeveloped land in the area and is the third largest unit of the National Park System in Virginia. That, combined with the fact that it is the largest example of a Piedmont forest ecosystem in the national park system, makes it a significant natural resource.

Geology

Prince William Forest Park straddles the fall zone, the boundary between the Coastal Plain and Piedmont physiographic provinces. This line separates relatively hard, resistant rocks to the west from soft, easily eroded rocks to the east (Thornberry-Ehrlich 2009). About one-third of the park lies in the Coastal Plain, with differing geological origins and flatter relief than the Piedmont. The Coastal Plain consists of stratified marine sediments (sand, silt, clay, and gravel), while the older Piedmont has largely granite, gneiss, hornblende gneiss, and mica schist (NPS 2009) (Figure 2-12).

The rocks in east-central Virginia reflect the tectonic forces that formed the Appalachian Mountains. Late Precambrian to early Paleozoic crystalline rocks and younger sandstone, shale, siltstone, carbonate rocks, and quartzite underlie the landscape (Thornberry-Ehrlich 2009). The region was compressed during three separate tectonic events: the Taconic, Acadian, and Alleghanian orogenies (mountain building events). The faulted and folded metamorphic gneiss underlying Prince William Forest Park records this regional deformation.

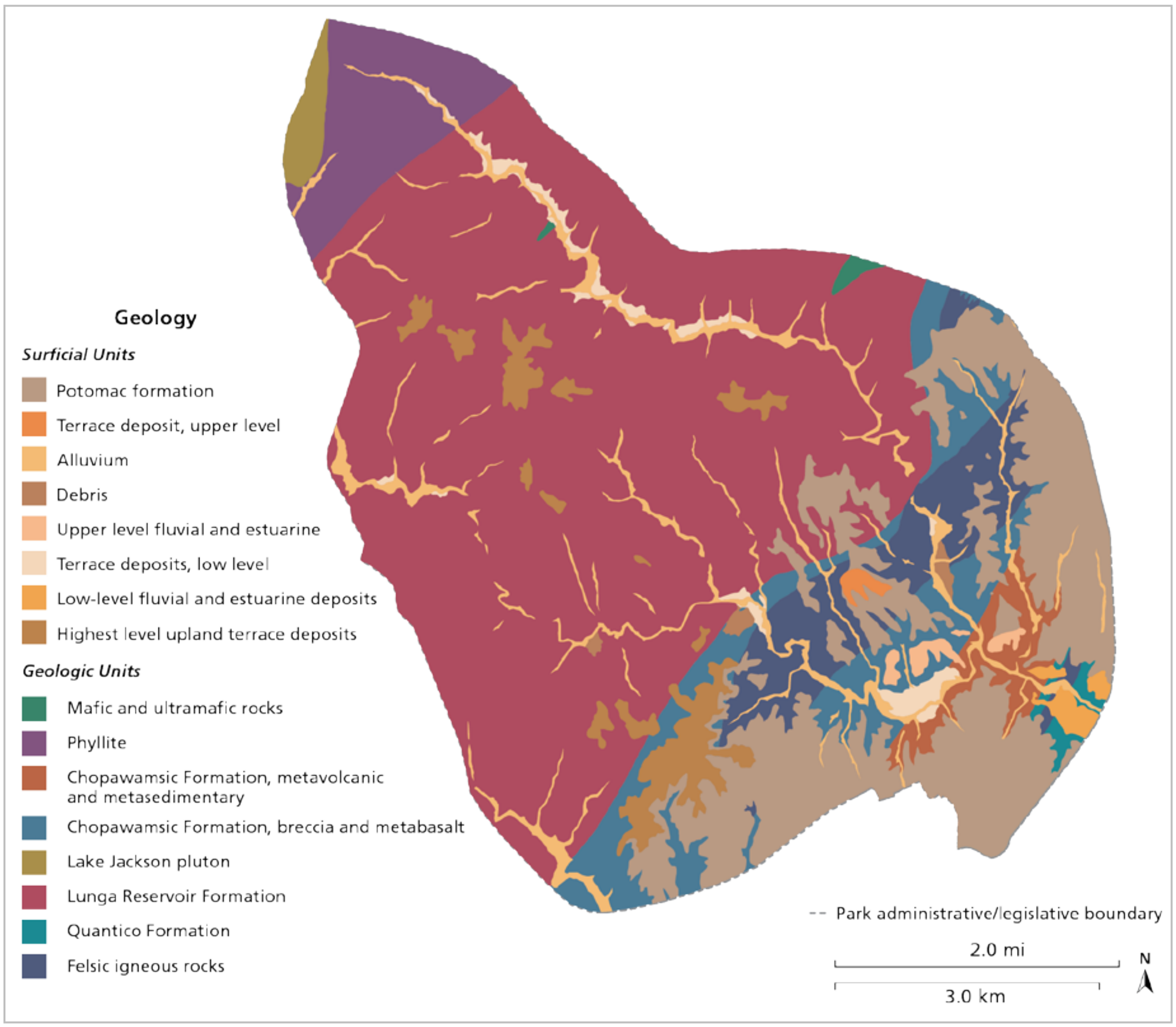

Figure 2-8 Geology of PRWI (Thornberry-Ehrlich 2006).

The bedrock is overlain by sediments of the Coastal Plain that are Cretaceous, about 150 mega annum (million years; Ma), to Pleistocene, (~10 Ma) in age. The forest and level ground seen along the scenic loop road show that the unconsolidated sediments of the Coastal Plain once extended far west of the present limit (Southworth and Denenny 2006).

The dominant rock in the park is a sedimentary mix commonly known as the Lunga Reservoir Formation (Pavlides 1980). The diamictite resembles a granitic rock with xenoliths, as it contains a mixture of pebbles and cobbles of other rock types (Southworth and Denenny 2006). The Lunga Reservoir Formation is exposed along the South Fork Quantico Creek (Southworth and Denenny 2006).

Several outcrops of folded and faulted metamorphic rocks are scattered throughout the park (NPS 1995; Thornberry-Ehrlich 2009). These rocks are indicative of the fall line, a geologic feature where streams may form falls or rapids as the physiographic provinces meet. Quantico Falls, along the main stem of Quantico Creek, is a classic example of a fall-line feature (Thornberry-Ehrlich 2009).

The park also has large mineral deposits, primarily iron pyrite and associated minerals. The largest concentration of pyrite is found at the confluence of Quantico Creek with South Branch Quantico Creek. This deposit is the largest of its kind in Prince William County and one of the largest in the United States (NPS 1995). Pyrite was mined from 1889 to 1919 at the Cabin Branch mine along the southwest side of Quantico Creek. The pyrite was mined for sulfur as an ingredient in gunpowder, especially during World War I (Southworth and Denenny 2006).

Soils

In 2005, the Soil Resources Inventory (SRI) Program of the NPS Geologic Resources Division worked with the Natural Resources Conservation Service (NRCS) to complete a soil survey of PRWI.

Soils within PRWI are generally sandy, poor in nutrients, and easily disturbed. The rolling terrain and poor quality soils combine to create severe erosion problems (Thornberry-Ehrlich 2009). Tobacco farming and poor farming practices within the region likely contributed to the long-term depletion of nutrients from which soils have yet to recover.

The park contains a total of 22 soil types (NPS 1995) (Figure 2-13). The ridges of the Piedmont are capped with thin mantels of coastal plain or other alluvial sediments in many places. Fairly broad flood plains have developed along the larger streams. The Coastal Plain is underlain by stratified marine sediments of sand, silt, clay, and gravel (Figure 2-14). The lowland soils are strongly acidic and of low natural fertility. Soils within PRWI are generally more acidic than in other parks within the region. The soils have low permeability and are generally well-drained, but may experience seasonal wetness. The slopes and gently sloping ridges are occupied by more porous soils that are more easily eroded. They also are strongly acidic and of low fertility. Unconsolidated soil types are generally located in the Coastal Plain, Coastal Plain caps, flood plains, and flood plain and stream terraces. The erosion potential in these areas ranges from moderate to high.

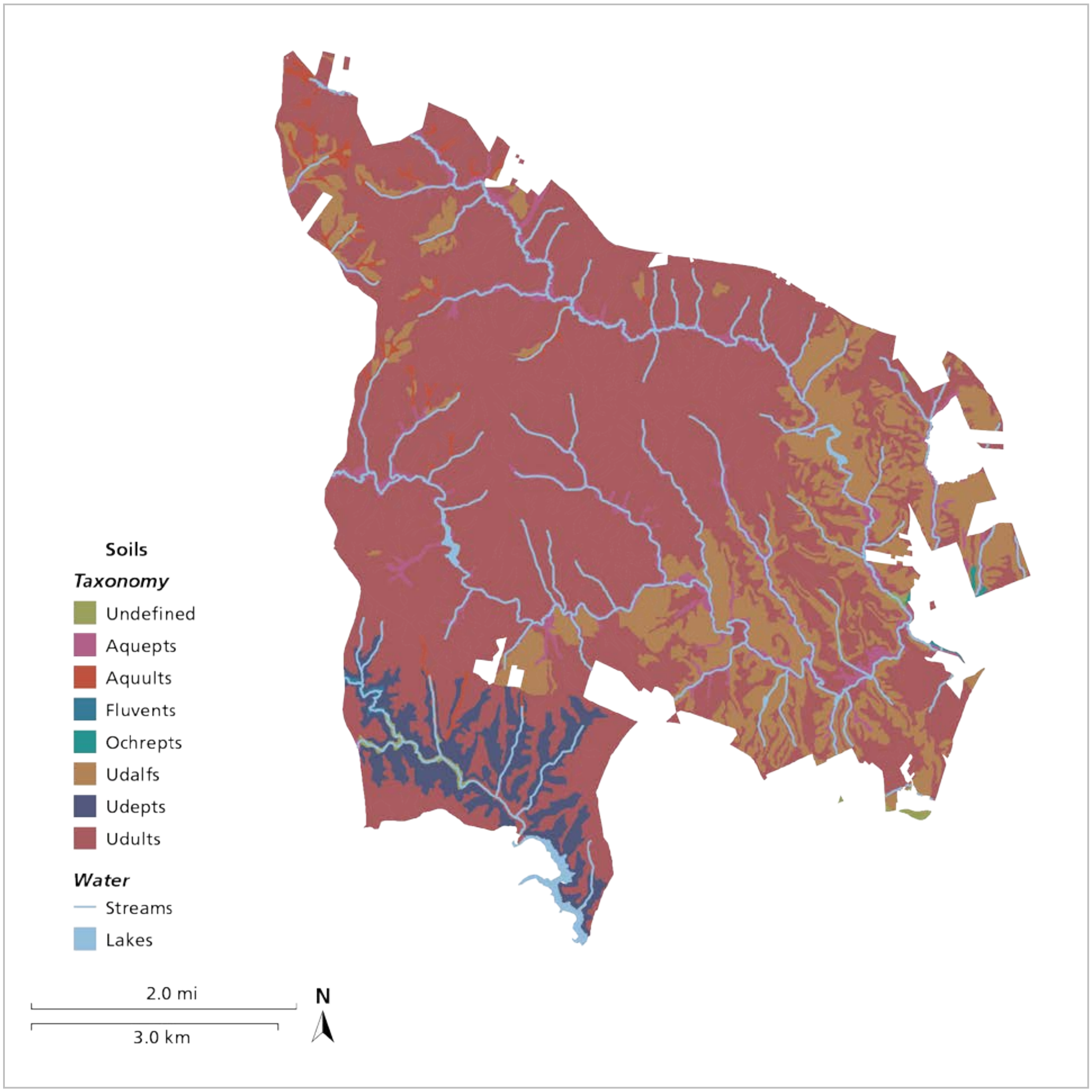

Figure 2-9 Soil taxonomy of PRWI.

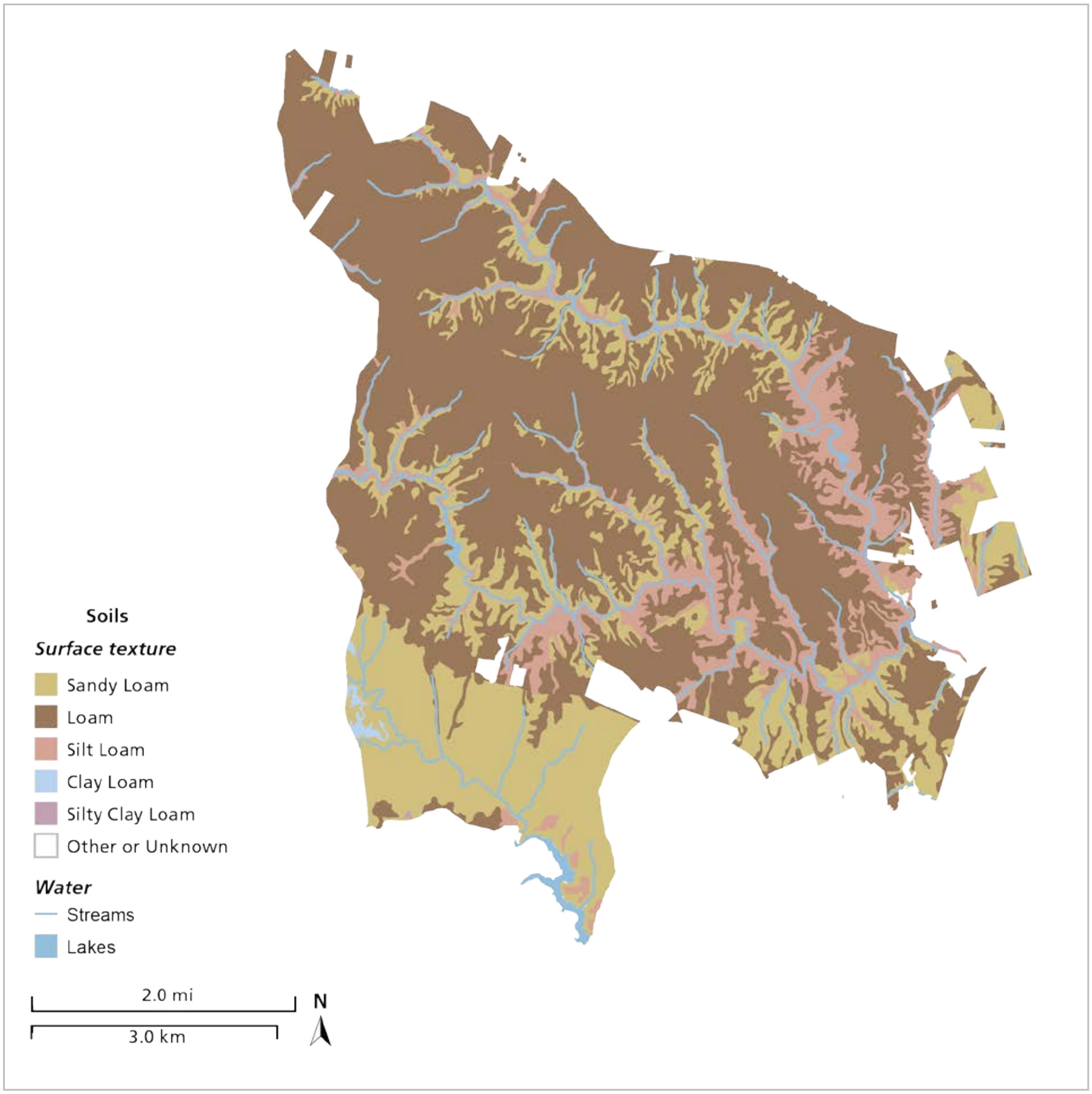

Figure 2-10 Soil surface texture.

Watershed/Waterways

Prince William Forest Park is located within the Lower Potomac River drainage basin (Figure 2-5). After the Susquehanna River, the Potomac is the second largest tributary to the Chesapeake Bay, the largest estuary in the United States. The bay watershed is 64,000 miles^2; extends into six states—Virginia, Maryland, Delaware, Pennsylvania, and New York; and is home to more than 17 million people (Chesapeake Bay Program 2013).

The Potomac River watershed drains 37,995 km^2 (14,670 mi^2) across Maryland, Virginia, West Virginia, Pennsylvania, and the District of Columbia (ICPRB 2012) (Figure 2-15). The major tributaries to the Potomac River are the Shenandoah River, South Branch, North Branch, Cacapon

River, Conococheague Creek, Monocacy River, and Anacostia River (Allen and Flack 2001; ICPRB 2012). Two stream systems run through the park, Quantico Creek and Chopawamsic Creek, and eventually empty into the Potomac River.

Quantico Creek is comprised of two streams: Quantico Creek proper and South Branch Quantico Creek. The 30 square-mile watershed of Quantico Creek is largely forested and protected as part of Prince William Forest Park and Marine Corps Base-Quantico (Schmit 2011) (Figure 2-15). The headwaters of South Fork Quantico Creek, 15 square kilometers (9 square miles), lie within Marine Corps Base-Quantico, and 6.4 km (4 miles) (downstream of PRWI) are in private ownership. The remaining 27 square kilometers (17 square miles) of watershed lie within the park (Pieper 2012). South Fork Quantico Creek joins Quantico Creek proper near the eastern boundary of the park. These streams receive more than 90% of the runoff from park lands. The natural courses of both Quantico Creek and South Fork Quantico Creek have been altered in the park to create recreational lakes for campers (NPS 1995). A series of small dams trap sediments from storm-water runoff, and these dams are periodically dredged. An intricate network of smaller streams drains the rest of the park.

Currently, eight sites are monitored in the park on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, total nitrate, total phosphorus, width, depth, flow, and discharge (Pieper 2012). Portions of the Quantico Creek watershed protected within the park are some of the most unspoiled in the Chesapeake Bay region, providing an important source of baseline condition data for environmental monitoring (NPS 2013c).

PRWI’s annual water quality monitoring program includes testing for *Escherichia coli* (*E. coli*) within recreational lakes, benthic macroinvertebrates, and water chemistry. *E. coli* is monitored as a requirement by the State Water Control Board for protecting public health at recreation lakes used for swimming.

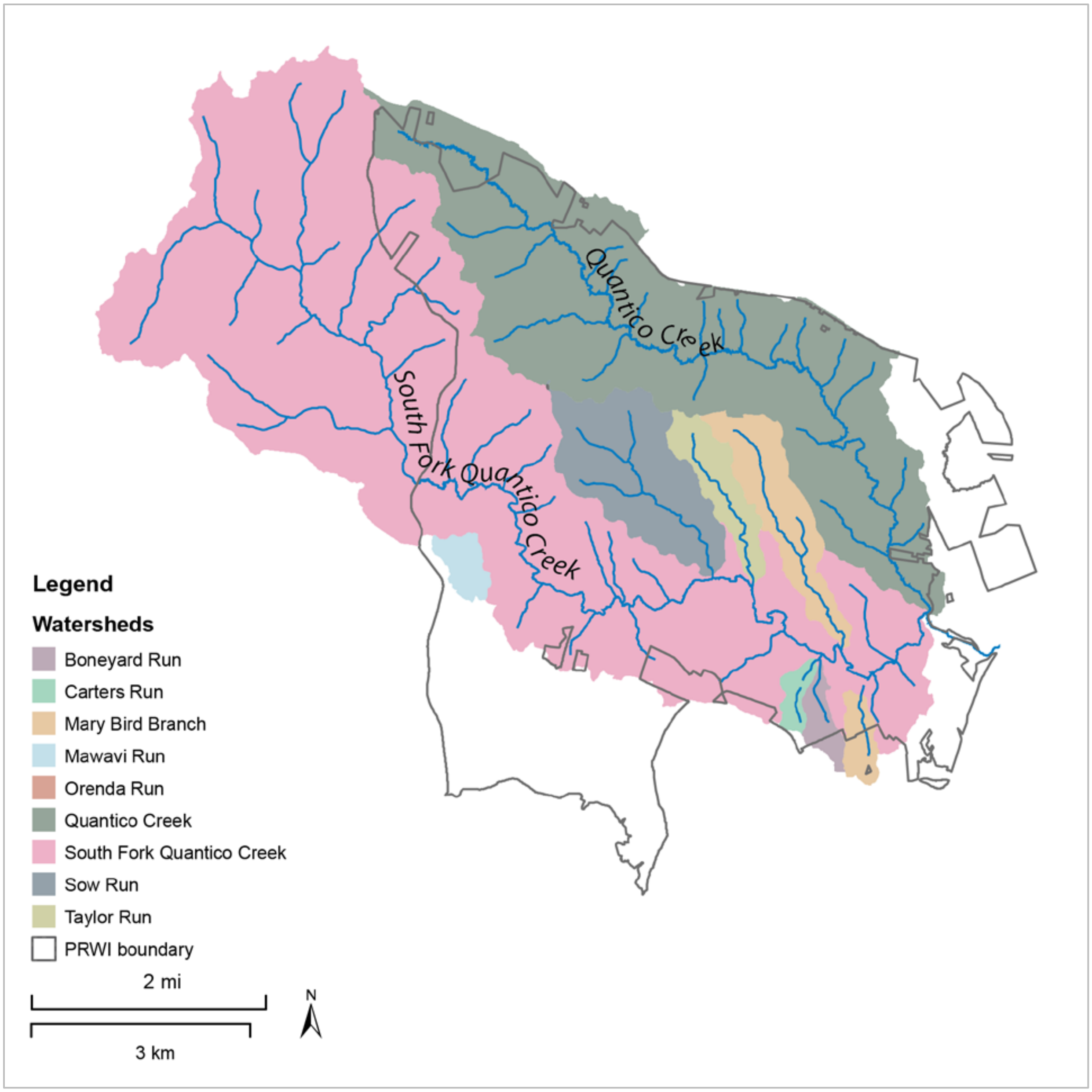

Figure 2-11 Quantico Creek watershed.

Wetlands

Wetlands are interspersed with forest environments in PRWI. Wetlands 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.

The park contains several vernal pools that serve as vital breeding areas for many species. These pools are underlain by a relatively impermeable geologic substrate, trapping seasonal precipitation.

In the north central portion of the park is an oligotrophic saturated forest, or "seepage swamp." These areas are generally found at stream heads or alongside streams. Seepage swamps support unusual vegetation that occur in no other habitat. This intact seepage wetland and its underlying aquifer help maintain water quality in Quantico Creek's adjacent streams (Petersen, no date given).

Flora

Prince William Forest Park contains several rare plant communities—a seepage swamp, remote stands of eastern hemlock, and several populations of the small-whorled pogonia (*Isotria medeoloides*), a federally threatened species. Because of its location between two physiographic provinces, several of the plant species found in PRWI are at the edge of their natural range.

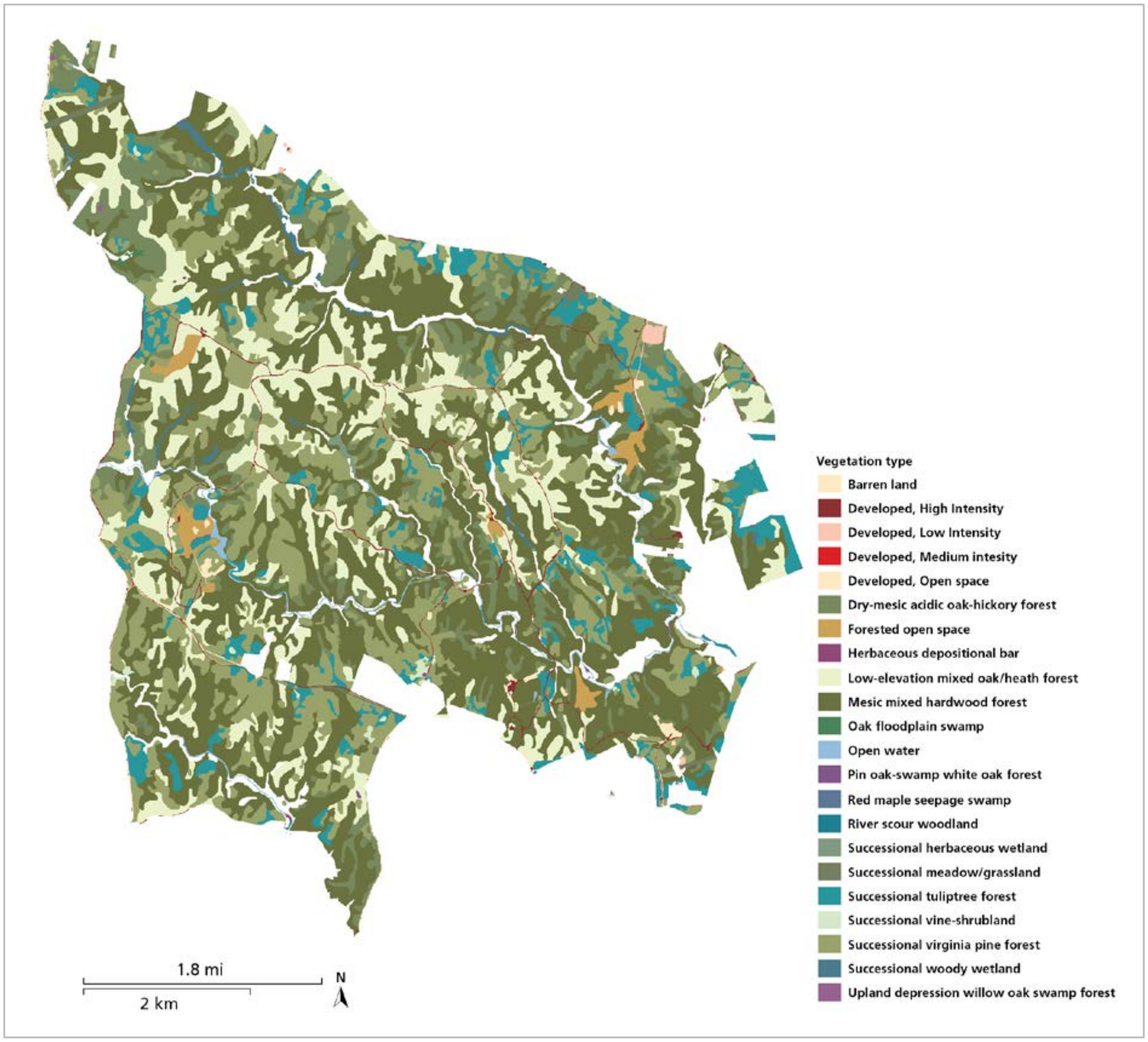

Figure 2-12 Vegetation map of PRWI.

With the exception of the five cabin camps, plus administrative and campground areas, the park is completely forested (Figure 2-16). The park was originally assembled from marginal and abandoned farmland and today younger successional areas. Based on monitoring projects, the forests within

Prince William Forest Park are relatively young. In comparison to other network parks, there is a higher density of smaller trees in PRWI, while larger trees have a lower density. This is likely due to the forests in PRWI being on average younger than the forests in other capital region parks (Schmit et al. 2012).

At least two distinct types of forest ecosystems are present in the upland areas of the park. These areas are controlled by their underlying geology. The ridges and slopes support a mixed oak forest, whereas the lower slopes support a mesic hardwood forest above the floodplain of the local waterways. Beeches (*Fagus* sp.), which are indicative of an undisturbed interior environment, are present in the park, as are a variety of rare species, including the butternut (*Juglans cinerea*), big tooth aspen (*Populus grandidentata*), black walnut (*Juglans nigra*), swamp white oak (*Quercus bicolor*), and cottonwood (*Populus deltoides*). The floodplain environments in the park support American beech (*Fagus grandifolia*), sweet gum (*Liquidambar styraciflua*), box elder (*Acer negundo*), and sycamore trees (*Platanus occidentalis*) (NPS 1995). The National Capital Region Network Inventory & Monitoring program's forest vegetation monitoring has documented 43 species of trees (including three types of oak hybrids), 19 species of shrubs, and 11 vines within PRWI.

Figure 2-13 Forest cover in Prince William Forest Park. Photo: National Park Service.

Figure 2-14 NCRN Inventory and Monitoring Network forest vegetation monitoring plot within Prince William Forest Park. Photo: National Park Service.

Some of the most common trees within the park are those that dominate in early succession, including Virginia pine (*Pinus virginiana*), tulip poplar (*Liriodendron tulipifera*), and sassafras (*Sassafras albidum*).

Other common trees include white oak (*Quercus alba*), scarlet oak (*Quercus coccinea*), American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), pignut hickory (*Carya glabra*), and black oak (*Quercus velutina*). All of these species are shade tolerant and dominate later in succession (Schmit et al. 2012).

Understory trees present within the park include American holly (*Ilex opaca*), flowering dogwood (*Cornus florida*), pawpaw (*Asimina triloba*), and American hornbeam (*Carpinus caroliniana*) (Schmit 2012). The shrub community in PRWI is dominated by mountain laurel (*Kalmia latifolia*). This species flourishes in response to fire and in areas where there are openings within the forest canopy. In areas with closed canopy and no fire, seedling production is less prolific (Schmit et al. 2012).

<u>Non-native plants</u>
Invasive exotic plant species 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. Since many of the native species present within PRWI are on the outer limits of their range, they can be particularly susceptible to changes in species composition, abundance, and diversity brought on by non-native species introduction (NPS 2011). A vegetation survey conducted in 2004 found some areas of significant incursion by exotic invasive species. Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), and mile-a-minute (*Persicaria perfoliata*) are widespread. Chinese wisteria (*Wisteria sinensis*) and Japanese knotweed (*Polygonum cuspidatum*) are more limited but still serious threats (Bradley et al. 2004).

Wisteria (*Wisteria* spp.), a non-native ornamental vine, is found on many old home sites in PRWI. In these areas, native vegetation has been disturbed by soil compaction and trampling, and replaced with invasive and/or exotic species (NPS 2011).

Fauna
Prince William Forest Park provides critical habitat for wildlife populations within the greater Washington, D.C. metropolitan area. Because of its location covering two physiographic provinces—the Coastal Plain and the Piedmont—and its location in a transition zone between northern and southern climates, the park has a wide variety of habitats that can support healthy breeding populations of numerous animal species.

Figure 2-15 The presence of bobcats (*Lynx rufus*) was confirmed in the park during a study completed in 2005-2008. Photo: National Park Service.

Prince William Forest Park is also host to more than 38 species of mammals, 24 species of amphibians, more than 100 species of birds, 27 species of reptiles, 23 species of fish, and many invertebrates (Thornberry-Ehrlich 2009). Of these inventoried species, there are a few rare or threatened species listed by the state of Virginia, or species of special concern.

<u>Mammals</u>

Thirty-eight species of mammals have been identified within the park, including two non-native species, the house mouse (*Mus musculus*) and the Norway rat (*Rattus norvegicus*) (NPSpecies). White-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), and American beaver (*Castor canadensis*) populations thrive within the park. Additionally there are two species of skunk within the park—the striped skunk (*Mephitis mephitis*) and spotted skunk (*Spilogale* spp.). American black bear (*Ursus americanus*) have been observed both in the park, on U.S. Marine Corps Base-Quantico, and in surrounding areas (NPS 1995). Coyotes (*Canis latrans*) are also present within the park, and as populations of coyotes continue to increase in northern Virginia, human-coyote interactions are also on the increase. The presence of bobcats (*Lynx rufus*) was confirmed during a carnivore study completed within the park between 2005-2008 (Edwards 2012).

With the development of the fur trade in the eighteenth and nineteenth centuries, the American beaver (*Castor canadensis*) was extirpated in Virginia by 1911 (Ernst and Brophy 1998). During the early 1950s, Virginia's Department of Game and Inland Fisheries reintroduced the species into northern Virginia, and that species still exists in the region today. A beaver population survey conducted in 1997-1998 estimated the population size within PRWI as 81.6 beavers (Ernst and Brophy 1998). Although the population is not believed to have reached its carrying capacity, flooding and tree-felling by beavers threaten the recreational trail network within Prince William Forest Park (NPS 2013).

Seven bat species have been documented in PRWI: big brown bats (*Eptesicus fuscus*), silver-haired bats (*Lasionycteris noctivagans*), eastern red bats (*Lasiurus borealis*), little brown bats (*Myotis lucifugus*), northern long-eared bats (*Myotis septentrionalis*), evening bats (*Nycticeius humeralis*), and eastern pipistrelle/tricolored bats (*Pipistrellus subflavus*) (NPSpecies 2013).

<u>Birds</u>

Approximately 133 species of birds are likely to occur in the park during some part of the year (NPSpecies 2013). Park residents include owls and hawks, pileated woodpeckers, warblers, bluebirds, and other songbirds.

An I&M-sponsored bird inventory in 2001 documented 100 species (Sinclair et al. 2004). From 2007 to 2010, the number of bird species observed during the I&M forest bird monitoring within PRWI ranged from 64 to 68.

Prince William Forest Park is home to 19 bird species of Conservation Concern (a designation of Partners in Flight). In 2009, the American Bird Conservancy and National Audubon Society named the park an Important Bird Area, which considers small sites that are either critical to rare species, or that support large concentrations of a species. Eight species present in the park are on the Partners in

Flight Watchlist, and 11 species are on the Stewardship Species list (NPS 2011) (Table 2-1). The bald eagle *(Haliaeetus leucocephalus)*, a formerly federally threatened species, is not known to nest in the park, but has been observed passing through the area (NPS 1995).

Table 2-1 PRWI Bird species listed on the Partners in Flight Watch List or Stewardship Species lists.

Partners in Flight Watch List	Stewardship Species List
Cerulean warbler (*Setophaga cerulea*) Kentucky warbler (*Oporornis formosus*) Prairie warbler (*Dendroica discolor*) Prothonotary warbler (*Protonotaria citrea*) Red-headed woodpecker (*Melanerpes* erythrocephalus) Wood thrush (*Hylocichla mustelina*) Worm-eating warbler (*Helmitheros vermivorus*)	Acadian flycatcher (*Empidonax virescens*) Carolina wren (Thryothorous ludovicianus) Eastern towhee (Pipilo erythrophthalmus) Hooded warbler (*Wilsonia citrina*) Indigo bunting (*Passerina cyanea*) Louisiana waterthrush (*Parkesia motacilla*) Red-bellied woodpecker (*Melanerpes carolinus*) Red-shouldered hawk (*Buteo lineatus*) White-eyed vireo (*Vireo griseus*) Yellow-throated vireo (*Vireo flavifrons*) Yellow-throated warbler (*Dendroica dominica*)

Herpetofauna

Streams in Prince William Forest Park were monitored by NCRN I&M in 2006, 2008, 2009, 2012, and 2013 for amphibian populations. Surveys have identified 20 species of amphibians present within PRWI—10 salamanders and 10 frogs. Streams are visited twice each year—leaf litter is searched and cover objects are turned to find adult salamanders. Habitat is also evaluated to determine potential effects that changes to stream dynamics could have on amphibians (Campbell et al. 2011). In 2013, 32 monitoring sites on 16 streams were visited (Nortrup and Campbell Grant 2013).

Historical stream species occupancy (presence) exists for three stream salamanders in PRWI: northern dusky salamander (*Desmognathus fuscus fuscus*), northern two-lined salamander (*Eurycea bislineata*), northern red salamander (*Pseudotriton ruber ruber*). The occupancy rate for each of these stream salamanders at PRWI is relatively stable (Nortrup and Campbell Grant, 2013; NPS 2013b). Pauley et al. (2005) found that mixed deciduous forests and aquatic habitats yielded the highest number of species, while floodplains contained few species.

Figure 2-16 The eastern box turtle (*Terrapene carolina carolina*) is native to Prince William Forest Park. Photo: National Park Service.

Ephemeral (vernal) pools are important breeding habitat for amphibians, and small streams contain numerous salamander species. Hydroperiod, the length of time and portion of year the wetland holds ponded water, is one of the most significant factors determining amphibian colonization of wetland habitat. Hydroperiod varies based on changes within the park (e.g. changes in water level), as well as changes outside the park (e.g. watershed modifications, water diversion, climate change) (Campbell et al. 2011). Hydroperiod determines not only the length of time that amphibian larvae have for developing to the point where they can leave the water for land, but also the number and types of predators to which they are exposed (Tarr and Babbitt 2008). Wetland size and flooding frequency, as well as the absence of fish, are also important habitat parameters for amphibians.

Twenty-three reptile species—13 snakes, four lizards, and six turtles—have been documented within PRWI (NPSpecies 2013). Of 13 species of snakes found in the park, only one—the northern copperhead (*Agkistrodon contortrix mokasen*)—is venomous. Additionally, a second venomous species, The timber rattlesnake (*Crotalus horridus*), was likely introduced into the park in the 1990s. This species had not been previously documented in Prince William County or the park prior to 1991, has been observed on a few occasions in the park, including a pregnant female who hatched 8 young (NPS 1995). There have been no reported sightings of a timber rattlesnake in PRWI since 2003.

Fish

Fish and aquatic communities are excellent indicators of watershed health and water quality. They are sensitive to many factors including pollution, stream physical habitat, diseases, and invasive organisms. Fish are also a vital part of ecosystems, consuming plankton, crustaceans, insects, and other organisms and in turn providing food for birds of prey, river otters, raccoons, and other creatures (NPS 2013h).

PRWI protects the main stem and South Fork of Quantico Creek. Within the park's boundaries, there are approximately eighteen miles of streams and two impoundments, which are open to the public for fishing. The water quality of Quantico Creek is generally healthy and supports numerous fish species and other aquatic life. According to records in the NPSpecies database, 27 species of fish occur within PRWI (NPSpecies 2013).

Species present during 2011 I&M monitoring include American eel (*Anguilla rostrata*), rosyside dace (*Clonostomus funduloides*), cutlips minnow (*Exoglossum maxillingua*), blacknose dace (*Rhinichthys atratulus*), redbreast sunfish (*Lepomis auritus*), fallfish (*Semotilus corporalis*), and margined madtom (*Noturus insignis*). Additionally, one gamefish, the chain pickerel (*Esox niger*) has been observed in park streams. No rare, threatened, or endangered fish species occur in any streams within PRWI (NPS 2013). Several non-native fish are present in PRWI streams, including green sunfish (*Lepomis auritus*),

Figure 2-17 The small whorled pogonia (*Isotria medeoloides*), a federally listed threatened species has been identified within Prince William Forest Park. Photo: National Park Service.

bluegill (*Lepomis macrochirus*), longear sunfish (*Lepomis megalotis*), and largemouth bass (*Micropterus salmoides*).

Rare, threatened, and endangered species

Several plants within PRWI have been identified as threatened and endangered species, or are found at the edge of their distributional range (Table 2-2). Threats to these species include poaching and loss of suitable habitat due to fragmentation (NPS 1995).

The small whorled pogonia (*Isotria medeoloides*), a federally listed threatened species, was discovered in Virginia in 1983, and has been identified within the park. A member of the orchid family, the species generally grows in upland mixed hardwood forests with trees of at least 40 years of age (Petersen 2004; Ware 1991; Ware 1987). Colonies are often found in an open shrub layer or near a canopy break. The primary threat to small whorled pogonia is loss of habitat. Only 47 colonies have been found within the state of Virginia, and few are on protected land. Seven colonies of the plant are known to be in PRWI.

Cardinal flower (*Lobelia cardinalis*) and Hercules club (*Aralia spinosa*) are common in the park although uncommon elsewhere. In addition, several state watch species—star-nosed mole (*Condylura cristata*), Diana butterfly (*Speyeria Diana*), and tiger beetle (*Cincidela unipunctata*) — have been documented in the park.

Freshwater sponges grow on sturdy submerged objects in clean streams, lakes, and rivers. Because they are sensitive to water conditions, their presence within an ecosystem indicates high water quality and low levels of pollutants (NPS 2013a). Freshwater sponges (species unidentified) with symbiotic algae were reported in the streams of Prince William Forest Park in the mid-1970s, but no sponges had since been recorded in PRWI until 2007. In 2007, the freshwater sponge species *Ephydatia muelleri* (Mueller's freshwater sponge) was observed in South Fork Quantico Creek. Mueller's freshwater sponge has also been found in abundance in a second section of South Fork Quantico Creek and in the main stem of Quantico Creek. Freshwater sponges are commonly found in water bodies with high water quality and low pollutants, disturbance, and silt (Holley 2009). The presence of the organisms may indicate that South Fork Quantico Creek is a high quality stream (Watts et al. 2010).

Table 2-2 Rare and threatened species observed within PRWI. Adapted from McAdory 2005; NPSpecies 2013.

Common Name	Scientific name	State listing	Confirmed occurrence in park
Small whorled pogonia	*Isotria medeoloides*	Endangered	Yes
Lemmer's pinion moth	*Lithophane lemmeri*	State special concern (S1S3)	In review
Sedge sprite	*Nehalennia irene*	State special concern (S1S2)	In review
Bald eagle	*Haliaeetus leucocephalus*	Threatened	Yes
Barn owl	*Tyto alba*	State special concern (S3B), vulnerable breeding populations	Yes
Long-eared owl	*Asio otus*	State special concern (S1B, S2N)	In review

Common Name	Scientific name	State listing	Confirmed occurrence in park
Red-breasted nuthatch	*Sitta canadensis*	State special concern	In review
Brown creeper	*Certhia americana*	State special concern (VA S3B, S5N)	Yes
Winter wren	*Troglodytes hiemalis*	State special concern (VA SC)	Yes
Hermit thrush	*Catharus guttatus*	State special concern (VA S1N, S5N)	Yes
Golden-crowned kinglet	*Regulus satrapa*	State special concern (VA SC; S2B, S5N)	Yes
Magnolia warbler	*Dendroica magnolia*	State special concern	Yes
Northern river otter	*Lontra canadensis*	State special concern	Yes
Purple finch	*Carpodacus purpureus*	State special concern	Yes

Integrated cultural and natural landscapes

Recognition of cultural landscapes as an important part of the National Capital Region's natural heritage is rooted in the history of historic preservation. 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 or aesthetic values." (Cultural Resource Management Guidelines NPS-28) (Slaiby and Mitchell 2003). 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).

Several important cultural landscapes occur within PRWI. These include remnants of the civil war era settlements Joplin, Hickory Ridge, and Batestown; the reclaimed remnants of Cabin Branch Pyrite Mine and Greenwood gold mine; Civilian Conservation Corps cabin camps dating back to the 1930s that reflect the history and legacy of the New Deal and Depression-era relief programs; and more recently the U.S. Army Office of Strategic Services use of the area and facilities (NPS 2013c).

Prince William Historic District is nationally significant as a model for the NPS Recreational Demonstration (RDA) program that was a product of the New Deal era. NPS used Prince William Forest Park to illustrate how RDAs could restore agriculturally depleted land, employ the labor of the newly established Civilian Conservation Corps (CCC), and benefit the impoverished children and families of the inner city with its campgrounds (NPS 2013c).

Soundscapes

The soundscape within a park comprises both the 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).

A visitor experience unusual to a majority of National Park areas within the National Capital Region is the natural quiet within a park (NPS 1995; NPS 2013b). In an increasingly urbanized region, the park offers visitors the opportunity to experience relative quiet. The natural quiet of the park is a valuable and vulnerable resource because of its proximity to the nation's capital, Interstate 95, local highways (State Highway 234 and State Highway 619), and local residential development.

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). Natural darkness is important to wildlife for mating, migration, sleep, foraging, orientation, and other aspects of their life cycle. Nocturnal animals, such as bats, rely on the cover of darkness to forage for prey. Cultural and historical resource parks value the night sky for preserving the sense of place and time inherent to the site.

Light pollution is increasing globally, especially in areas of high growth such as the east coast of the United States. Longcore and Rich (2004) recognize two types of light pollution: astronomical and ecological. Astronomical light pollution impedes the ability to see stars and other celestial bodies. Sky glow, or the nighttime illumination of the sky resulting from the multitudes of human-caused light scattered into the atmosphere, contributes to astronomical light pollution. Ecological light pollution alters the natural patterns of light and dark in ecosystems and has adverse effects on wildlife (Longcore and Rich 2004). Ecological light pollution includes direct glare, sky glow, and temporary, unexpected fluctuations in lighting. Behavior and population-level ecology is affected based on individual and species differences in orientation or disorientation to increased light availability, attraction or repulsion to light sources, lowered reproductive capacity, and hindered visual and audio intraspecies communication. These factors culminate in changes in community ecology, influencing competition, resource partitioning, and predation, and ultimately favoring species that are most light tolerant (Longcore and Rich 2004).

Resource Issues Overview

Internal park threats

Acidic streams/soils

Following the passage of the Clean Water Act in 1970, the National Park Service began work to reclaim lands around the Cabin Branch Pyrite Mine. At that time, the water pH of Quantico Creek in the region directly in front of the mine was 3.8, equal to that of vinegar (NPS 2013). Unreclaimed mine areas can contribute to water and soil pollution through acid drainage and sediment loading resulting from severe erosion. The largest reclamation project to date began in 1994, when the pyrite tailings were buried under topsoil and lime. Channels were dug around hot spots to divert rainwater and prevent acidic runoff from entering the creek. Additionally, measures were taken to secure the creek banks, and mineshafts were capped with concrete. Today, the Cabin Branch mine site is undergoing recovery. Vegetation (including Virginia pines planted by the NPS) now covers the once highly disturbed, barren landscape. Post-reclamation water samples have been collected below the mine site and results show that iron, copper, and zinc concentrations in Quantico Creek are below pre-reclamation levels (Hamblin-Katnik 2000; NPS 2013c). Levels of stream pH are now within the normal range (Pieper et al. 2012).

Dams

Dams can cause significant adverse impacts to the ecology of rivers and streams by blocking migration of fish to upriver spawning habitat, warming water temperatures in impoundments well above downstream conditions, and accumulating sediments that degrade water quality and can bury high quality fishery habitat (American Rivers 2013). The natural course of Quantico Creek has been altered in the park to create recreational lakes near the cabin camps. These dams act as sediment traps for erosion runoff, thereby accelerating lake sedimentation and adversely affecting fish populations (NPS 1992). These dams must be periodically dredged, which is costly and can be damaging to resources (NPS 1992).

Exotic species

Exotic invasive species may outcompete threatened and endangered species. Many invasive plants thrive on disturbances created within ecosystems, such as fragmentation, wildfires, or flooding. When native species are displaced by disturbances, invasive species can more rapidly colonize an area, further driving competition for resources. 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.

PRWI has some areas of significant incursion by exotic invasive species. Japanese stiltgrass (*Microstegium vimineum)* and Japanese honeysuckle (*Lonicera japonica)* are widespread. Less prevalent invasive species include Chinese wisteria (*Wisteria sinensis)* and Japanese knotweed (*Polygonum cuspidatum)* (Bradley et al. 2005).

Forest pests and diseases

The trees of the park are susceptible to infections from dogwood anthracnose (*Discula destructiva*) and oak decline (*Armillaria mellea* and *Agrilis bilineatus*) and insect infestations including gypsy moth (*Lymantria dispar dispar*), eastern tent caterpillar (*Malacosoma americanum*), and southern pine beetle (*Dendroctonus frontalis*) (NPS 1995).

Dogwood anthracnose, a disease caused by the fungus *Discula destructiva*, was found during NCRN I&M forest monitoring on a single tree within Prince William Forest Park in 2009.

Oak defoliation as a result of gypsy moth infestations were at their height in the early 1990's where an average of about 7-8,000 acres of oak trees were defoliated yearly (1990-1993), with a significant percentage resulting in tree mortality (NPS 1995).

Deer overpopulation

Figure 2-18 A white-tailed deer (*Odocoileus virginianus*) within Prince William Forest Park. Photo: National Park Service.

At a regional level, white-tailed deer (*Odocoileus virginianus*) densities have risen rapidly in the past few decades in response to a lack of natural predators, increased forage area due to land fragmentation for suburban growth, and declines in hunting outside park lands (Bates 2009).

Densities above eight deer per square kilometer exert a negative effect on vegetation (Bates, 2008; Horsley et al. 2003). Densities above 16 deer per square kilometer (40 per square mile) can cause negative effects to other wildlife species (Bates 2008; deCalesta 1999). With the exception of 2003, the deer population within PRWI has been less than 16 deer per square kilometer (40 per square mile). In 2008, deer density within PRWI was 11.7 deer per square kilometer (30 per square mile). This was a 127% increase from the previous years' deer counts (Bates 2008).

Over browsing 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 amphibian egg masses in ephemeral pools (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 also carry disease, such as Lyme disease, which is spread through deer ticks. In recent years, epizootic hemorrhagic disease as well as chronic wasting disease have also threatened deer populations within PRWI (NPS 2013c).

Adverse recreational use

Unauthorized visitor use within PRWI threatens sensitive habitat areas throughout the park. The park includes an extensive backcountry area, and social trails created through the park damage resources and cause erosion. In addition, the cabin camps do not have sufficient parking, which has led to unauthorized parking on roadsides and other associated problems.

Bacteria in lakes

Several artificial lakes exist at cabin camps for recreational purposes. Septic drainage fields above these lakes periodically cause elevated lake levels of fecal coliforms. Park staff test lake water quality after rainfall events and if levels of *Escherichia coli* surpass EPA standards (> 235 colonies per 100 ml in freshwater), lakes are closed to recreation (U.S. EPA 2014).

Regional threats

<u>Development/encroachment</u>

As development continues in the Northern Virginia area, the park will become more valuable as a protected watershed and a significant natural resource. It will also become increasingly threatened by external development and greater demand for recreational outlets (NPS 1995).

Intense development within Prince William County has occurred along the park's eastern and northern boundary paralleling VA Route 234. Increases in impervious surface cover contribute to increased stormwater runoff and lower groundwater infiltration. Water that runs off impervious surfaces is also of higher temperature, contributing to higher stream temperatures (although no trend in water temperatures was seen during regular I&M monitoring from 2005-2013). This water also contributes to stream bank erosion due to higher and accelerated stream flows. The use of road de-icing salt and other chemical treatments for snow melt can enter neighboring streams through runoff, where they can alter stream chemistry and threaten stream fauna.

Roads and development fragment the habitat, restricting or impeding the movement and migration of terrestrial and aquatic organisms. Roads also affect the ambient soundscape, further altering wildlife behavior. The road network along the eastern United States is dense, particularly around the National Capital Region.

Work began in April 2013 to construct auxiliary lanes and widen the shoulders on a seven-mile stretch of Interstate 95 in Prince William County, VA (Virginia DOT). The current expansion of the I-95 corridor runs along the east-southeastern border of the park. Threats from adjacent development include habitat fragmentation and introduction of exotic and invasive species.

<u>Extreme storm events</u>

Tropical storms and hurricanes are significant extreme storm events that occasionally impact the National Capitol Region. Although some wind damage can accompany these storms, the heavy precipitation and flooding from these storms is by far a more important disturbance factor for NCRN ecosystems (Davey et al. 2006). Within PRWI, heavy precipitation can lead to flooding along stream banks, and increased erosion. Erosion of the landscape can result in increased sediment loads throughout the park. Sediment loads and distribution can result in changes to channel morphology and an increase in the frequency of overbank flooding (Thornberry-Erhlich 2008). Additionally, these disturbances can result in a change, or loss of in-stream habitat.

<u>Stream sedimentation</u>

Erosion of topsoil has an impact on water quality within Prince William Forest Park. The recreational lakes have significant sediment deposition, and dredging is necessary to remove excess sediment. Additionally, clear-cutting is conducted at Marine Corps Base-Quantico, which causes increased sedimentation and decreasing water quality (NPS 2013c).

Insufficient aquifer recharge

Streams dry up with a lack of sufficient groundwater recharge during periods of drought, due to the shallow impervious geology underlying PRWI. Many of the streams and rivers dominating the landscape around PRWI begin along the slopes of the Blue Ridge, dissecting them into ridges and ravines. The Blue Ridge province is typified by steep terrain covered by thin, shallow soils, resulting in rapid runoff and low groundwater recharge rates (Thornberry-Ehrlich 2009).

The post-Early Cretaceous Stafford fault system, consisting of a series of northeast-trending, high-angle reverse faults in the unconsolidated deposits, lies parallel to the fall line in northeastern Virginia (Mixon and Newell 1977). These faults commonly act as conduits to ground-water flow, but can also offset and thereby seal pre-existing fractures and aquifers (Nelms and Brockman 1997; Thornberry-Ehrlich 2009).

Nutrient pollution and contamination of streams

Where agricultural remnants, construction materials, and other wastes are present, contaminant levels including nitrogen in the water may reach dangerous levels. A comparison between historical data and new data show that of 37 stream measurement locations within PRWI, four had metal concentrations greater than the previous mean concentration data (Komalowski et al. 2005).

Until 1994, mine tailings from the Cabin Branch Pyrite mine were exposed to precipitation that washed residual acid and metals into the Quantico Creek. Although complete reclamation of the land around the mine has been completed, measurements of riverbed sediments near the pyrite mining area along the east side of PRWI show that stream sediment is contaminated with metals (Komalowski et al. 2005).

There is also potential for metal pollution in streambed sediments due to ongoing military activities at U.S. Marine Corps Base-Quantico; however, no contribution to metal contamination has been shown to occur from the base. Runoff from roadways commonly contains high levels of oil and other car effluents, which are carried into park waterways and seep into the soil. Some metal contamination comes into the park from surrounding roads, an impact that could grow based on increased development within the area (Komalowski et al. 2005).

Air quality

The greatest threat to air quality in PRWI is industrialization in northern Virginia, auto emissions, and local interstate traffic (NPS 1995).

Air pollution originates from several different sources—mobile sources (cars and trucks); burning coal, oil, and other fossil fuels; and manufacturing chemicals (US EPA 2012). The most common air pollutants are ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead, with ozone and particulate matter being the most threatening to human health (US EPA 2012). The U.S. east coast 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 causing eutrophication. Air pollution can be transported over long distances, making management difficult at the local scale.

Climate change

Climate change, and the associated temperature and precipitation shifts, will likely alter the phenology of plant species (NPS 2013d). The timing of flowering is tied to pollinator activity, a relationship that might become decoupled as temperature increases shift the first flowering date earlier in the season (Davis 2011). In the Washington, DC area, the timing of first flowering has shifted earlier by 0.2 to 46 days for early-flowering plants, and later in the season by 0.3 to 10.4 days for late-flowering plants (Davis 2011). Diversity of native plants will likely decrease with climate change. This increased growing period, as well as changes in biodiversity, provides increased opportunity for exotic invasive species.

Climate change will manifest itself not only as changes in average conditions, but also changes in particular climate events (e.g., more intense storms, floods, or drought). Extreme climate events can cause widespread and fundamental shifts in conditions of park resources (Monahan and Fisichelli 2014). Changes in precipitation and stream discharge are also possible with climate change. Stream discharge influences distribution of sediments and nutrients in water, which can impact stream dwelling species. Within Prince William Forest Park, increased temperatures and hydraulic changes have the potential to alter the natural and manmade landscapes of the park, impacting a variety of ecological, cultural, and recreational features.

Light and sound pollution

The lower 48 states of the U.S. have some of the highest levels of artificial lighting in the world. The lack of dark night skies has ecological impacts on wildlife habitat quality, species interactions, and migration patterns. In addition, park soundscapes have also been highly degraded in parks throughout the U.S. due to development, even at distances that can be far from park boundaries. Both light and noise pollution can also distract visitors from their appreciation of the park’s natural and cultural resources.

A primary detractor from the natural quiet within the park is the frequent training practices occurring on the U.S. Marine Corps Base-Quantico adjacent to the park (NPS 1995). Daily detonations and explosions are at times heard deep within the park. Less frequently, military aircraft are seen and heard flying over the park outside of the authorized military airspace (NPS 1995). U.S. Marine Corps Base-Quantico negatively impacts the natural soundscape, threatening opportunities for quiet and solitude within the park, particularly in the backcountry area (NPS 2013c).

Wildlife relies on sound for intraspecies communication and territory establishment, courtship and mating, nurture and protection of young, predation and predatory avoidance, and effective habitat use (NPS 2012). Alteration of the natural soundscape can adversely affect wildlife by displacing individuals or habituating them to sounds such that they eventually do not react to them (Barber *et al.* 2009). Wildlife behavior alteration (e.g., vocalization patterns) has also been observed in areas of anthropogenic noise (Goodwin 2009; Barber et al. 2011). Human-made sounds originating from outside the park might include road traffic, construction, and aircraft noise.

Resource Stewardship

Management directives and planning guidance

Park Purpose

The NPS Organic Act of 1916 states that the purpose of the National Park Service is "to conserve the scenery and the natural and historic objects and the wildlife 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."

Planning focuses first on why a park was established and what conditions should exist there before delving into details about specific actions. The purpose statement identifies the specific reason(s) for establishment of a particular park. The purpose statement for Prince William Forest Park was drafted through a careful analysis of its enabling legislation and the legislative history that influenced its development. The park was established by Executive Order on November 14, 1936. The purpose statement lays the foundation for understanding what is most important about the park:

"Prince William Forest Park offers recreational opportunities rooted in its legacy as the model for the New Deal-era recreational demonstration area program, and preserves, protects, and interprets a diverse array of natural and cultural resources."

Park significance

Significance statements express why a park's resources and values are important enough to merit designation as a unit of the national park system. These statements are linked to the purpose of Prince William Forest Park, and are supported by data, research, and consensus. Statements of significance describe the distinctive nature of the park and why an area is important within a global, national, regional, and system wide context. They focus on the most important resources and values that will assist in park planning and management.

The following significance statements have been identified for Prince William Forest Park. (Please note that the sequence of the statements do not reflect the level of significance).

- Prince William Forest Park is home to the largest protected Eastern Piedmont forest in the United States.
- Through the protection of a large percentage of the Quantico Creek watershed, Prince William Forest Park provides outstanding opportunities for education and scientific study.
- During World War II, Prince William Forest Park served as a training site for the Office of Strategic Services, the United States' first centralized intelligence agency; the changes to the landscape from their occupation and use of the park provide tangible connections to this clandestine chapter in American history.
- During the 1930's, the Civilian Conservation Corps and Works Progress Administration transformed a landscape of sub-marginal farmlands into the Chopawamsic Recreational Demonstration area; today the park contains the largest concentration of CCC and WPA structures in the national park system.

- Chopawamsic Recreational Demonstration Area was the model for the recreational demonstration area program, a New Deal-era (1933-1938) initiative that built parks for the nation's urban youth and families.
- During a time of racial segregation, Prince William Forest Park was the first recreational demonstration area in the southern states to provide opportunities for African Americans to connect with the outdoors through cabin camping opportunities.
- Prince William Forest Park protects the longest intact section of the Washington-Rochambeau Revolutionary Route National Historic Trail found within the national park system.
- Prince William Forest park provides diverse recreational opportunities and solitude within one of the most densely populated regions of the United States.

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 2013c):

- 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).

PRWI is one of the 11 parks served by the National Capital Region I&M Network (NCRN I&M). Numerous baseline inventories have been conducted at Prince William Forest Park 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

The National Park Service has performed its own research and collaborated with a variety of outside researchers and to fill gaps in knowledge and have a better understanding of park resources (Table 2-3). Collaborators have included various state and federal government agencies, George Mason University, the University of Virginia, and non-government organizations. A partial bibliography of research that has been completed at PRWI can be seen in Table 2-4.

Table 2-3 Status of NCRN I&M inventories at Prince William Forest Park.

Inventory	Description	Status
Air Quality Data	One of the 12 core natural resource inventories, the Air Quality Inventory objective is to provide 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 2006
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 1994
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. A part of the program's mission is to provide more than 270 parks with digital geologic-GIS data and a geology report.	Completed 2006
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 Geographic (SSURGO) database. SRI data are intended to serve as the official database for all agency applications regarding soil resources.	Completed 2005
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 2-4 A partial bibliography of research that has been completed at Prince William Forest Park.

Study topic	Reference
Air quality	Lawrey 2011; Sullivan et al. 2011;
Birds	Sinclair et al. 2004; Goodwin 2009; Ladin and Shriver 2013;
Fungi	Hawkins and Brantley 2007
Geology & Soils	Thornberry-Ehrlich 2009
Habitat	Schmit et al. 2012;
Herptofauna	Mitchell 1996
Mammals	Siemer et al. 2007; Edwards 2012
Plants	Bradley et al. 2005; Watts et al. 2010; Elmore et al. 2013
Water quality	Hamblin-Katnik et al. 2000; Hilderbrand and Raesly 2007; Norris and Pieper 2010; Schmit 2011; Pieper et al. 2012;

Legislation

Unlike many units of the national park system, Prince William Forest (Chopawamsic) has no single comprehensive enabling legislation. Rather the establishment and operation of the park is influenced by numerous pieces of federal legislation and executive orders (Table 2-5). Emerging as a recreational demonstration area out the New Deal legislation in the 1930s, Prince William Forest (Chopawamsic) was transferred to the National Park Service by Executive Order 7496 dated November 14, 1936. Public Law 2852 dated June 6, 1942, required that all RDA project areas be maintained for “public park, recreational, and conservation purposes.”

Table 2-5 Legislation and Acts.

Park Enabling Legislation	Date	Description
Emergency Relief and Construction Act of 1932 47 Stat. 717	July 21, 1932	Authorizes the acquisition of land by purchase, condemnation, or otherwise that would be needed for “emergency construction of public building projects outside the District of Columbia.”
Federal Emergency Relief Act	May 12, 1933	Created Federal Emergency Relief Administration (FERA) with responsibilities to conduct investigations dealing with problems of unemployment relief, provide “grants to the several States to aid in meeting the costs of furnishing relief and work relief….”
National Industrial Recovery Act 48 Stat. 200.	June 16, 1933	This act authorized the president to establish agencies for the purpose of implementing the act with termination of agencies, etc. “at the expiration of two years after the date of enactment of this Act….” It also authorized the establishment of public works programs and projects.
Fourth Deficiency Act	June 16, 1933	This act authorized the president to establish agencies for the purpose of implementing the act with termination of agencies, etc. “at the expiration of two years after the date of enactment of this Act….” It also authorized the establishment of public works programs and projects.
Fourth Deficiency Act	June 16, 1933	During Fiscal Year 1933 this act provided funding for activities approved under the National Industrial Recovery Act.
Emergency Relief Appropriation Act	April 8, 1935	During Fiscal Year 1935, this act authorized appropriations pursuant to title II of the National Industrial Recover Act and the Federal Emergency Relief Act of 1933 for the benefits of public works and “to meet the emergency and necessity for relief in stricken agricultural areas.”
54 Stat. 785 Public Law 763	August 13, 1940	An act to provide for the operation of the recreational facilities within the Chopawamsic Recreational Demonstration Project, near Dumfries, Virginia, by the Secretary of the Interior through the National park Service, and for other purposes.

Table 2-5 (continued) Legislation and Acts

Park Enabling Legislation	Date	Description
56 Stat. 326 Public Law 2852	June 6, 1942	Required that all RDA project areas be maintained for "public park, recreational and conservation purposes." Authorized the conveyance of "recreation demonstration project lands to the States with the approval of the President."
62 Stat. 571 Public Law 736	June 22, 1948	An act to authorize the transfer of certain federal lands within the Chopawamsic Park to the Secretary of the Navy, the additional lands needed to round out the boundaries of the park, to change the name of said park to Prince William Forest Park, and for other purposes.
Public Law 640	August 3, 1950	"To authorize grantees of recreation demonstration project lands to make land exchanges relating to such properties, and for other purposes."
67 Stat. 184 Public Law 83-144	July 26, 1953	An act to authorize the exchange of lands acquired by the United States for Prince William Forest Park, Prince William County Virginia, for the purpose of consolidating federal holdings therein, and for other purposes.
116 Stat. 2458 § 2835 P.L. 107-314	January 1, 2002	An act to authorize appropriations for fiscal year 2003 for military activities of the Department of Defense, for military construction and for defense activities of the Department of Energy, to prescribe personal strengths for such fiscal year for the Armed Forces, and for other purposes (short title: "Bob Stump National Defense Authorization Act for Fiscal Year 2003").
6747	June 23, 1934	Allocated funds to "meet the Emergency and Necessity for relief in stricken Agricultural Areas and specifically to FERA for making grants to States…."
6910-B	December 1, 1934	Allocated to FERA the sum of $5,000,000 for the purpose of affording relief through the purchase of sub-marginal lands in the stricken agricultural areas including the necessary costs of administration of such lands as may be acquired for such purpose, and to the Emergency Conservation Fund the sum of $10,000,000, for the establishment and maintenance of Civilian Conservation Corps camps.
6983	March 6, 1935	Authorizes FERA to acquire property "connection with the construction or carrying on of any project or program financed by allocations, allotments, or transfers made, or to be made, to FERA under the authority and in accordance with the provisions of the said National Industrial Recovery Act...."
7027	April 30, 1935	Established the "Resettlement Administration" to "initiate and administer a program of approved projects with respect to soil erosion, stream pollution, seacoast erosion, reforestation, forestation, and flood control."
7028	April 30, 1935	Transfers from FERA to the Resettlement Administration all of the real and personal property or any interest therein… acquired by the FERA administrator and the Director of the Land Program.
7034	May 6, 1935	The Works Progress Administration was established as a successor to the Civil Works Administration.
7496	November 14, 1936	Transferred recreation demonstration project lands from the Resettlement Administration to the Secretary of the Interior for the National Park Service to complete and administer the projects being transferred.

Study Scoping and Design

Preliminary scoping and park involvement

Preliminary scoping for the assessment of Prince William Forest Park (PRWI) began in March 2013 with a meeting at Prince William Forest Park. In attendance were staffs from PRWI, Wolf Trap National Park for the Performing Arts, 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). Project goals and reporting areas were established during the initial scoping meeting with the PRWI park staff (Figure 3-1). Park staff helped identify key indicators of environmental health for the park. Archived data for park resources from PRWI 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 3-19 Participants at the preliminary scoping workshop for Prince William Forest Park. 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 PRWI, 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 PRWI 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 indicator 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). Indicators 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 such large-scale monitoring programs to be the development of information products, which integrate and translate large amounts of complex scientific data into highly aggregated indicators for communication to policy-makers and non-scientists. Aggregated indices were developed and are presented within the current natural resources assessment for Prince William Forest Park.

General approach and methods

The general approach taken to assess natural resource condition was to determine indicators appropriate to inform current status of each indicator, 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 an indicator-by-indicator 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 vital sign category scores were averaged to calculate an overall park assessment score.

Thresholds

A natural resource condition assessment requires the establishment of criteria for defining desired, as well as current, ecological conditions, and the current assessment is based upon explicitly defined threshold values. Thresholds 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 thresholds, there is still the question of how best to use these threshold values in a management context (Groffman et al. 2006). Recognizing these challenges, thresholds can still be effectively used to track ecosystem change and define achievable management goals (Biggs 2004). As long as threshold values are clearly defined and justified, they can be updated in 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).

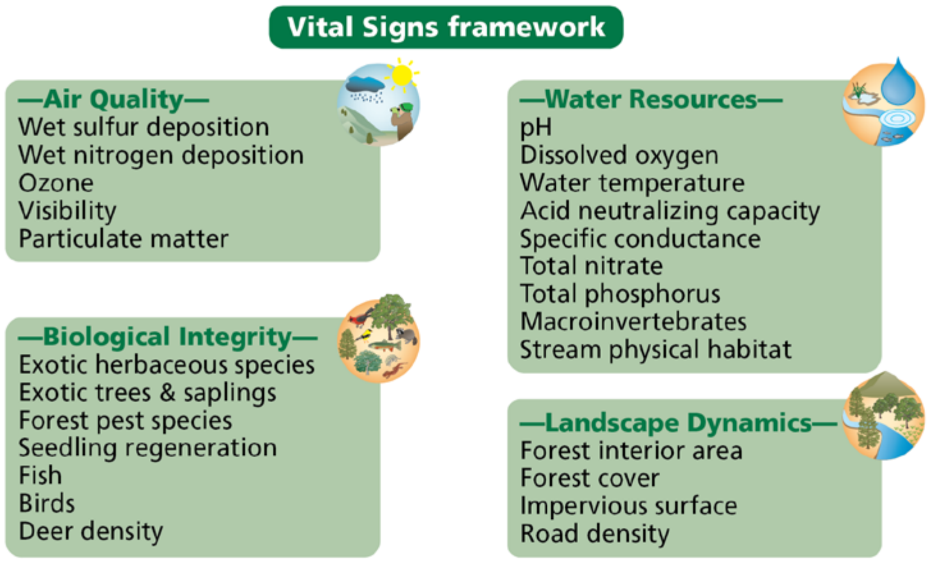

Figure 3-20 Vital signs framework used in this assessment.

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-indicator 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-indicator 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). Multi-indicator 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. 1989, 2000, Harrison and Whitfield 2004).

Condition assessment calculations

A total of 25 vital sign indicators were used to determine the natural resource condition of Prince William Forest Park. Mercury deposition, *E. coli* levels, and amphibian occupancy were also assessed within this report, but not included in the overall resource condition. The approach for assessing resource condition within PRWI required establishment of a reference condition (i.e. threshold) for each indicator. 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 indicators, medians were presented as the overall result instead of means.

Reference condition attainment of indicators was calculated based on the percentage of sites or samples that met or exceeded reference condition values set for each indicator. An indicator attainment score of 100% reflected that the indicator at all sites and at all times met the reference condition identified to maintain natural resources. Conversely, a score of 0% indicated that no sites at any sampling time met the reference condition value. Once attainment was calculated for each indicator, 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 indicator 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

Nine indicators were used to assess water resources in Prince William Forest Park—pH, dissolved oxygen (DO), water temperature, acid neutralizing capacity (ANC), specific conductance, nitrate, total phosphorus, benthic index of biotic integrity (BIBI), and physical habitat index (PHI) (Table 4-1). A tenth indicator (*E. coli* level) was included for informational purposes but not included in the overall assessment. Data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff. Water quality monitoring sites are shown in Figure 4-1 and BIBI and PHI monitoring sites are shown in Figure 4-2. *E. coli* monitoring sites are shown in Figure 4-3.

Table 4-6 Ecological monitoring framework data for Water Resources provided by agencies and specific sources included in the assessment of PRWI.

Indicator	Agency	Source
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
E. coli	PRWI	U.S. EPA

Reference conditions were established for each of the nine indicators (Table 4-2) and the data were compared to these reference conditions to obtain the percent attainment. Prince William Forest Park scored as very good (88-100% attainment) for all water quality indicators except total phosphorus (8% attainment, or very degraded), Benthic Index of Biotic Integrity (75% attainment, or good), and Physical Habitat Index (47.5% attainment, or degraded) (Table 4-3).

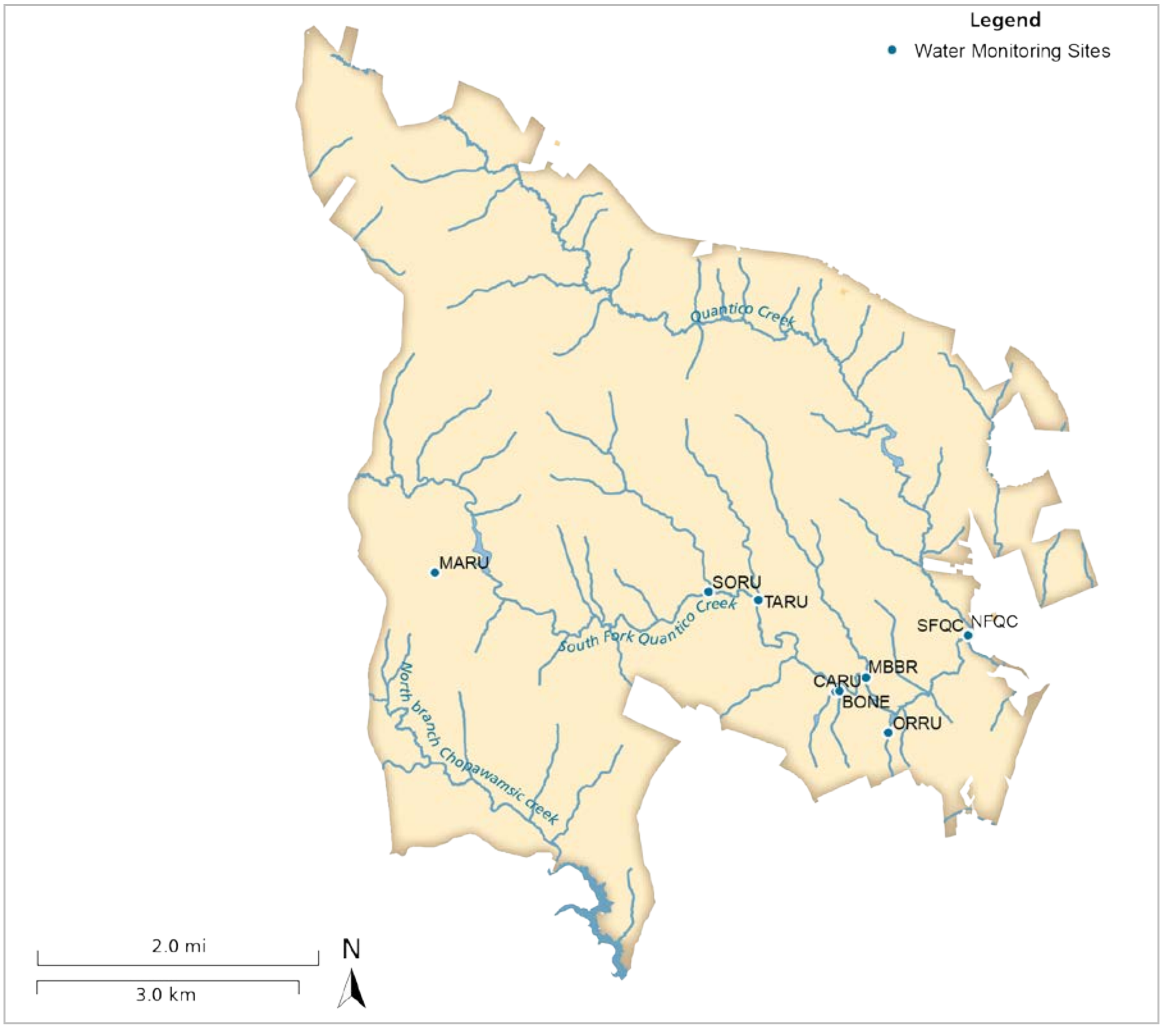

Figure 4-21 Stream sampling locations in PRWI used for long-term water quality monitoring (Norris et al. 2007).

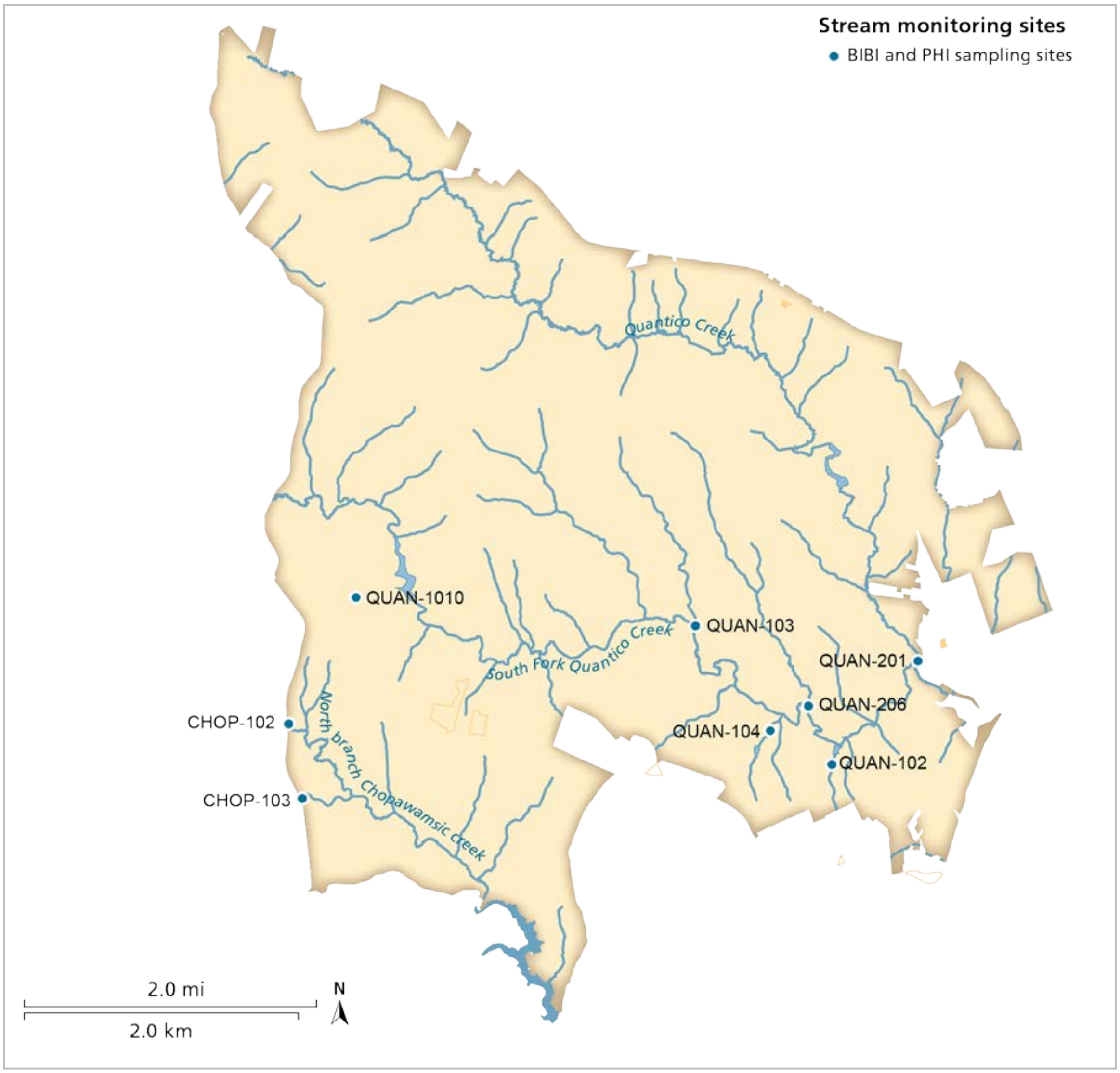

Figure 4-22 Stream sampling locations in PRWI monitored for stream macroinvertebrates (BIBI), and physical habitat index (PHI).

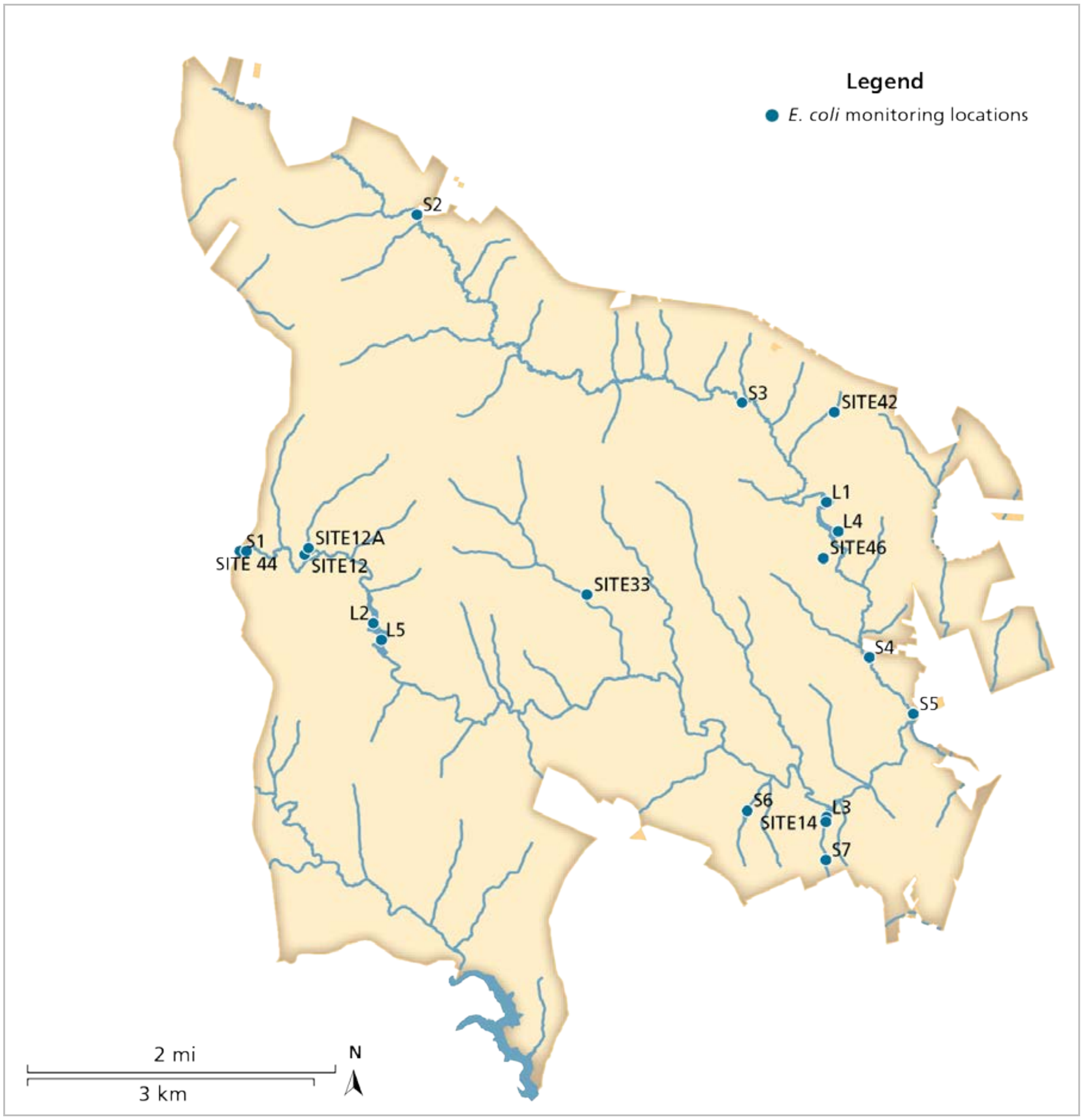

Figure 4-23 Sampling locations in PRWI monitored for *E. coli* levels.

Table 4-7 Water resource indicators, data availability reference conditions, and condition assessment categories used in the natural resource condition assessment of Prince William Forest Park.

Water resource indicator	Number of sites	Number of samples	Period of observation	Reference condition	Percent attainment applied
pH	9	625	2005-2013	6.0≤pH ≤ 9.0	0-100% Scaled linearly
Dissolved oxygen (mg/L)	9	593	2005-2013	≥ 6.0	
Water temperature (°C)	9	589		≤ 32	
Acid neutralizing capacity (µeq/L)	9	590	2005-2013	≥ 200	
Specific conductance (µS/cm)	9	590	2005-2013	≤ 171	
Nitrate (mg/L)	9	532	2005-2013	≤ 2	
Total phosphorus (mg/L)	9	461	2005-2013	≤ 0.037	
Benthic Index of Biotic Integrity	8	11	2004-2011	4.0-5.0 3.0-3.9 2.0-2.9 1.0-1.9	0-100% Scaled linearly
Physical Habitat Index	8	11	2004-2011	81-100	75-100% (Scaled linearly)
				66-80	50-75% (Scaled linearly)
				51-65	25-50% (Scaled linearly)
				0-50	0-25% (Scaled linearly)
E. coli (colonies/100mL)	12	312	2011-2013	NA	NA

Table 4-8 Summary of water resource condition assessment at PRWI.

Water resource indicator	PRWI result	Percent attainment of reference condition	Condition assessment	Overall water quality condition
pH	7.02	92	Very good	77% Good
Dissolved oxygen (mg/L)	8.80	97	Very good	
Water temperature (°C)	13.5	100	Very good	
Acid neutralizing capacity (µeq/L)	329	72	Good	
Specific conductance (µS/cm)	66	97	Very good	
Nitrate (mg/L)	0.6	100	Very good	
Total phosphorus (mg/L)	0.08	8	Very degraded	
Benthic Index of Biotic Integrity	4.00	75	Good	
Physical Habitat Index	64.6	48	Degraded	
E. coli (colonies/100mL)	Lakes 25.4 Streams 119.6	NA	NA	

Water pH

Description

The streams in and adjacent to PRWI are an important and unique 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 (Sardinski and Dunson 1992; NPS ARD 2010). Aquatic animals are susceptible to extreme pH values and can be limited by food availability even at less extreme acidification by, for example, reduced zooplankton and periphyton communities (Sadinski and Dunson 1992; Barr and Babbitt 2002). Surveys in North Carolina found a decline in amphibian species richness with reduced (more acidic) pH, with some frog and newt species being totally absent in the more acidic ponds (Easton and Fauth 2001). Reduced pH can also result in reduced salamander hatching success, suppression of larval newt survival, and impacts on frog metamorphosis (Sadinski and Dunson 1992).

Data and methods

Data was collected monthly between 2005 and 2013 at nine sites 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. Measurements were taken monthly as instantaneous records. Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results were 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). Streams within PRWI are designated warm water streams. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-3).

Condition and trend

Condition of pH in PRWI between 2005 and 2013 was very good, with a median pH of 7.0 and 91.5% of data points attaining the reference conditions of 6.0-9.0. Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4-4).

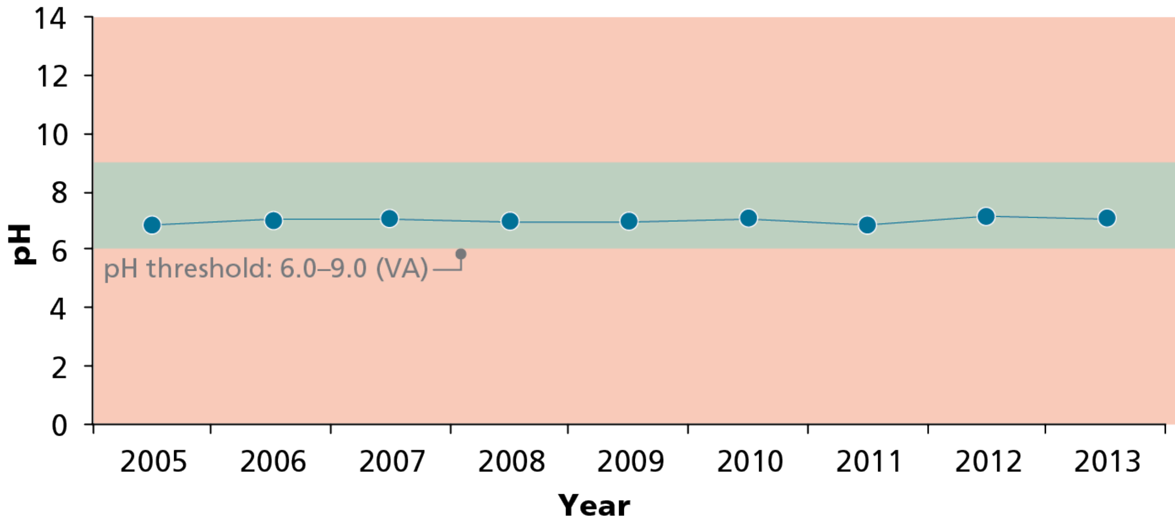

Figure 4-24 Annual median pH values from 2005 to 2013 for nine stream sampling locations in PRWI. Reference conditions (6.0 ≤ pH ≥ 9.0) are shown in green.

Sources of expertise

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

Figure 4-25 Attainment of pH reference condition by site from 2005 to 2013 for 9 stream sampling locations near PRWI. Site medians were used for this analysis.

Dissolved oxygen

Description

Dissolved oxygen (DO) concentration in water is often used as an indicator to gauge the overall health of the aquatic environment, as 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 under-saturated 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.

Data and methods

Data was collected monthly between 2005 to 2013 at nine sites 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. Measurements were taken monthly as instantaneous records.

A reference condition of ≥ 5.0 mg/L DO 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 (Table 4-2); each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-3).

Condition and trend

Current condition of dissolved oxygen in PRWI was very good, with a median DO of 8.8 mg/L and 97% of data points attaining reference condition. Over the data range available, no significant trend was present (*p*-value >0.01) (Figure 4-6, Figure 4-7).

Sources of expertise

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

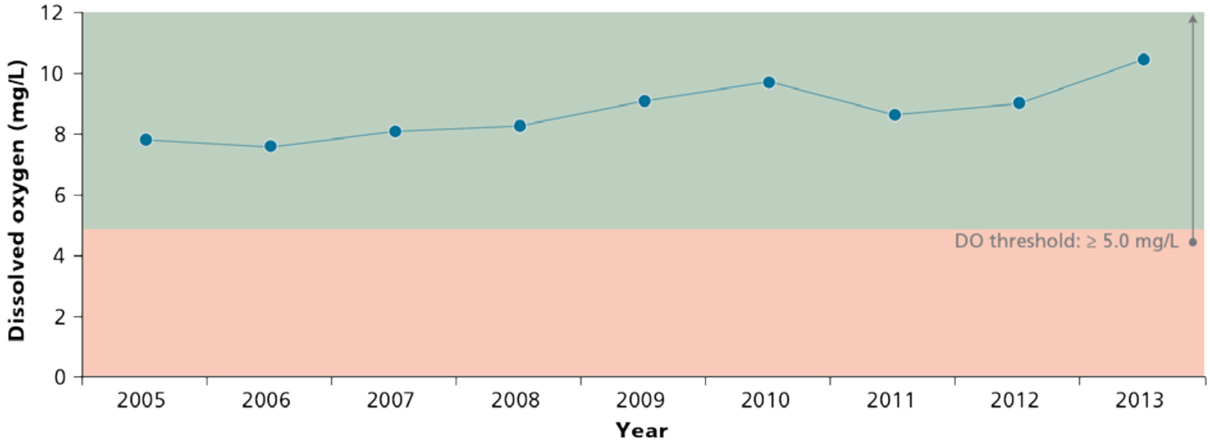

Figure 4-26 Annual mean dissolved oxygen concentrations (mg/L) from 2005 to 2013 for nine stream sampling sites in PRWI. Reference conditions are shown in green.

Figure 4-27 Attainment of dissolved oxygen reference condition by site from 2005 to 2013 for 9 stream sampling locations in PRWI. Site medians were used for this analysis.

Water temperature

<u>Description</u>

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 to 2013 at nine sites by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) 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 assigned a pass or fail result 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 Water Control Board 2011) (Table 4-2). Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-3).

Condition and trend

Current condition of water temperature in PRWI was very good, with a mean temperature of 13.5°C and 100% of data points attaining reference condition. When the seasonal median water temperatures were calculated, temperatures were highest in the summer months (median of 21.2°C), and lower in the spring, fall and winter months (15.2°C, 10.5°C, and 7.3°C respectively) (Figure 4-8).

Sources of expertise

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

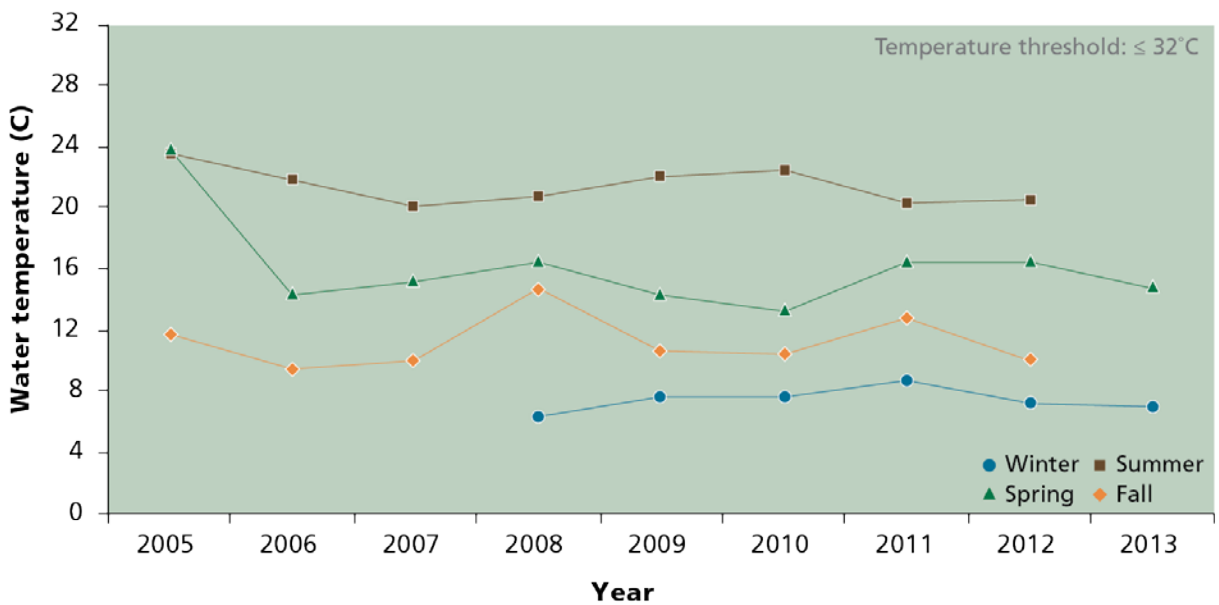

Figure 4-28 Seasonal median water temperature values (°C) from 2005 to 2013 for nine stream sampling locations in PRWI. Reference condition (temperature ≤ 32°C) is shown at top of figure.

Figure 4-29 Attainment of water temperature reference condition by site from 2005 to 2013 for nine stream sampling locations in PRWI. Site medians were used for this analysis.

Acid neutralizing capacity

Description

Acid neutralizing capacity (ANC) is the prime indicator of a water body'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 less affected by acid rain and other acid inputs than streams with lower ANC values (Welch *et al.* 1998).

Data and methods

Data was collected monthly between 2005 to 2013 at nine sites by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) 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.

The acid neutralizing capacity (ANC) reference condition was developed by the Maryland Biological Stream Survey (MBSS) program 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 linked to degraded streams was values less than 200 µeq/L, which was used as the reference condition in this assessment (Table 4-2, 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 4-3). 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 PRWI was good, with a median ANC of 329 µeq /L and 72% of data points attaining the 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 4-10,Table 4-3).

Sources of expertise

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

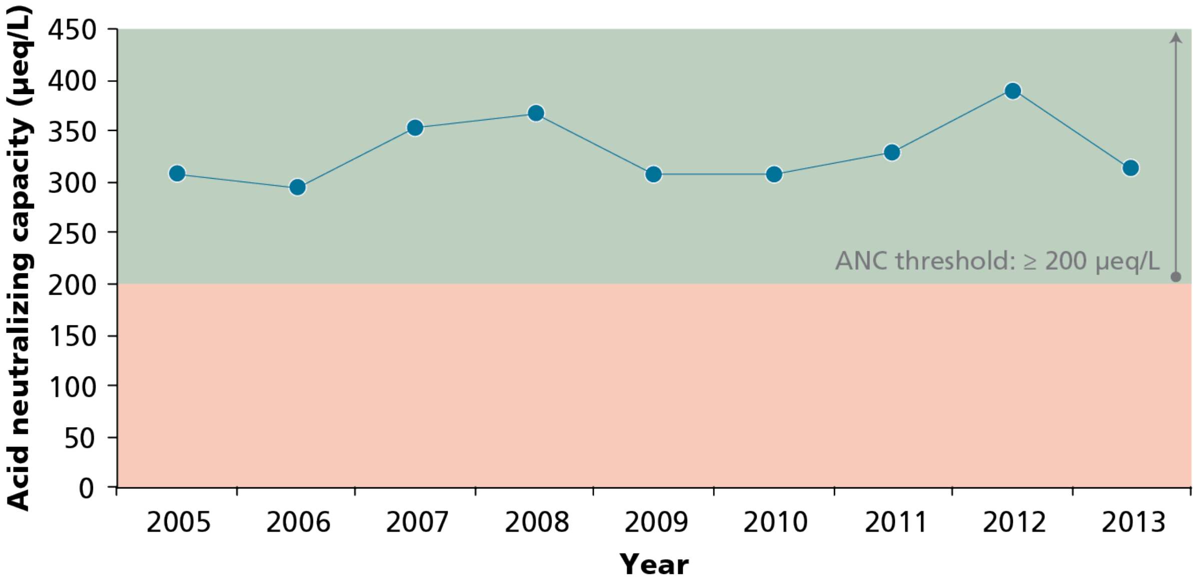

Figure 4-30 Median acid neutralizing capacity values (μeq/L) from 2005 to 2013 for nine stream sampling locations in PRWI. Reference conditions (ANC ≥ 200 μeq/L) is shown in green.

Figure 4-31 Attainment of acid neutralizing condition reference condition by site from 2005 to 2013 for nine stream sampling locations in PRWI. Site medians were used for this analysis.

Specific conductance

<u>Description</u>

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 will be (Radtke et al. 1998). Because conductivity changes with temperature, it must be normalized to a temperature of 25°C and reported as specific conductance to enable comparisons.

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).

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). De-icing compounds alone are significantly elevating the specific conductance of some streams in the northeast during winter periods (Kaushal et al. 2005; Allan and Castillo 2007).

<u>Data and methods</u>

Data was collected monthly between 2005 to 2013 at nine sites by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Figure 4-1, Table 4-2; Norris and Pieper 2010). 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 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 4-3).

<u>Condition and trends</u>

Condition of specific conductance in PRWI between 2005 and 2013 was very good, with a median conductance of 6.2 µS/cm and 97% 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 4-12).

<u>Sources of expertise</u>

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

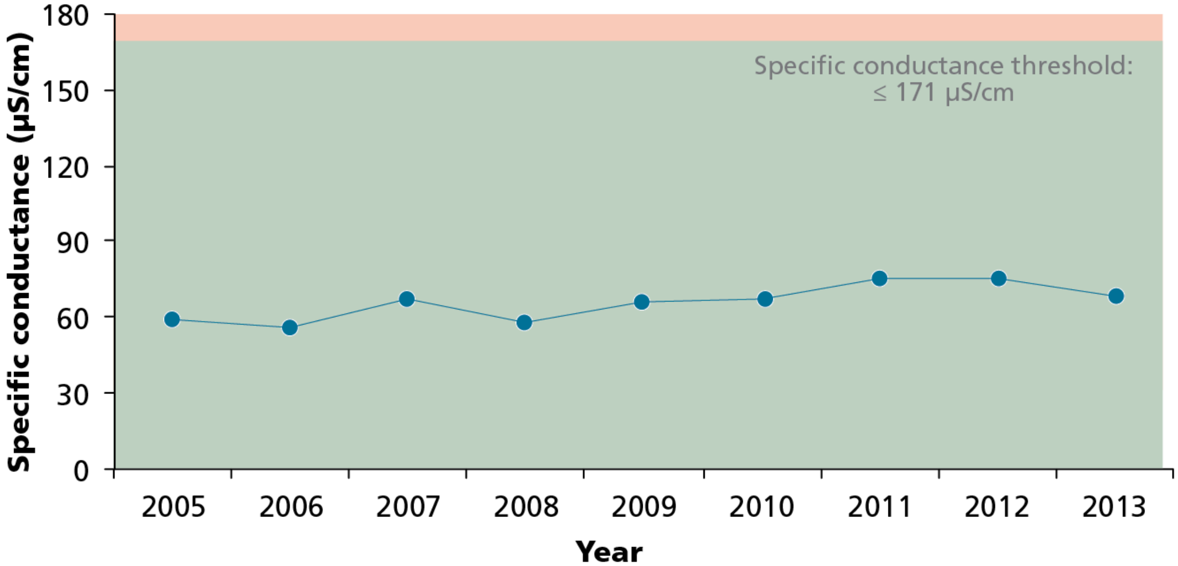

Figure 4-32 Annual median specific conductance values (µS/cm) from 2005 to 2013 for nine stream sampling locations in PRWI. Reference condition (specific conductance ≤ µS/cm) is shown in green.

Figure 4-33 Attainment of specific conductance reference condition by site from 2005 to 2013 for nine stream sampling locations in PRWI. Site medians were used for this analysis.

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. Nitrate is highly mobile in surface and groundwater and may seep into streams, lakes, and estuaries from groundwater enriched by animal or human wastes and commercial fertilizers. High concentrations of nitrate 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. In most natural waters, inorganic nitrogen as ammonium or nitrate is not the growth-limiting nutrient unless phosphorus is unusually high. Nitrate is typically indicative of agricultural pollution. Nitrate in surface water may occur in dissolved or particulate form resulting from inorganic sources. The dissolved, inorganic forms of nitrogen are most available for biological uptake and chemical transformation. Nitrate also travels freely through soil and therefore may pollute groundwater.

Data and methods

Data was collected monthly between 2005 to 2013 at nine sites by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) 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 assigned a pass or fail result 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 mg/L (2 ppm) indicated stream degradation (Southerland et al. 2007, Norris and Sanders 2009). Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-3).

Condition and trend

Current condition of nitrate in PRWI was very good, with a median nitrate concentration of 0.6 mg/L and 100% of data points attaining reference condition of < 2.0 mg/L between 2005 and 2013 (Figure 4-14). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4-14).

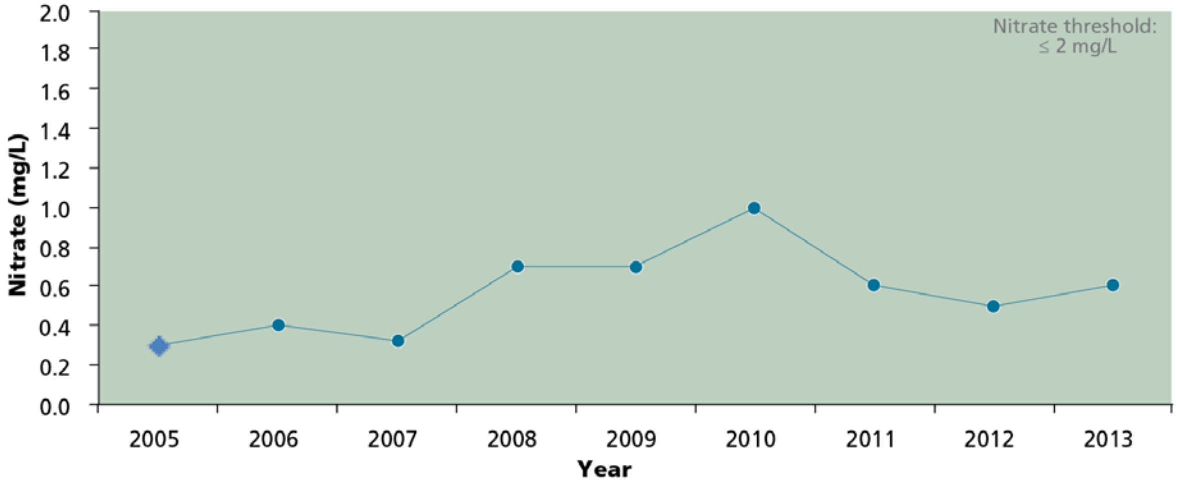

Figure 4-34 Annual median nitrate concentrations (mg/L) from 2005 to 2013 for nine stream sampling locations in PRWI. Reference condition ($NO_3 \leq 2.0$ mg/L) is shown in green.

<u>Sources of expertise</u>

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

Figure 4-35 Attainment of nitrate reference condition by site from 2005 to 2013 for nine stream sampling locations in PRWI. Site medians were used for this analysis.

Total Phosphorus

Description

Phosphorus is an essential nutrient for plants to live and is frequently the limiting nutrient for plant growth in aquatic systems. Consequently, a minor increase in phosphorus concentration can significantly affect water quality by stimulating algal growth, 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 nine sites by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Figure 4-1,Table 4-2) (Norris and Pieper 2010). 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 assigned a pass or fail result and the percentage of passing results were 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. Prince William Forest Park 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 0.010 mg/L P, which equates to a phosphate reference condition of 0.037 mg/L PO_4 (Table 4-2; U.S. EPA 2000). Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-3).

Condition and trend

Current condition of total phosphorus in PRWI was very poor, with a median phosphate of 0.08 mg/L and only 8% 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) (Table 4-3, Figure 4-16).

Sources of expertise

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

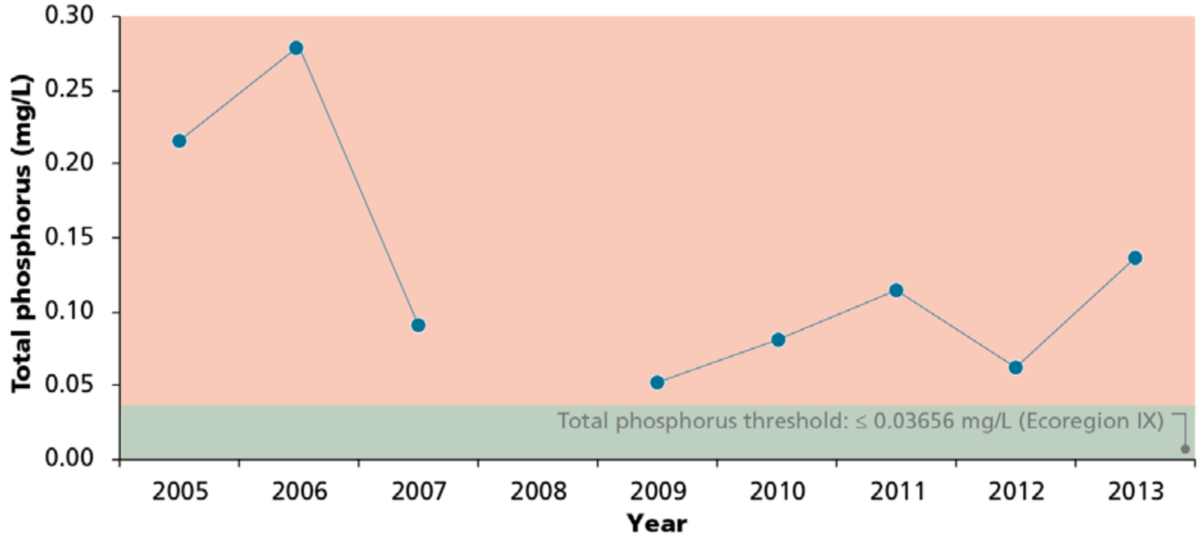

Figure 4-36 Annual median total phosphorus concentrations (mg/L) from 2005 to 2013 for nine stream sampling locations in PRWI. Total phosphorus reference condition (≤ 0.037 mg/L) is shown in green.

Figure 4-37 Attainment of phosphorus reference condition by site from 2005 to 2013 for nine stream sampling locations in PRWI. Site medians were used for this analysis.

Stream macroinvertebrates

Description

The Benthic Index of Biotic Integrity (BIBI) is a multi-indicator index developed 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 created 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 eight sites between 2004 and 2011 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.

Condition and trend

Current condition of benthic macroinvertebrates in PRWI was good, with a median BIBI of 4.00 based on eleven data points between 2005-2011 from eight sites (Table 4-4). This equates to 75% attainment of reference condition (Figure 4-18). No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-9 Benthic Index of Biotic Integrity (BIBI) in PRWI.

Year	Site	Location	BIBI
2011	QUAN-104-N-2011	Carter's Run	4.14
2011	QUAN-101-N-2011	Mawavi Run	4.00
2011	QUAN-206-N-2011	Mary Bird Branch	4.43
2011	CHOP-103-N-2011	Middle Branch Chopawamsic	4.00
2011	QUAN-201-N-2011	Quantico Creek	4.33
2011	CHOP-102-N-2011	North Branch Chopawamsic	4.33
2011	QUAN-102-N-2011	Orenda Run	3.33
2011	QUAN-103-N-2011	Taylor Run	4.33
2006	CHOP-102-N-2006	North Branch Chopawamsic	3.33
2004	CHOP-103-N-2004	Middle Branch Chopawamsic	3.67
2004	CHOP-102-N-2004	North Branch Chopawamsic	3.67

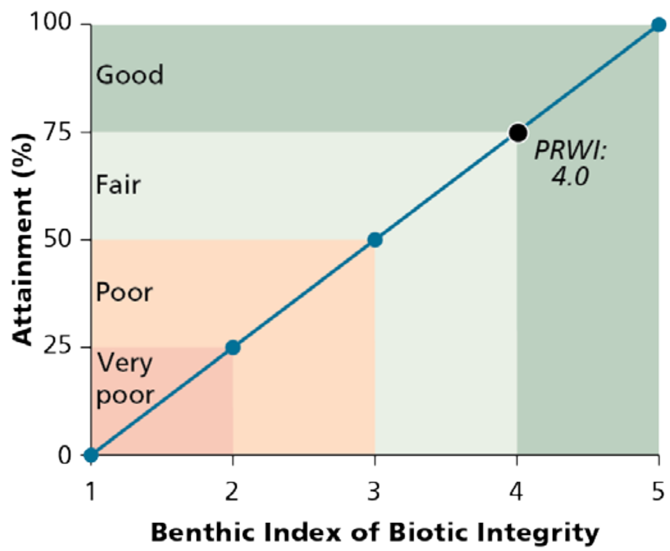

Figure 4-38 Application of percent attainment categories to the Benthic Index of Biotic Integrity (BIBI) categories. BIBI at PRWI was good, with a median of 4.00, which equated to 75% of the reference condition.

Figure 4-39 Attainment of Benthic Index of Biotic Integrity (BIBI) reference condition by site for eight stream sampling locations in PRWI.

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 eight sites between 2004 and 2011. NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Habitat assessments are determined based on data from numerous indicators 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 (Section 4.2.5 Acid neutralizing capacity). 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 (Table 4-3).

Condition and trend

Current condition of PHI in PRWI was degraded based on eleven data points between 2004-2011 from eight sites, with a median PHI of 64.59, which equated to a 47.5% attainment of the reference condition (Table 4-5, Figure 4-21). No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-10 Stream physical Habitat Index (PHI) in PRWI.

Year	Site	Location	PHI
2011	QUAN-104-N-2011	Carter's Run	64.59
2011	QUAN-101-N-2011	Mawavi Run	40.94
2011	QUAN-206-N-2011	Mary Bird Branch	82.83
2011	CHOP-103-N-2011	Middle Branch Chopawamsic	43.45
2011	QUAN-201-N-2011	Quantico Creek	68.70
2011	CHOP-102-N-2011	North Branch Chopawamsic	57.09
2011	QUAN-102-N-2011	Orenda Run	48.56
2011	QUAN-103-N-2011	Taylor Run	59.30
2006	CHOP-102-N-2006	North Branch Chopawamsic	72.90
2004	CHOP-103-N-2004	Middle Branch Chopawamsic	80.59
2004	CHOP-102-N-2004	North Branch Chopawamsic	70.75

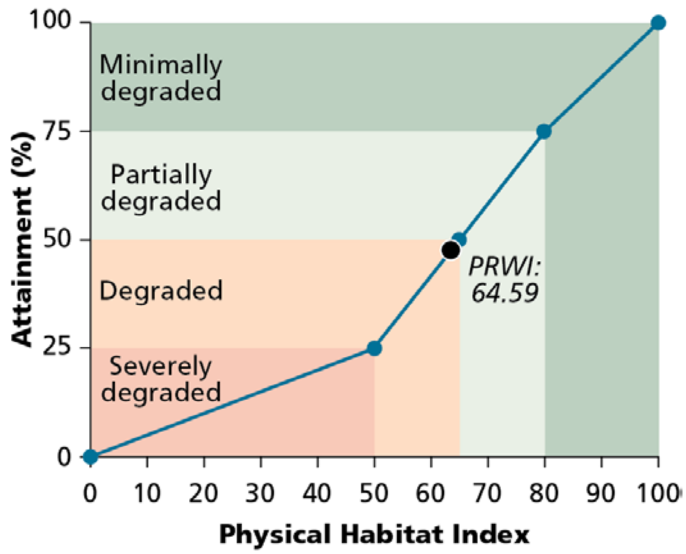

Figure 4-40 Application of the percent attainment categories to the Physical Habitat Index (PHI) value categories. PHI at PRWI was 64.59, which equated to 47.5% attainment of the reference condition.

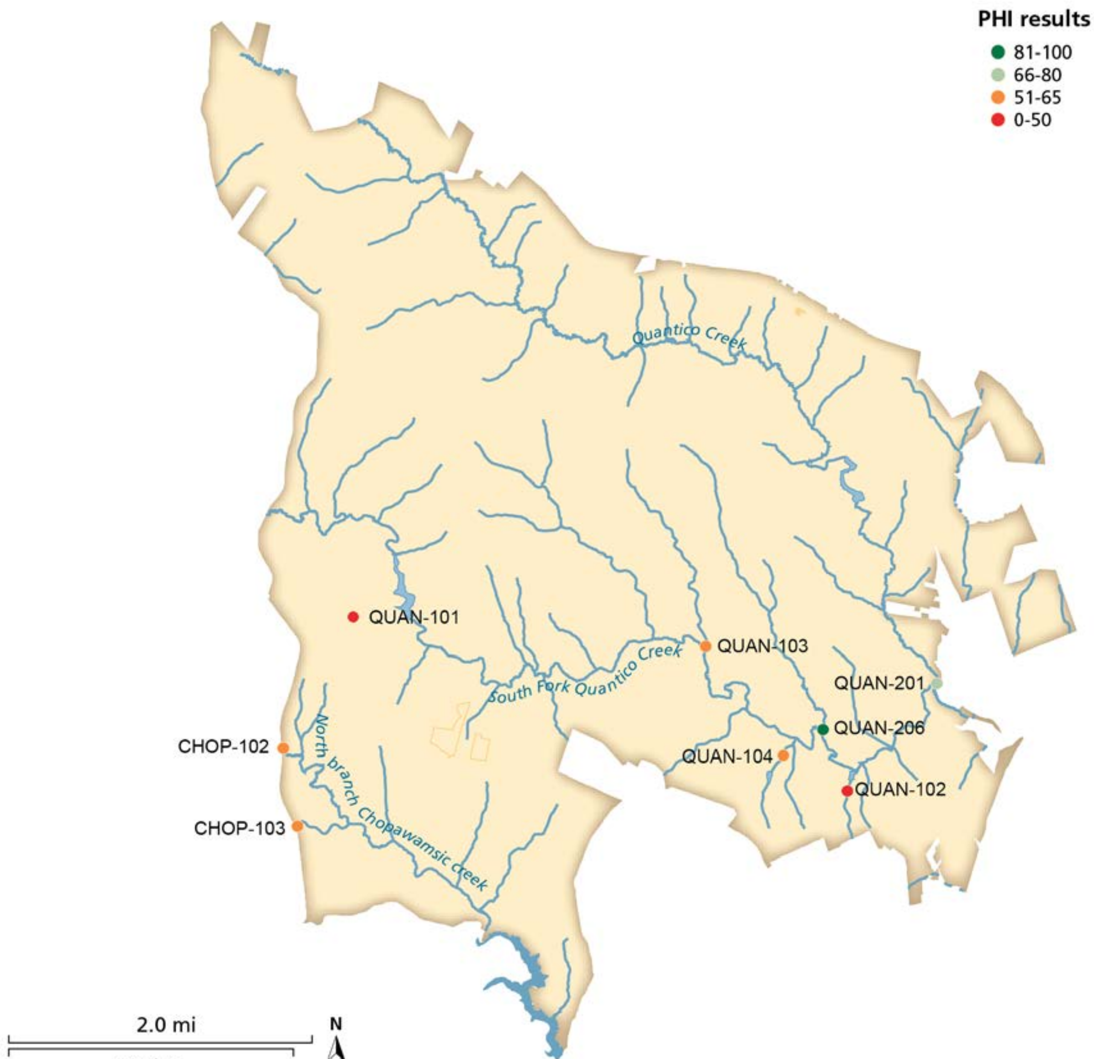

Figure 4-41 Attainment of Physical Habitat Index (PHI) reference condition by site for eight stream sampling locations in PRWI.

Escherichia coli

Description

Escherichia coli (E. coli) is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. The U.S. EPA recommends *E. coli* as the best indicator of human health risk from water contact in recreational freshwaters (U.S. EPA 2012). Most strains of *E. coli* are harmless to humans, but their presence in waterways can indicate fecal contamination and the potential presence of other pathogenic bacteria in recreational and drinking waters (CDC 2012).

Data and methods

Between 2011 and 2013, the Prince William Forest Park staff collected data at 12 sites; six lake sites and six stream sites. Due to the limited spatial and temporal coverage of data for this indicator, *E. coli* was not included in calculating the overall assessment of PRWI, and is included for informational purposes only.

Condition and Trend

The twelve sites monitored in PRWI for *E. coli* had a median result of 98 colonies/100 mL. Current condition of lakes within PRWI was very good, with a median of 25.4 colonies/100 mL, and 81% of sites attaining the reference condition of < 235 colonies/100 mL (Figure 4-22). Condition of streams within PRWI was good, with a median value of 119.6 colonies/100 mL, and 79.5% of sites attaining the reference condition of < 235 colonies/100 mL) (Figure 4-23).

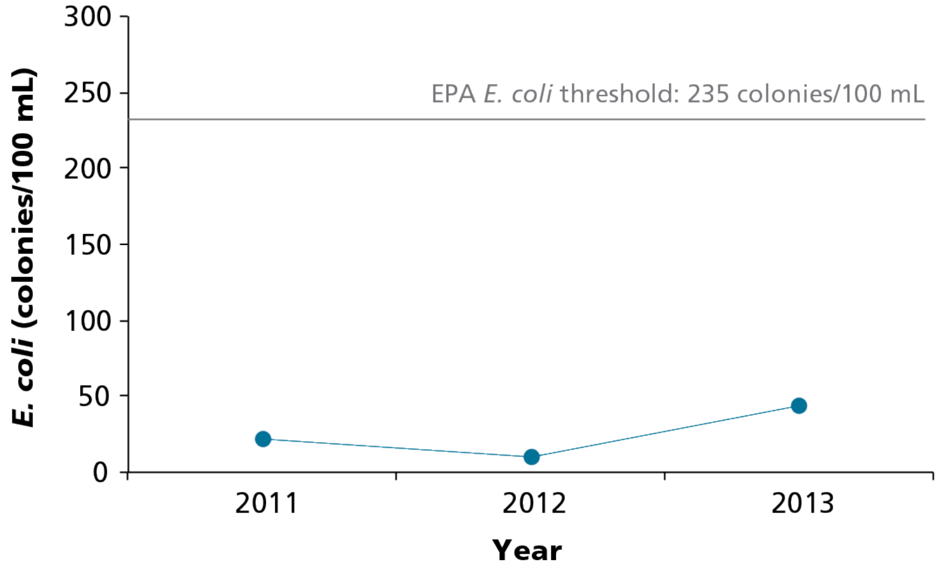

Figure 4-42 Annual median *E. coli* values (colonies/100 mL) from 2011 to 2013 for six lake sampling sites in PRWI.

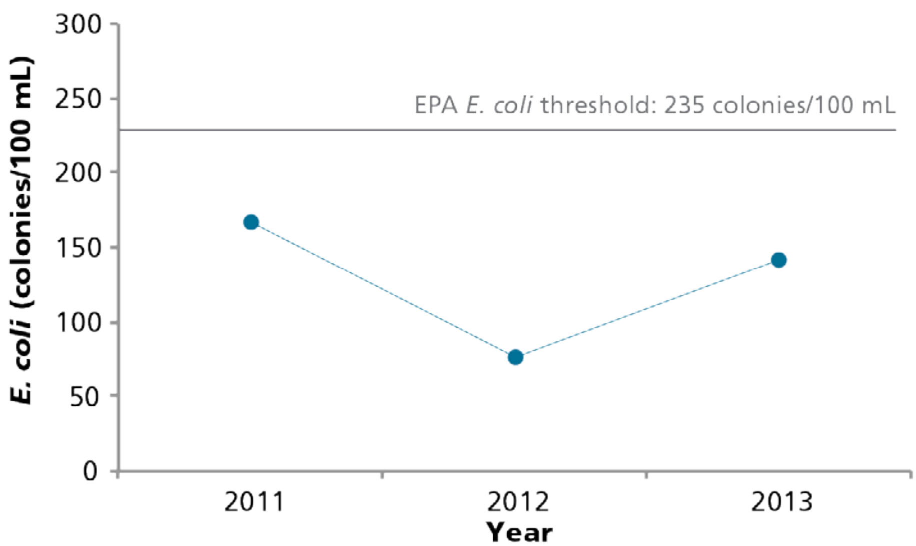

Figure 4-43 Annual median *E. coli* values (colonies/100 mL) from 2011-2013 for six stream sampling sites in PRWI.

Biological integrity

Seven indicators were used to assess biological integrity in Prince William Forest Park—exotic herbaceous species, exotic trees and saplings, forest pests, tree seedlings and forest regeneration, fish index of biotic integrity (FIBI), bird community index (BCI), and deer density (Table 4-6). An additional metric, amphibian stream species occupancy was include for informational purposes but not included in the overall assessment. All data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff except for deer data which was collected by park staff in collaboration with the regional wildlife biologist (Table 4-6). Forest monitoring sites and deer counting routes are shown in Figure 4-24, and FIBI monitoring sites are shown in Figure 4-25.

Table 4-11 Ecological monitoring framework data for Biological Integrity provided by agencies and specific sources included in the assessment of PRWI.

Indicator	Agency	Source
Cover of exotic herbaceous species	NCRN I&M	Schmit et al. 2009, 2010
Area of exotic trees & saplings	NCRN I&M	Schmit et al. 2009, 2010
Presence of forest pest species	NCRN I&M	Schmit et al. 2009, 2010
Stocking index	NCRN I&M	Schmit et al. 2009, 2010
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 2006, 2009
Amphibian stream species occupancy	NCRN I&M	Mattfeldt et al. 2008

Reference conditions were established for each metric (Table 4-7) and the data were compared to these reference conditions to obtain the percent attainment (Table 4-8). Single reference conditions were used for exotic plants, forest pests, tree seedling regeneration, and deer density, while multiple reference conditions were used for FIBI and BCI (Table 4-7).

Prince William Forest Park had variable results for biological integrity (Table 4-8). The park scored as very good condition for area of exotic trees and saplings and presence of forest pests (100% attainment); degraded condition for birds (22.6% attainment); and very degraded for exotic herbaceous species and tree seedlings and forest regeneration (0% attainment).

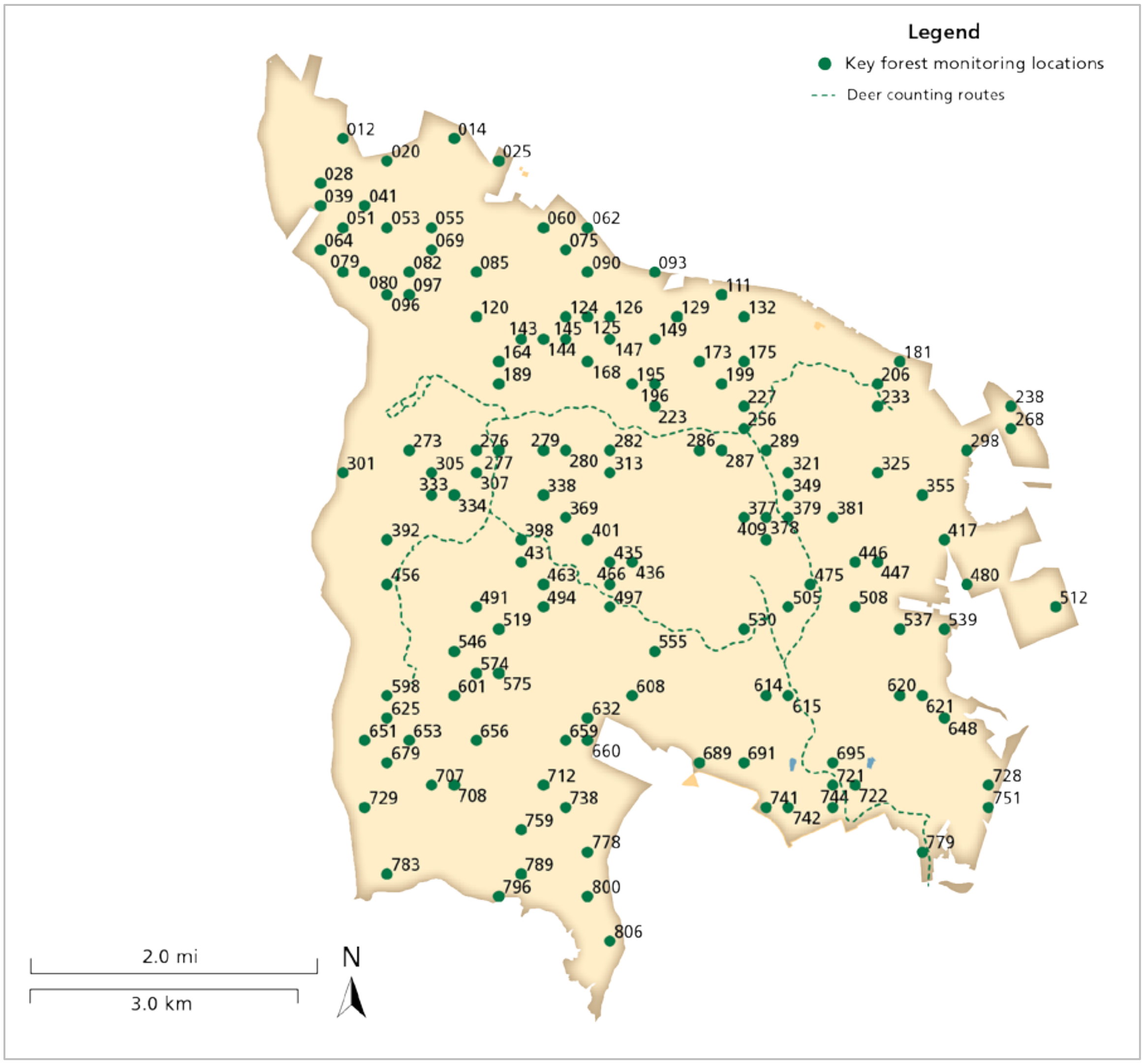

Figure 4-44 Forest monitoring and deer counting routes in PRWI.

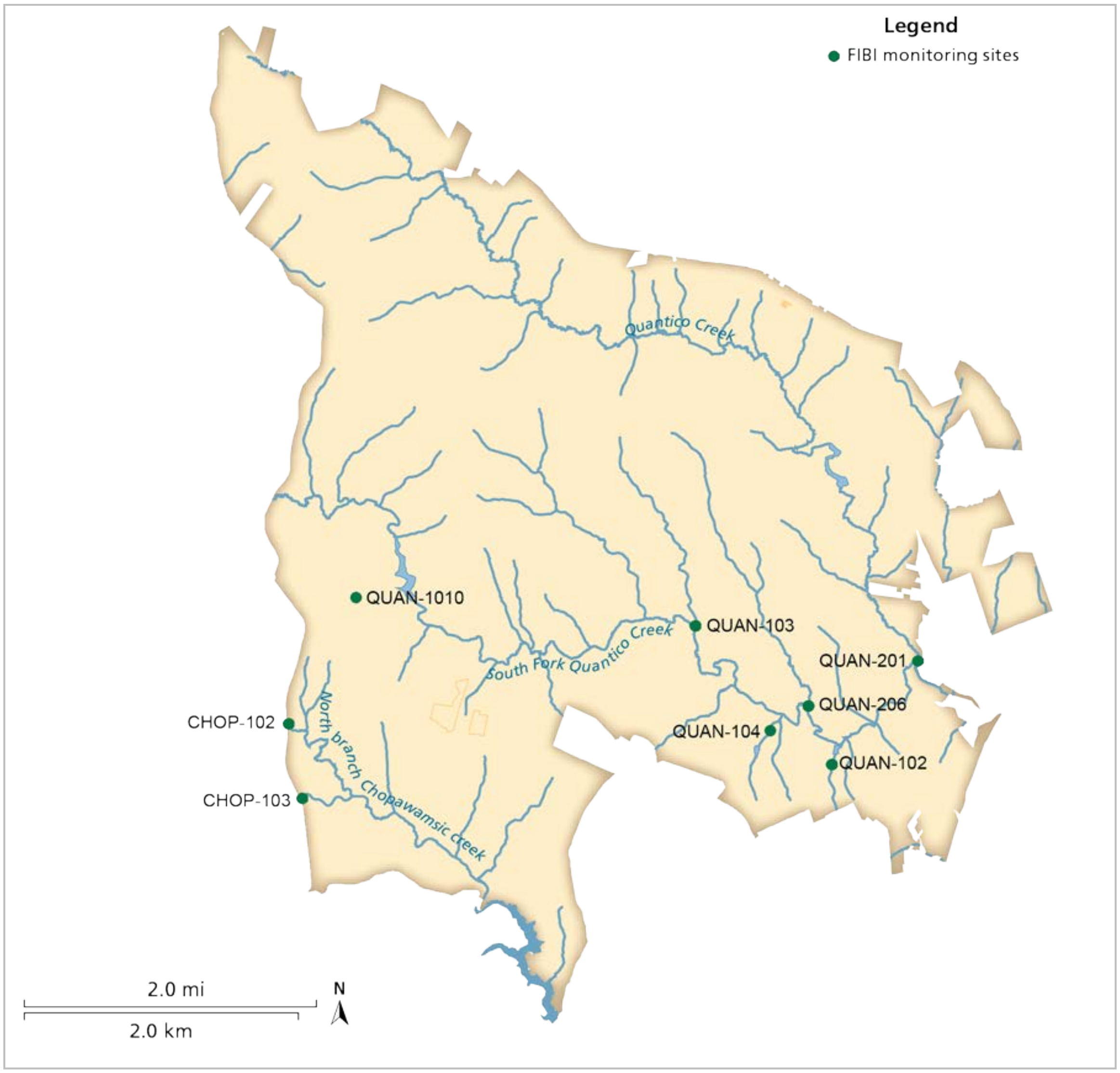

Figure 4-45 Fish index of biotic integrity (FIBI) monitoring sites in PRWI.

Table 4-12 Biological integrity reference conditions for PRWI.

Biological integrity indicator	Number of sites	Number of samples	Period of observation	Reference condition	Percent attainment applied
Presence of exotic herbaceous species (% of plots with exotic species)	145	145	2010-2013	0% (absence)	0-100% scaled linearly
Area of exotic trees & saplings (% of basal area)	145	145	2010-2013	< 5%	0-100% scaled linearly
Presence of forest pest species (% trees infested)	290	145	2010-2013	< 1%	0-100% scaled linearly
Stocking index	145	145	2010-2013	> 115	0-100% scaled linearly
Fish index of biotic integrity	1	1	2007-2013	1.0-1.9; 2.0-2.9; 3.0-3.9; 4.0-5.0	0-100% scaled linearly
Bird community index	132	917	2007-2013	< 40; 40.1-52; 52.1-60; >60	0-100% scaled linearly
Deer density	Park	12	2001-2012	< 8	0-100% scaled linearly
Amphibian stream species occupancy	32		2005-2013	N/A	N/A

Table 4-13 Summary of resource condition assessment of Biological Integrity in PRWI.

Indicator	PRWI result	Percent attainment of reference condition	Condition	Biological integrity condition
Presence of exotic herbaceous species (% of plots with exotic species)	0.9%	79	Good	57% Moderate
Area of exotic trees & saplings (% of basal area)	0%	100	Very good	
Presence of forest pest species (% trees infested)	0%	100	Very good	
Stocking index	17.0	8	Very degraded	
Fish index of biotic integrity	2.7	42	Moderate	
Bird community index	54.0	54	High integrity	
Deer density	12.40	17	Very degraded	
Amphibian stream species occupancy		N/A	N/A	

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 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 (NCRN 2008, 2010).

Exotic herbaceous plants make up the majority of exotic plant species found in the forests of parks of the National Capital Region, and so pose the biggest problem to park management in terms of exotic plants (NRCN 2008, 2010; Schmit et al. 2010). Compared to other NCRN parks, PRWI had a low infestation of forest floor exotic species, with exotic species infesting the floor in less than 20% of plots. Several exotic herbaceous species are present within PRWI, including Japanese honeysuckle (*Lonicera japonica)*, Japanese stiltgrass (*Microstegium vimineum*), Wisteria (*Wisteria floribunda*), Japanese Knotweed (*Fallopia japonica*), and Mile-a-Minute (*Persicaria perfoliata*) (Schmit et al. 2012).

<u>Data and methods</u>

Forest monitoring took place at 145 sites in PRWI from 2010 to 2013, but not all plots were measured every year (Schmit et al. 2009). 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 assigned a pass or fail result and the percentage of passing results were 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 Section 2.1- Park enabling 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 (Table 4-7). Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4-8).

<u>Condition and trend</u>

Current condition for cover of exotic herbaceous species in PRWI was good, with 79% of plots attaining the reference condition of having no exotic herbaceous species present (Table 4-8, Figure 4-26). Therefore, only 21% of plots contained at least one exotic herbaceous plant. No trend analysis was possible with the current data set.

<u>Sources of expertise</u>

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

Table 4-14 Presence of exotic herbaceous plants. Site locations are shown in Figure 4-26.

Monitoring Plot	Year	Exotic Plants
PRWI-0014	2013	Absent
PRWI-0028	2013	Absent
PRWI-0055	2013	Present*
PRWI-0060	2013	Absent
PRWI-0079	2013	Absent
PRWI-0082	2013	Absent
PRWI-0090	2013	Absent
PRWI-0111	2013	Present*
PRWI-0126	2013	Present*
PRWI-0147	2013	Absent
PRWI-0149	2013	Absent
PRWI-0164	2013	Absent
PRWI-0168	2013	Absent
PRWI-0195	2013	Absent
PRWI-0256	2013	Absent
PRWI-0268	2013	Absent
PRWI-0279	2013	Absent
PRWI-0280	2013	Absent
PRWI-0286	2013	Present*
PRWI-0301	2013	Absent
PRWI-0305	2013	Absent
PRWI-0307	2013	Absent
PRWI-0435	2013	Present*
PRWI-0447	2013	Absent
PRWI-0456	2013	Absent
PRWI-0480	2013	Present*
PRWI-0494	2013	Absent
PRWI-0497	2013	Absent
PRWI-0519	2013	Absent
PRWI-0539	2013	Absent
PRWI-0574	2013	Absent
PRWI-0598	2013	Absent
PRWI-0614	2013	Absent
PRWI-0615	2013	Absent
PRWI-0620	2013	Present*
PRWI-0632	2013	Absent
PRWI-0648	2013	Absent
PRWI-0659	2013	Absent
PRWI-0679	2013	Absent
PRWI-0707	2013	Present*
PRWI-0708	2013	Absent
PRWI-0729	2013	Present*
PRWI-0778	2013	Absent
PRWI-0806	2013	Absent
PRWI-0020	2012	Absent
PRWI-0053	2012	Absent
PRWI-0064	2012	Absent
PRWI-0069	2012	Present*

Monitoring Plot	Year	Exotic Plants
PRWI-0096	2012	Absent
PRWI-0124	2012	Absent
PRWI-0125	2012	Absent
PRWI-0129	2012	Absent
PRWI-0132	2012	Absent
PRWI-0144	2012	Absent
PRWI-0196	2012	Absent
PRWI-0273	2012	Present*
PRWI-0334	2012	Present*
PRWI-0349	2012	Absent
PRWI-0355	2012	Absent
PRWI-0369	2012	Absent
PRWI-0377	2012	Present*
PRWI-0379	2012	Absent
PRWI-0392	2012	Absent
PRWI-0401	2012	Absent
PRWI-0409	2012	Absent
PRWI-0466	2012	Absent
PRWI-0505	2012	Present*
PRWI-0530	2012	Absent
PRWI-0555	2012	Absent
PRWI-0601	2012	Absent
PRWI-0653	2012	Absent
PRWI-0660	2012	Absent
PRWI-0689	2012	Absent
PRWI-0721	2012	Absent
PRWI-0759	2012	Absent
PRWI-0783	2012	Absent
PRWI-0800	2012	Absent
PRWI-0025	2011	Absent
PRWI-0039	2011	Absent
PRWI-0041	2011	Absent
PRWI-0097	2011	Absent
PRWI-0120	2011	Present*
PRWI-0143	2011	Absent
PRWI-0189	2011	Absent
PRWI-0206	2011	Present*
PRWI-0227	2011	Absent
PRWI-0287	2011	Absent
PRWI-0289	2011	Absent
PRWI-0298	2011	Absent
PRWI-0313	2011	Absent
PRWI-0325	2011	Absent
PRWI-0378	2011	Present*
PRWI-0381	2011	Absent
PRWI-0417	2011	Present*
PRWI-0431	2011	Absent
PRWI-0475	2011	Present*

Table 4-9 (continued) Presence of exotic herbaceous plants. Site locations shown in Figure 4-26.

Monitoring Plot	Year	Exotic Plants
PRWI-0512	2011	Absent
PRWI-0537	2011	Absent
PRWI-0546	2011	Absent
PRWI-0575	2011	Absent
PRWI-0608	2011	Absent
PRWI-0625	2011	Absent
PRWI-0651	2011	Absent
PRWI-0656	2011	Absent
PRWI-0691	2011	Absent
PRWI-0738	2011	Absent
PRWI-0741	2011	Absent
PRWI-0742	2011	Absent
PRWI-0744	2011	Absent
PRWI-0779	2011	Present*
PRWI-0012	2010	Absent
PRWI-0051	2010	Absent
PRWI-0062	2010	Absent
PRWI-0075	2010	Absent
PRWI-0080	2010	Absent
PRWI-0085	2010	Absent
PRWI-0093	2010	Absent
PRWI-0145	2010	Present*
PRWI-0173	2010	Absent
PRWI-0175	2010	Present*
PRWI-0181	2010	Present*
PRWI-0199	2010	Absent

Monitoring Plot	Year	Exotic Plants
PRWI-0223	2010	Absent
PRWI-0233	2010	Absent
PRWI-0238	2010	Present*
PRWI-0276	2010	Absent
PRWI-0277	2010	Absent
PRWI-0282	2010	Absent
PRWI-0321	2010	Present*
PRWI-0333	2010	Absent
PRWI-0338	2010	Absent
PRWI-0398	2010	Absent
PRWI-0436	2010	Absent
PRWI-0446	2010	Absent
PRWI-0463	2010	Absent
PRWI-0491	2010	Absent
PRWI-0508	2010	Absent
PRWI-0621	2010	Present*
PRWI-0695	2010	Present*
PRWI-0712	2010	Absent
PRWI-0722	2010	Absent
PRWI-0728	2010	Present*
PRWI-0751	2010	Present*
PRWI-0789	2010	Absent
PRWI-0796	2010	Present*

*Values outside of reference condition of having no exotic herbaceous plants present.

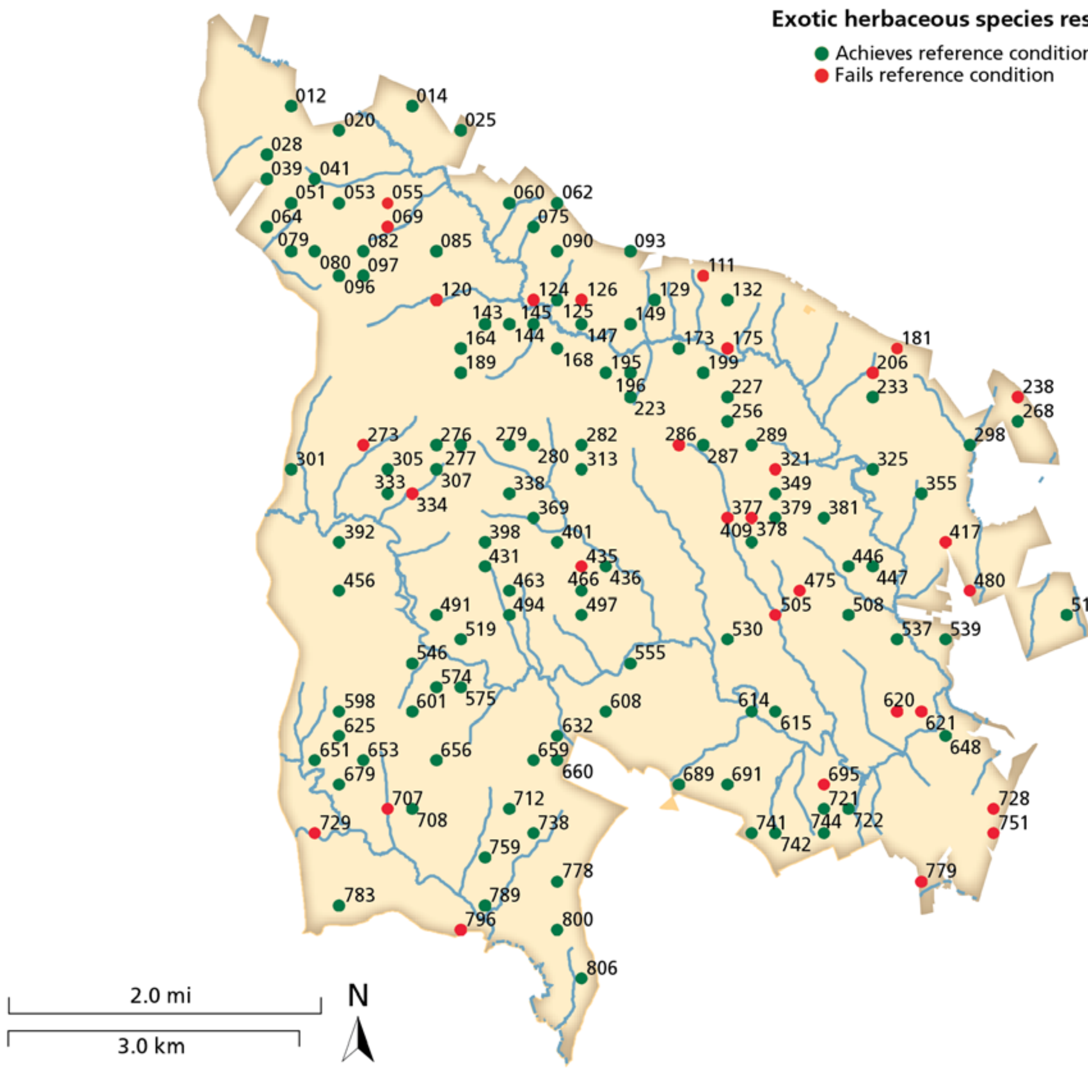

Figure 4-46 Exotic herbaceous species results by site for PRWI.

Exotic trees & saplings

<u>Description</u>

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 plant species, especially those that are invasive, are a ubiquitous and growing threat in the National Capital Region (NCRN 2008, 2010). NCRN Inventory and Monitoring sampling identified two exotic tree species in PRWI, represented by a single individual of each species. Tree of heaven (*Ailanthus altissima*) and common pear (*Pyrus communis*). No exotic saplings were recorded in the park (Schmit et al. 2012). The National Park Service exotic plants management team has identified several exotic tree species within PRWI, including *Paulownia tomentosa* (empress tree), *Albizia julibrissin* (Persian silk or mimosa tree), and *Picea abies* (Norway spruce).

Data and methods

Forest monitoring took place annually but not all plots were measured every year, and data was recorded for four years (2010-2013) (Schmit et al. 2009; Schmit et al. 2012). 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 reference condition used for this assessment was that the abundance of these invasive exotic plants should not exceed 5% of total basal area (Table 4-7). 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- Park 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 PRWI, 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 was very good, with a mean of 0% total basal area and 100% of data plots attaining the reference condition of ≤ 5% of total basal area (Table 4-8,

Table 4-10). There were however two plots containing exotic trees, PRWI-0111 and PRWI-0126, but in both cases, % basal area was below the reference condition of ≤ 5% (1.9% and 0.5% respectively) (Table 4-8). No trend analysis was possible with the current data set.

Table 4-15 Percent basal area of exotic trees and exotic saplings. Site locations are shown in Figure 4-39.

Monitoring Plot	Date	Exotic trees (% basal area)	Exotic saplings (% basal area)
PRWI-0614	6/11/13	0	0
PRWI-0615	6/11/13	0	0
PRWI-0778	6/13/13	0	0
PRWI-0806	6/13/13	0	0
PRWI-0256	6/17/13	0	0
PRWI-0497	6/17/13	0	0
PRWI-0028	6/19/13	0	0
PRWI-0079	6/19/13	0	0
PRWI-0679	6/20/13	0	0
PRWI-0729	6/20/13	0	0
PRWI-0060	6/24/13	0	0
PRWI-0090	6/24/13	0	0
PRWI-0286	6/25/13	0	0

Table 4-10 (continued) Percent basal area of exotic tree and exotic saplings. Site locations are shown in Figure 4-39.

Monitoring Plot	Date	Exotic trees (% basal area)	Exotic saplings (% basal area)
PRWI-0111	6/27/13	1.9	0
PRWI-0268	6/27/13	0	0
PRWI-0279	7/1/13	0	0
PRWI-0280	7/1/13	0	0
PRWI-0632	7/2/13	0	0
PRWI-0659	7/2/13	0	0
PRWI-0620	7/8/13	0	0
PRWI-0648	7/8/13	0	0
PRWI-0164	7/10/13	0	0
PRWI-0195	7/10/13	0	0
PRWI-0168	7/12/13	0	0
PRWI-0435	7/12/13	0	0
PRWI-0305	7/15/13	0	0
PRWI-0307	7/15/13	0	0
PRWI-0055	7/22/13	0	0
PRWI-0126	7/23/13	0.5	0
PRWI-0147	7/23/13	0	0
PRWI-0519	7/25/13	0	0
PRWI-0707	7/31/13	0	0
PRWI-0494	8/1/13	0	0
PRWI-0598	8/5/13	0	0
PRWI-0082	8/6/13	0	0
PRWI-0301	8/6/13	0	0
PRWI-0149	8/9/13	0	0
PRWI-0456	8/16/13	0	0
PRWI-0447	8/21/13	0	0
PRWI-0539	8/21/13	0	0
PRWI-0574	8/23/13	0	0
PRWI-0014	8/30/13	0	0
PRWI-0708	9/9/13	0	0
PRWI-0480	9/16/13	0	0
PRWI-0530	6/26/12	0	0
PRWI-0721	6/26/12	0	0
PRWI-0377	6/27/12	0	0
PRWI-0409	6/27/12	0	0
PRWI-0369	7/9/12	0	0
PRWI-0401	7/9/12	0	0
PRWI-0129	7/23/12	0	0
PRWI-0132	7/23/12	0	0
PRWI-0466	7/25/12	0	0
PRWI-0505	7/27/12	0	0
PRWI-0759	7/30/12	0	0
PRWI-0800	7/30/12	0	0
PRWI-0783	7/31/12	0	0
PRWI-0069	8/1/12	0	0
PRWI-0096	8/1/12	0	0
PRWI-0601	8/6/12	0	0
PRWI-0653	8/14/12	0	0

Table 4-10 (continued) Percent basal area of exotic tree and exotic saplings. Site locations are shown in Figure 4-39.

Monitoring Plot	Date	Exotic trees (% basal area)	Exotic saplings (% basal area)
PRWI-0379	8/16/12	0	0
PRWI-0660	8/20/12	0	0
PRWI-0349	8/21/12	0	0
PRWI-0020	8/22/12	0	0
PRWI-0689	8/23/12	0	0
PRWI-0555	8/28/12	0	0
PRWI-0144	8/29/12	0	0
PRWI-0392	8/30/12	0	0
PRWI-0053	9/4/12	0	0
PRWI-0064	9/7/12	0	0
PRWI-0355	9/10/12	0	0
PRWI-0334	9/12/12	0	0
PRWI-0196	9/13/12	0	0
PRWI-0124	9/26/12	0	0
PRWI-0273	10/2/12	0	0
PRWI-0289	6/2/11	0	0
PRWI-0206	6/7/11	0	0
PRWI-0741	6/13/11	0	0
PRWI-0227	6/16/11	0	0
PRWI-0298	6/23/11	0	0
PRWI-0512	6/23/11	0	0
PRWI-0417	6/29/11	0	0
PRWI-0742	6/29/11	0	0
PRWI-0025	7/1/11	0	0
PRWI-0738	7/8/11	0	0
PRWI-0189	7/11/11	0	0
PRWI-0381	7/11/11	0	0
PRWI-0143	7/13/11	0	0
PRWI-0537	7/15/11	0	0
PRWI-0325	7/18/11	0	0
PRWI-0575	7/19/11	0	0
PRWI-0608	7/19/11	0	0
PRWI-0313	7/25/11	0	0
PRWI-0039	7/26/11	0	0
PRWI-0041	7/26/11	0	0
PRWI-0097	7/27/11	0	0
PRWI-0120	7/28/11	0	0
PRWI-0651	8/2/11	0	0
PRWI-0744	8/5/11	0	0
PRWI-0475	8/10/11	0	0
PRWI-0625	8/12/11	0	0
PRWI-0779	8/22/11	0	0
PRWI-0691	8/26/11	0	0
PRWI-0378	8/30/11	0	0
PRWI-0431	9/1/11	0	0
PRWI-0287	9/9/11	0	0
PRWI-0546	9/14/11	0	0
PRWI-0656	9/29/11	0	0

Table 4-10 (continued) Percent basal area of exotic tree and exotic saplings. Site locations are shown in Figure 4-39.

Monitoring Plot	Date	Exotic trees (% basal area)	Exotic saplings (% basal area)
PRWI-0398	5/21/10	0	0
PRWI-0621	6/1/10	0	0
PRWI-0223	6/2/10	0	0
PRWI-0276	6/4/10	0	0
PRWI-0722	6/11/10	0	0
PRWI-0446	6/14/10	0	0
PRWI-0508	6/15/10	0	0
PRWI-0751	6/15/10	0	0
PRWI-0728	6/16/10	0	0
PRWI-0436	6/25/10	0	0
PRWI-0463	6/28/10	0	0
PRWI-0238	7/9/10	0	0
PRWI-0062	7/12/10	0	0
PRWI-0093	7/12/10	0	0
PRWI-0181	7/13/10	0	0
PRWI-0233	7/13/10	0	0
PRWI-0695	7/14/10	0	0
PRWI-0175	7/15/10	0	0
PRWI-0796	7/21/10	0	0
PRWI-0085	7/27/10	0	0
PRWI-0080	7/29/10	0	0
PRWI-0012	8/3/10	0	0
PRWI-0277	8/20/10	0	0
PRWI-0321	8/25/10	0	0
PRWI-0173	8/27/10	0	0
PRWI-0199	8/27/10	0	0
PRWI-0075	9/3/10	0	0
PRWI-0051	9/10/10	0	0
PRWI-0491	9/14/10	0	0
PRWI-0712	9/21/10	0	0
PRWI-0789	9/21/10	0	0
PRWI-0282	9/22/10	0	0
PRWI-0338	9/27/10	0	0
PRWI-0333	9/28/10	0	0
PRWI-0145	9/29/10	0	0

* Values outside of reference condition of ≤ 5% cover. Blank cells indicate there were no saplings present in the plot.

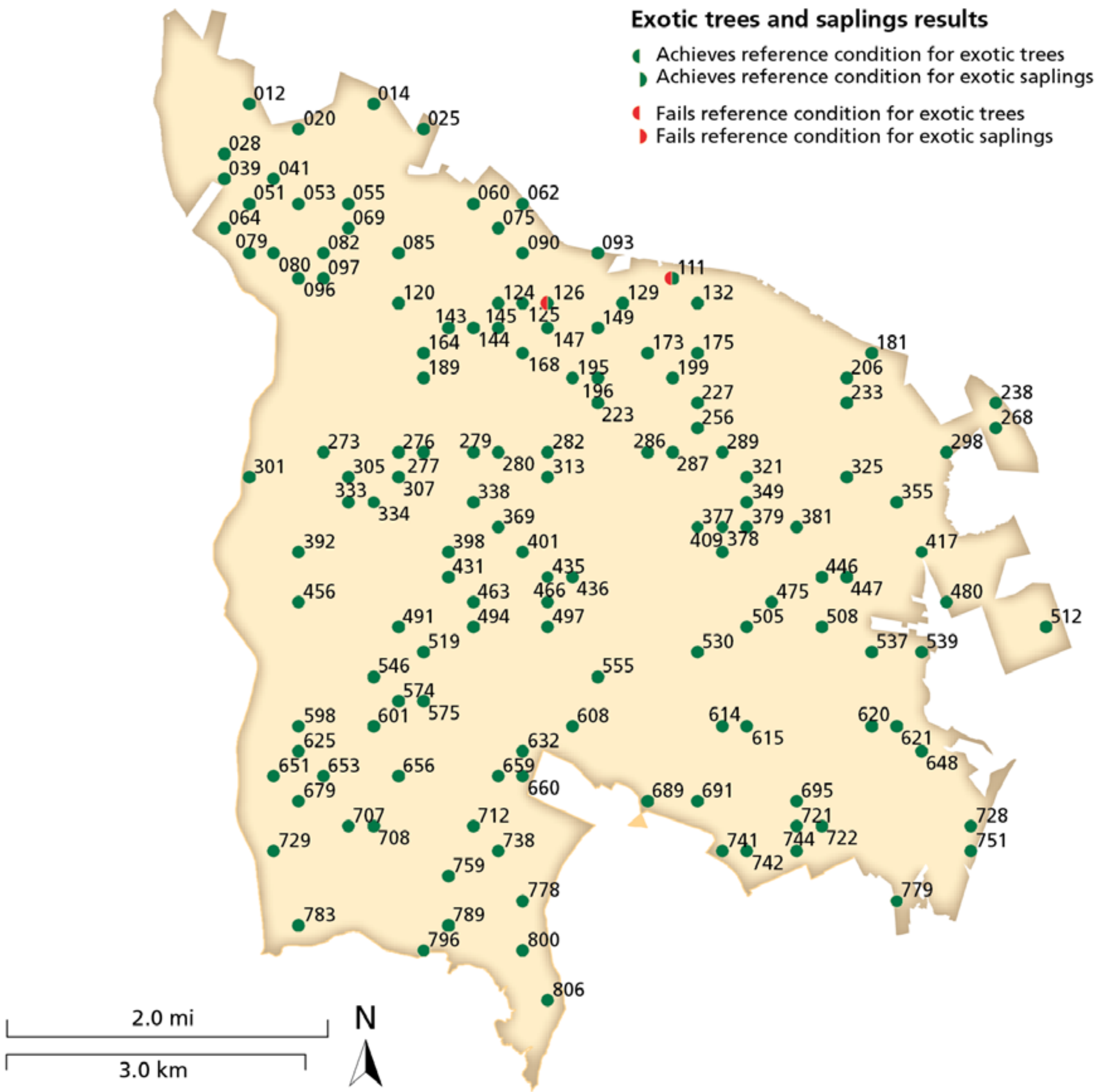

Figure 4-47 Exotic tree and sapling results by site for PRWI.

Sources of expertise

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

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 loads.

The gypsy moth (*Lymantria dispar*) was accidentally introduced to North America in the late 1860s and has spread widely, resulting in an estimated 160,000 km^2 (62,500 mi^2) of forest defoliation during the 1980s alone (Liebhold et al. 1994, Montgomery 1990). The gypsy moth larvae feed on the foliage of hundreds of species of plants in North America, but its most common hosts are oak (*Quercus* spp.) and aspen (*Populus* spp.) trees (USDA Forest Service 2009a).

Hemlock woolly adelgid (*Adelges tsugae*) is another insect pest first reported in the eastern United States in 1951 near Richmond, Virginia (USDA Forest Service 2009b). This aphid-like insect is originally from Asia and feeds on eastern hemlock trees (*Tsuga canadensis*), which are often damaged and killed within a few years of becoming infested. Remnant stands of hemlock have been reported to be infested with hemlock woolly adelgid (pers. comm. Paul Peterson 2014).

During NCRN I&M forest vegetation monitoring, one dogwood tree in PRWI was found to be exhibiting signs of dogwood anthracnose infestation (caused by the fungus *Discula destructiva*) between 2006 and 2009 (Schmit et al. 2012).

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; Schmit et al. 2012). 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 assigned a pass or fail result and the percentage of passing results were used as the percent attainment. Data reported for each plot were for hemlock woolly adelgid, gypsy moth, and “other insect damage.”

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 4-8).

Condition and trend

Current condition for insect pests in PRWI was very good, with a mean of 0.06% of trees infested and 99% of data points attaining reference condition (Table 4-8, Table 4-11, Figure 4-28). No trend analysis was possible with the current data set.

Table 4-16 Percent of trees with evidence of forest pest species.

Monitoring Plot	Year	% trees with pests
PRWI-0014	2013	0.0
PRWI-0028	2013	0.0
PRWI-0055	2013	0.0
PRWI-0060	2013	0.0
PRWI-0079	2013	0.0
PRWI-0082	2013	0.0
PRWI-0090	2013	0.0
PRWI-0111	2013	0.0
PRWI-0126	2013	0.0
PRWI-0147	2013	0.0
PRWI-0149	2013	0.0
PRWI-0164	2013	0.0
PRWI-0168	2013	0.0
PRWI-0195	2013	0.0
PRWI-0256	2013	0.0
PRWI-0268	2013	0.0
PRWI-0279	2013	0.0
PRWI-0280	2013	0.0
PRWI-0286	2013	0.0
PRWI-0301	2013	0.0
PRWI-0305	2013	0.0
PRWI-0307	2013	0.0
PRWI-0435	2013	0.0
PRWI-0447	2013	0.0
PRWI-0456	2013	4.7*
PRWI-0480	2013	0.0
PRWI-0494	2013	0.0
PRWI-0497	2013	0.0
PRWI-0519	2013	0.0
PRWI-0539	2013	0.0
PRWI-0574	2013	0.0
PRWI-0598	2013	4.3*
PRWI-0614	2013	0.0
PRWI-0615	2013	0.0
PRWI-0620	2013	0.0
PRWI-0632	2013	0.0
PRWI-0648	2013	0.0
PRWI-0659	2013	0.0
PRWI-0679	2013	0.0
PRWI-0707	2013	0.0
PRWI-0708	2013	0.0
PRWI-0729	2013	0.0
PRWI-0778	2013	0.0
PRWI-0806	2013	0.0
PRWI-0020	2012	0.0
PRWI-0053	2012	0.0
PRWI-0064	2012	0.0
PRWI-0069	2012	0.0
PRWI-0096	2012	0.0
PRWI-0124	2012	0.0
PRWI-0125	2012	0.0
PRWI-0129	2012	0.0
PRWI-0132	2012	0.0
PRWI-0144	2012	0.0
PRWI-0196	2012	0.0
PRWI-0273	2012	0.0
PRWI-0334	2012	0.0
PRWI-0349	2012	0.0
PRWI-0355	2012	0.0
PRWI-0369	2012	0.0
PRWI-0377	2012	0.0
PRWI-0379	2012	0.0
PRWI-0392	2012	0.0
PRWI-0401	2012	0.0
PRWI-0409	2012	0.0
PRWI-0466	2012	0.0
PRWI-0505	2012	0.0
PRWI-0530	2012	0.0
PRWI-0555	2012	0.0
PRWI-0601	2012	0.0
PRWI-0653	2012	0.0
PRWI-0660	2012	0.0
PRWI-0689	2012	0.0
PRWI-0721	2012	0.0
PRWI-0759	2012	0.0
PRWI-0783	2012	0.0
PRWI-0800	2012	0.0
PRWI-0025	2011	0.0
PRWI-0039	2011	0.0
PRWI-0041	2011	0.0
PRWI-0097	2011	0.0
PRWI-0120	2011	0.0
PRWI-0143	2011	0.0
PRWI-0189	2011	0.0
PRWI-0206	2011	0.0
PRWI-0227	2011	0.0
PRWI-0287	2011	0.0
PRWI-0289	2011	0.0

Table 4-11 (continued) Percent of trees with evidence of forest pest species

PRWI-0298	**2011**	**0.0**
PRWI-0313	2011	0.0
PRWI-0325	2011	0.0
PRWI-0378	2011	0.0
PRWI-0381	2011	0.0
PRWI-0417	2011	0.0
PRWI-0431	2011	0.0
PRWI-0475	2011	0.0
PRWI-0512	2011	0.0
PRWI-0537	2011	0.0
PRWI-0546	2011	0.0
PRWI-0575	2011	0.0
PRWI-0608	2011	0.0
PRWI-0625	2011	0.0
PRWI-0651	2011	0.0
PRWI-0656	2011	0.0
PRWI-0691	2011	0.0
PRWI-0738	2011	0.0
PRWI-0741	2011	0.0
PRWI-0742	2011	0.0
PRWI-0744	2011	0.0
PRWI-0779	2011	0.0
PRWI-0012	2010	0.0
PRWI-0051	2010	0.0
PRWI-0062	2010	0.0
PRWI-0075	2010	0.0
PRWI-0080	2010	0.0
PRWI-0085	2010	0.0
PRWI-0093	2010	0.0
PRWI-0145	2010	0.0
PRWI-0173	2010	0.0
PRWI-0175	2010	0.0
PRWI-0181	2010	0.0
PRWI-0199	2010	0.0
PRWI-0223	2010	0.0
PRWI-0233	2010	0.0
PRWI-0238	2010	0.0
PRWI-0276	2010	0.0
PRWI-0277	2010	0.0
PRWI-0282	2010	0.0
PRWI-0321	2010	0.0
PRWI-0333	2010	0.0
PRWI-0338	2010	0.0
PRWI-0398	2010	0.0
PRWI-0436	2010	0.0
PRWI-0446	2010	0.0
PRWI-0463	2010	0.0
PRWI-0491	2010	0.0
PRWI-0508	2010	0.0
PRWI-0621	2010	0.0
PRWI-0695	2010	0.0
PRWI-0712	2010	0.0
PRWI-0722	2010	0.0
PRWI-0728	2010	0.0
PRWI-0751	2010	0.0
PRWI-0789	2010	0.0
PRWI-0796	2010	0.0

*Values outside of reference condition of having no evidence of forest pests.

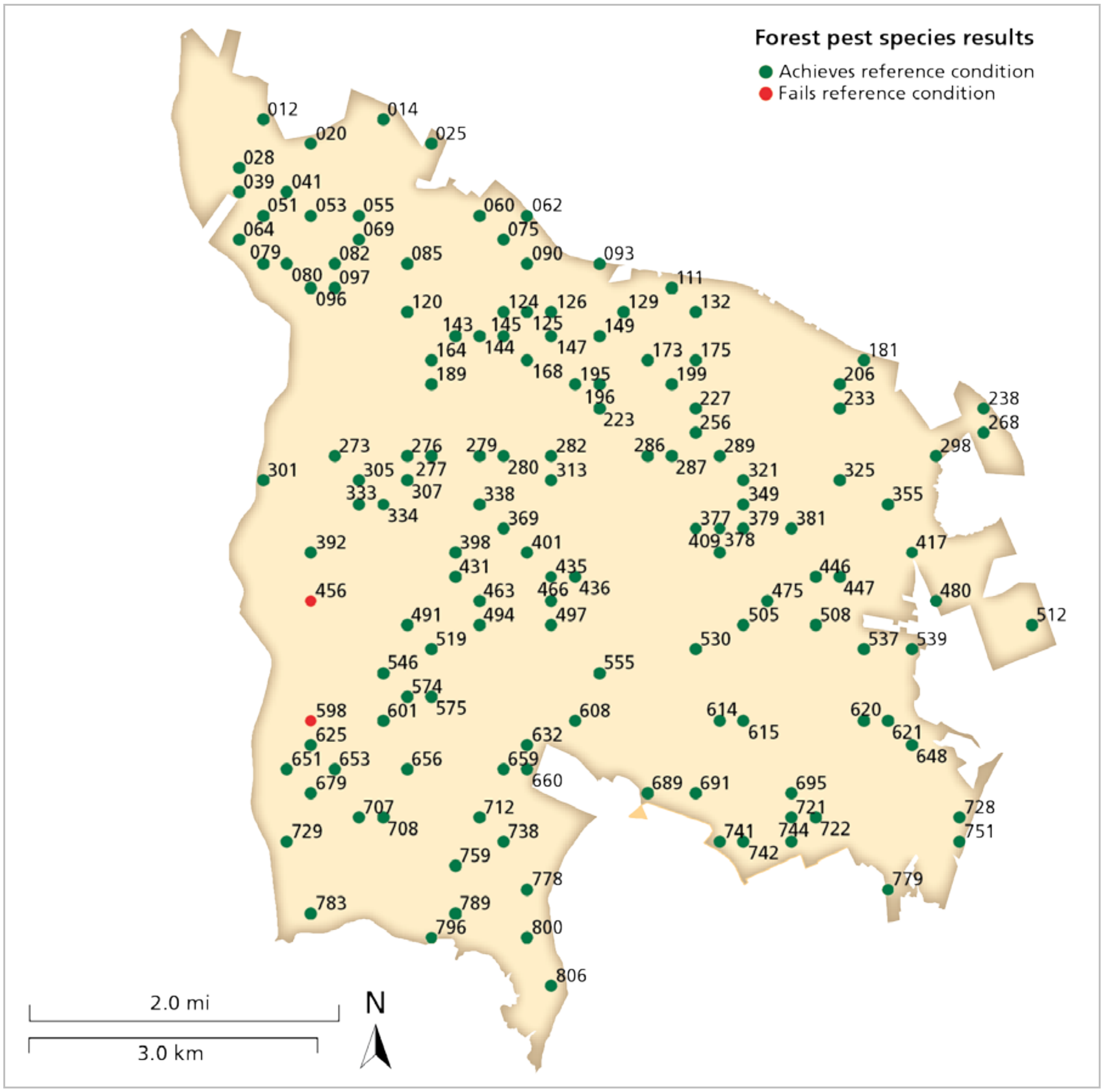

Figure 4-48 Forest pest species results by site for PRWI.

Seedlings and forest regeneration

<u>Description</u>

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 (Jordan 1967, Marquis 1981, Tilghman 1989, Tierson et al. 1996, 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 the seedlings and small saplings present.

Data and methods

Forest monitoring took place annually between 2010 and 2013 but not all plots were measured every year (Schmit *et al.* 2009). 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 is given a score, with older/larger seedlings and saplings receiving a higher score than smaller plants. Only seedlings ≥ 15 cm height and 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 assigned a pass or fail result and the percentage of passing results were used as the percent attainment.

Condition and trend

Current condition for native tree seedling regeneration in PRWI was very degraded, with a mean stocking index value of 17 seedlings/ha and 8% of data points attaining reference condition of > 115 (Table 4-8, Table 4-12, Figure 4-29). No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-17 Stocking index values.

Monitoring Plot	Year	Stocking Index	Monitoring Plot	Year	Stocking Index
PRWI-0014	2013	1*	PRWI-0435	2013	31.75*
PRWI-0028	2013	30.25*	PRWI-0447	2013	20.25*
PRWI-0055	2013	0*	PRWI-0456	2013	194.5
PRWI-0060	2013	6.25*	PRWI-0480	2013	1*
PRWI-0079	2013	8.25*	PRWI-0494	2013	330.25
PRWI-0082	2013	70.5*	PRWI-0497	2013	9.5*
PRWI-0090	2013	12.75*	PRWI-0519	2013	6.25*
PRWI-0111	2013	4*	PRWI-0539	2013	17*
PRWI-0126	2013	71.25*	PRWI-0574	2013	0*
PRWI-0147	2013	21.25*	PRWI-0598	2013	11.25*
PRWI-0149	2013	11.25*	PRWI-0614	2013	13.25*
PRWI-0164	2013	24.5*	PRWI-0615	2013	10.25*
PRWI-0168	2013	79.75*	PRWI-0620	2013	5.25*
PRWI-0195	2013	7.25*	PRWI-0632	2013	2*
PRWI-0256	2013	137	PRWI-0648	2013	54.25*
PRWI-0268	2013	28.5*	PRWI-0659	2013	43.25*
PRWI-0279	2013	18.75*	PRWI-0679	2013	12.25*
PRWI-0280	2013	17*	PRWI-0707	2013	80.25*
PRWI-0286	2013	56.5*	PRWI-0708	2013	32*
PRWI-0301	2013	48.5*	PRWI-0729	2013	120.75
PRWI-0305	2013	10*	PRWI-0778	2013	27.5*
PRWI-0307	2013	10*	PRWI-0806	2013	26*

Table 4-12 (continued) Stocking index values

Monitoring Plot	Year	Stocking Index	Monitoring Plot	Year	Stocking Index
PRWI-0020	2012	0*	PRWI-0381	2011	17*
PRWI-0053	2012	12.5*	PRWI-0417	2011	4.25*
PRWI-0064	2012	184	PRWI-0431	2011	14.25*
PRWI-0069	2012	17*	PRWI-0475	2011	20.75*
PRWI-0096	2012	10.25*	PRWI-0512	2011	19*
PRWI-0124	2012	36*	PRWI-0537	2011	180
PRWI-0125	2012	44.25*	PRWI-0546	2011	7.25*
PRWI-0129	2012	18.5*	PRWI-0575	2011	1*
PRWI-0132	2012	3*	PRWI-0608	2011	1*
PRWI-0144	2012	7.25*	PRWI-0625	2011	16*
PRWI-0196	2012	27.25*	PRWI-0651	2011	15*
PRWI-0273	2012	234.25	PRWI-0656	2011	1*
PRWI-0334	2012	108.25*	PRWI-0691	2011	8.5*
PRWI-0349	2012	27.25*	PRWI-0738	2011	30.25*
PRWI-0355	2012	32*	PRWI-0741	2011	23*
PRWI-0369	2012	15.5*	PRWI-0742	2011	26. 5*
PRWI-0377	2012	11.25*	PRWI-0744	2011	8*
PRWI-0379	2012	57.25*	PRWI-0779	2011	13.75*
PRWI-0392	2012	238.25	PRWI-0012	2010	9.25*
PRWI-0401	2012	25*	PRWI-0051	2010	19.75*
PRWI-0409	2012	66*	PRWI-0062	2010	9*
PRWI-0466	2012	1*	PRWI-0075	2010	11.5*
PRWI-0505	2012	29*	PRWI-0080	2010	153.5
PRWI-0530	2012	6.25*	PRWI-0085	2010	10.5*
PRWI-0555	2012	10.5*	PRWI-0093	2010	7*
PRWI-0601	2012	23.75*	PRWI-0145	2010	26.5*
PRWI-0653	2012	3*	PRWI-0173	2010	21.75*
PRWI-0660	2012	6.25*	PRWI-0175	2010	10.5*
PRWI-0689	2012	7.25*	PRWI-0181	2010	38*
PRWI-0721	2012	30.5*	PRWI-0199	2010	5.25*
PRWI-0759	2012	35.75*	PRWI-0223	2010	13.5*
PRWI-0783	2012	5*	PRWI-0233	2010	4.25*
PRWI-0800	2012	22.75*	PRWI-0238	2010	32.75*
PRWI-0025	2011	35*	PRWI-0276	2010	66.25*
PRWI-0039	2011	122.75	PRWI-0277	2010	11.25*
PRWI-0041	2011	8.5*	PRWI-0282	2010	40.75*
PRWI-0097	2011	17*	PRWI-0321	2010	6*
PRWI-0120	2011	190.5	PRWI-0333	2010	462
PRWI-0143	2011	3*	PRWI-0338	2010	28.25*
PRWI-0189	2011	10.25*	PRWI-0398	2010	26.5*
PRWI-0206	2011	13*	PRWI-0436	2010	12.75*
PRWI-0227	2011	38.25*	PRWI-0446	2010	4.25*
PRWI-0287	2011	13.5*	PRWI-0463	2010	13.75*
PRWI-0289	2011	29.75*	PRWI-0491	2010	195.5
PRWI-0298	2011	19*	PRWI-0508	2010	26*
PRWI-0313	2011	39.75*	PRWI-0621	2010	8.5*
PRWI-0325	2011	8.25*	PRWI-0695	2010	39*
PRWI-0378	2011	31.25*	PRWI-0712	2010	52.25*

*Values outside of the stocking index reference condition of > 115.

Table 4-12 (continued) Stocking index values

Monitoring Plot	Year	Stocking Index
PRWI-0722	2010	10.5*
PRWI-0728	2010	5.25*
PRWI-0751	2010	11.5*
PRWI-0789	2010	6*
PRWI-0796	2010	34*

*Values outside of the stocking index reference condition of > 115.

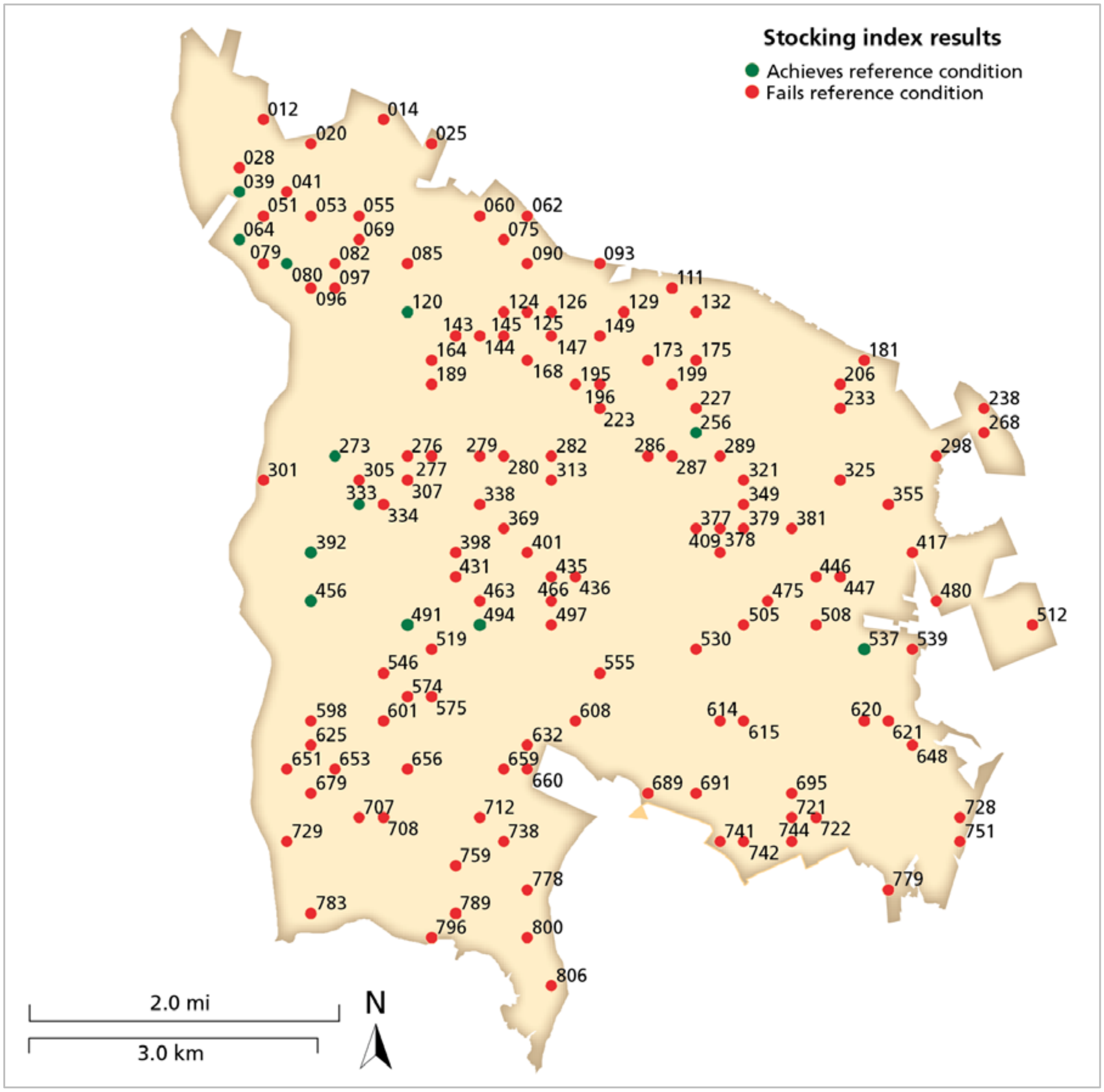

Figure 4-49 Stocking Index results by site for PRWI.

Fish

<u>Description</u>

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 indicators alone (Karr 1981). The indicator 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 eight sites during 2004, 2006, and 2011. 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 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 trends

Current condition of FIBI in PRWI was poor, with a mean FIBI of 2.67 and 41.8% attainment of reference condition (Table 4-8, Table 4-13, Figure 4-30, Figure 4-31).

No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-18 Fish Index of Biotic Integrity (FIBI) in PRWI. Monitoring sites are shown in Figure 4-25.

Year	Site	Location	FIBI
2011	QUAN-104-N-2011	Carter's Run	1.00
2011	QUAN-101-N-2011	Mawavi Run	1.33
2011	QUAN-206-N-2011	Mary Bird Branch	3.00
2011	CHOP-103-N-2011	Middle Branch Chopawamsic	3.67
2011	QUAN-201-N-2011	Quantico Creek	2.67
2011	CHOP-102-N-2011	North Branch Chopawamsic	3.67
2011	QUAN-102-N-2011	Orenda Run	1.67
2011	QUAN-103-N-2011	Taylor Run	4.00
2006	CHOP-102-N-2006	North Branch Chopawamsic	2.33
2004	CHOP-103-N-2004	Middle Branch Chopawamsic	3.33
2004	CHOP-102-N-2004	North Branch Chopawamsic	2.33

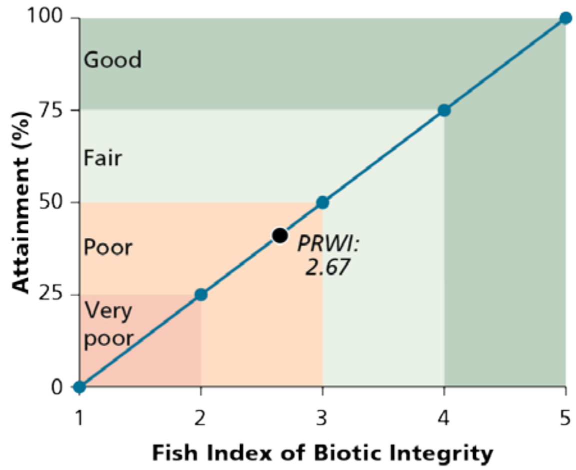

Figure 4-50 Application of the percent attainment categories to the Fish Index of Biotic Integrity (FIBI) value categories. FIBI at PRWI was 2.67, which equated to 41.8% attainment of the reference condition.

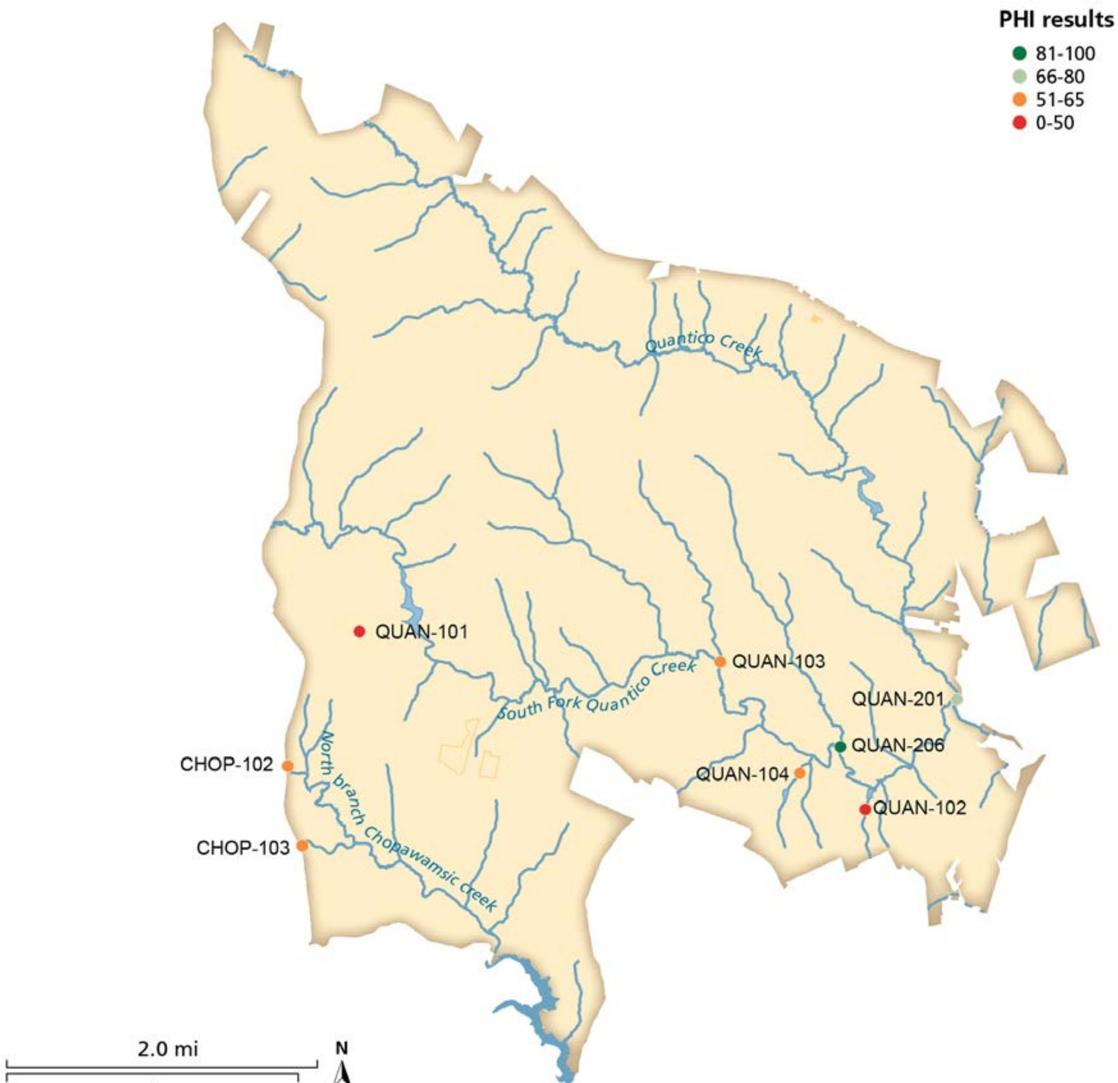

Figure 4-51 Attainment of Fish Index of Biotic Integrity (FIBI) reference condition by site for eight sampling locations in PRWI. Result for PRWI is the mean for three sampling years.

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 132 sites between 2007 and 2013. 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 (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), and these were the scale and categories used in this assessment (O'Connell *et al.* 1998).

Each of the four BCI value categories was assigned a percent attainment range. The median of all of 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 trend

The BCI of forest sites in PRWI showed high integrity, with a median bird community index of 54.0 and 54.2% attainment of reference condition (Table 4-8, Table 4-14, Figure 4-32, Figure 4-33).

Sources of expertise

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

Table 4-19 The median Bird Community Index (BCI) score for all sites in PRWI. Monitoring site location shown in Figure 4-33.

Year	Median Bird Community Index (BCI)
2013	67.5
2012	62.5
2011	62.5
2010	63.5
2009	64.5
2008	63.5
2007	64.5

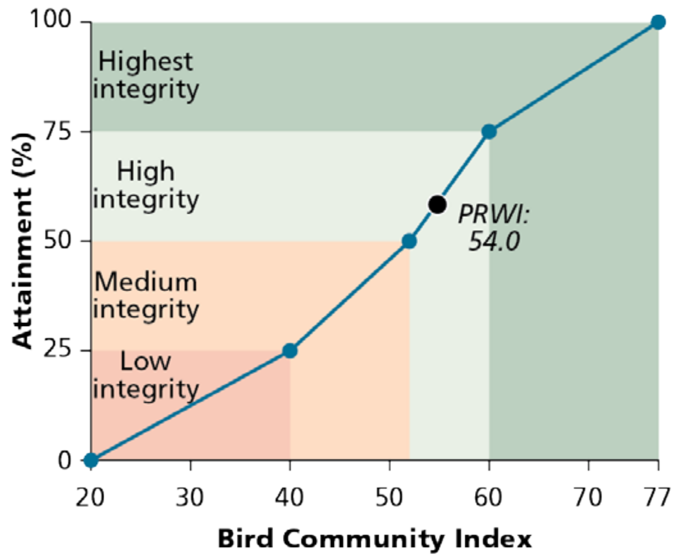

Figure 4-52 Application of the percent attainment categories to the Bird Community Index (BCI) value categories. BCI at PRWI was 54.0, which equated to 54.2% attainment of the reference condition.

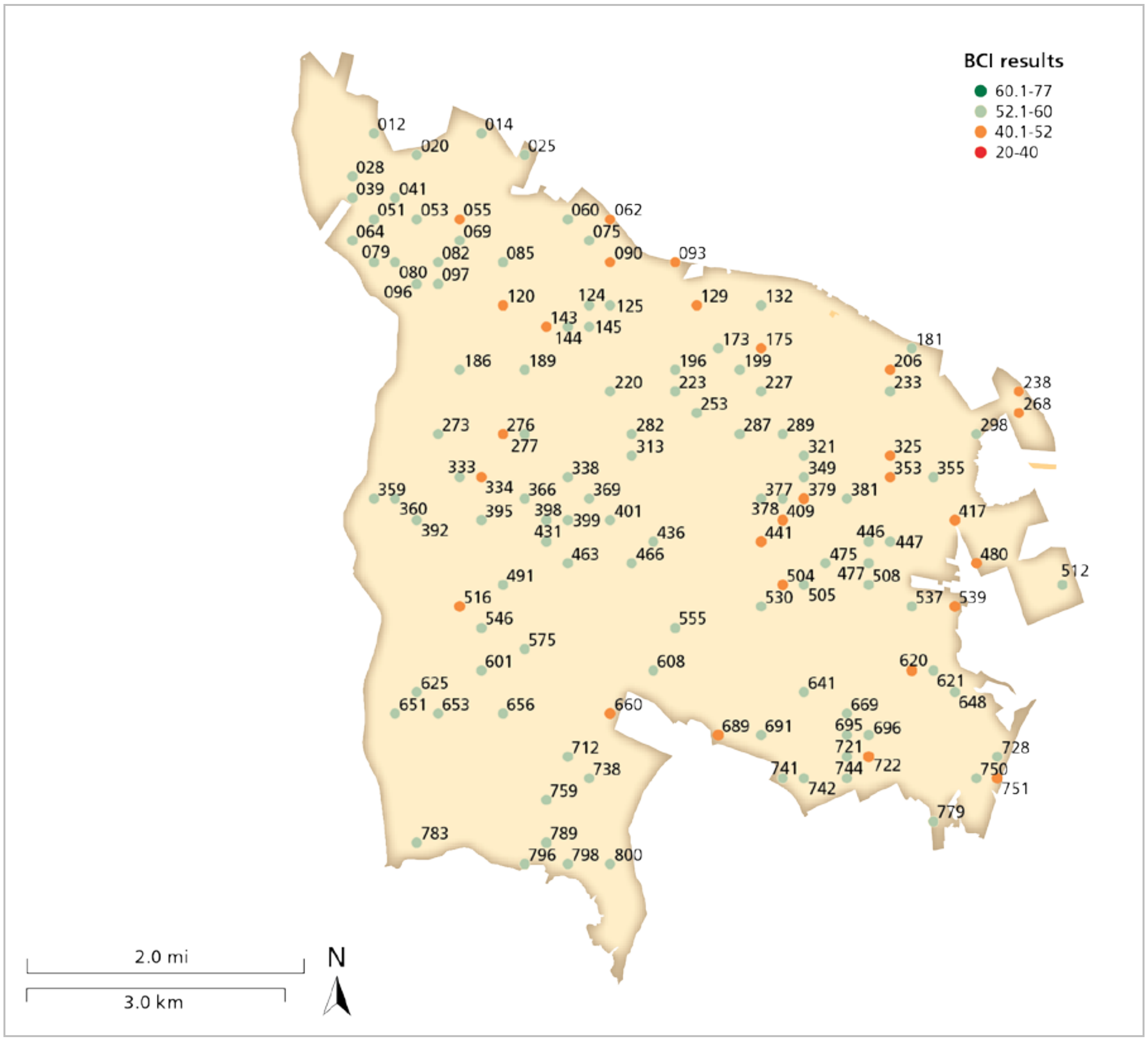

Figure 4-53 Bird Community Index (BCI) condition by site from 2007 to 2013 at 132 monitoring locations in PRWI. Median of all years was used for analysis.

Deer density

Description

White-tailed deer (*Odocoileus virginianus*) are 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 annually between 2001 and 2012 using the distance survey method (Bates 2006, 2009) (Figure 4-34). Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results were 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) (Table 4-7). 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 (Table 4-8).

Condition and trend

Current condition of deer population density in PRWI was very degraded, with 16.7% attainment of the reference condition (< 8.0 deer/km^2) for deer population density from 2001-2012 (Table 4-8, Figure 4-34). Population estimates for deer population for 2001–2012 exceeded the reference condition of < 8 deer/km^2, in all but two years, 2007 and 2010, with a median deer population of 12.4 deer/km^2 for all years.

There were no major changes in overall deer population size during the seven years of monitoring.

<u>Sources of expertise</u>

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

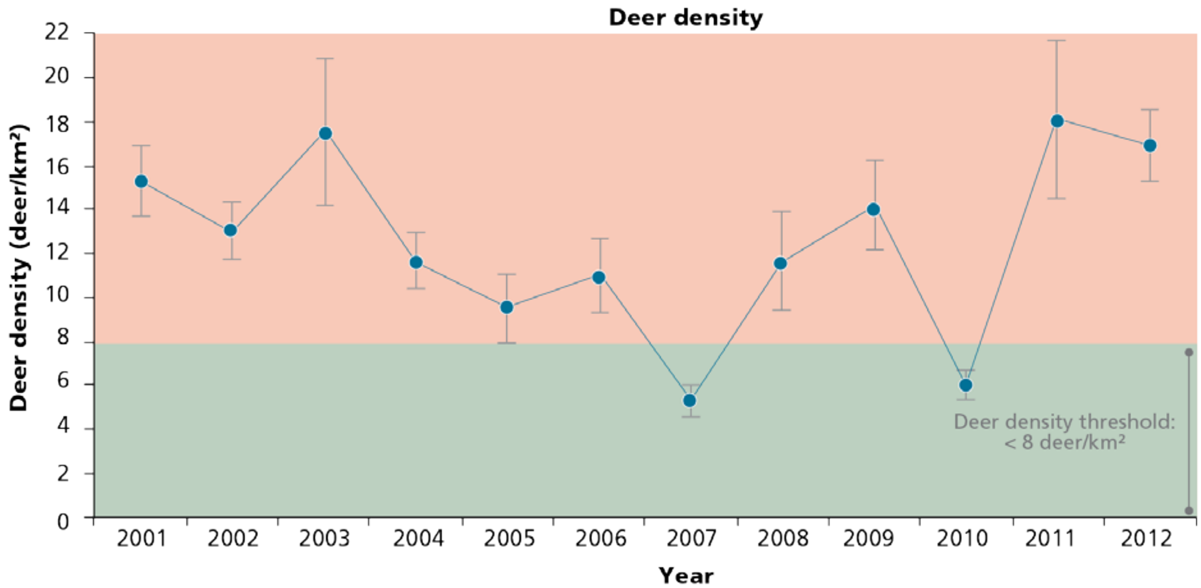

Figure 4-54 Annual mean deer density (deer/km^2) from 2001 to 2012 in PRWI. Reference condition (< 8 deer/km^2) is shown in green. Error bars represent ± the 95% confidence interval.

Amphibian stream species occupancy

<u>Description</u>

Amphibians are among the first hibernating animals to emerge in the spring and, as a result, provide food for predators when other food sources are less available (Mattfeldt et al. 2008, Campbell Grant et al. 2011). Adult amphibians are secondary and tertiary consumers and larvae are primary consumers in forest and pond ecosystems (Dunson 1982). Predatory salamander larvae are important in determining abundance of zooplankton and aquatic insects (Dodson 1970, Dodson and Dodson 1971), and tadpoles are important in determining types and amounts of phytoplankton, magnitude of nutrient cycling, and levels of primary production (Seale 1980).

Amphibians (frogs, toads, and salamanders) also serve as indicators of environmental change due to their sensitivity to factors such as pollution, drought, habitat loss, and disease. These factors may cause changes in amphibian distribution, abundance, species richness, and increases in both diseases and malformations.

<u>Data and methods</u>

Data were collected between 2006 and 2013 at 32 monitoring sites on 16 streams within Prince William Forest Park. Park-specific, annual estimates of occupancy for each species were calculated as the balance of extinctions and colonizations, given occupancy in the previous year. Goals of amphibian monitoring include determining the current distribution and status of amphibian populations, determining possible causes for changes to amphibian populations, and providing park managers with the information necessary to make management decisions.

Condition and trend

Four species of stream salamanders were encountered in Prince William Forest Park: northern dusky salamander (*Desmognathus fuscus*), northern two-lined salamander (*Eurycea bislineata*), northern red salamander (*Pseudotriton ruber*), and three-lined salamander (*Eurycea guttolineata*). The occupancy rate for three of these stream salamanders within PRWI is relatively stable. The occupancy of the three-lined salamander could not be estimated due to very low encounter rates.

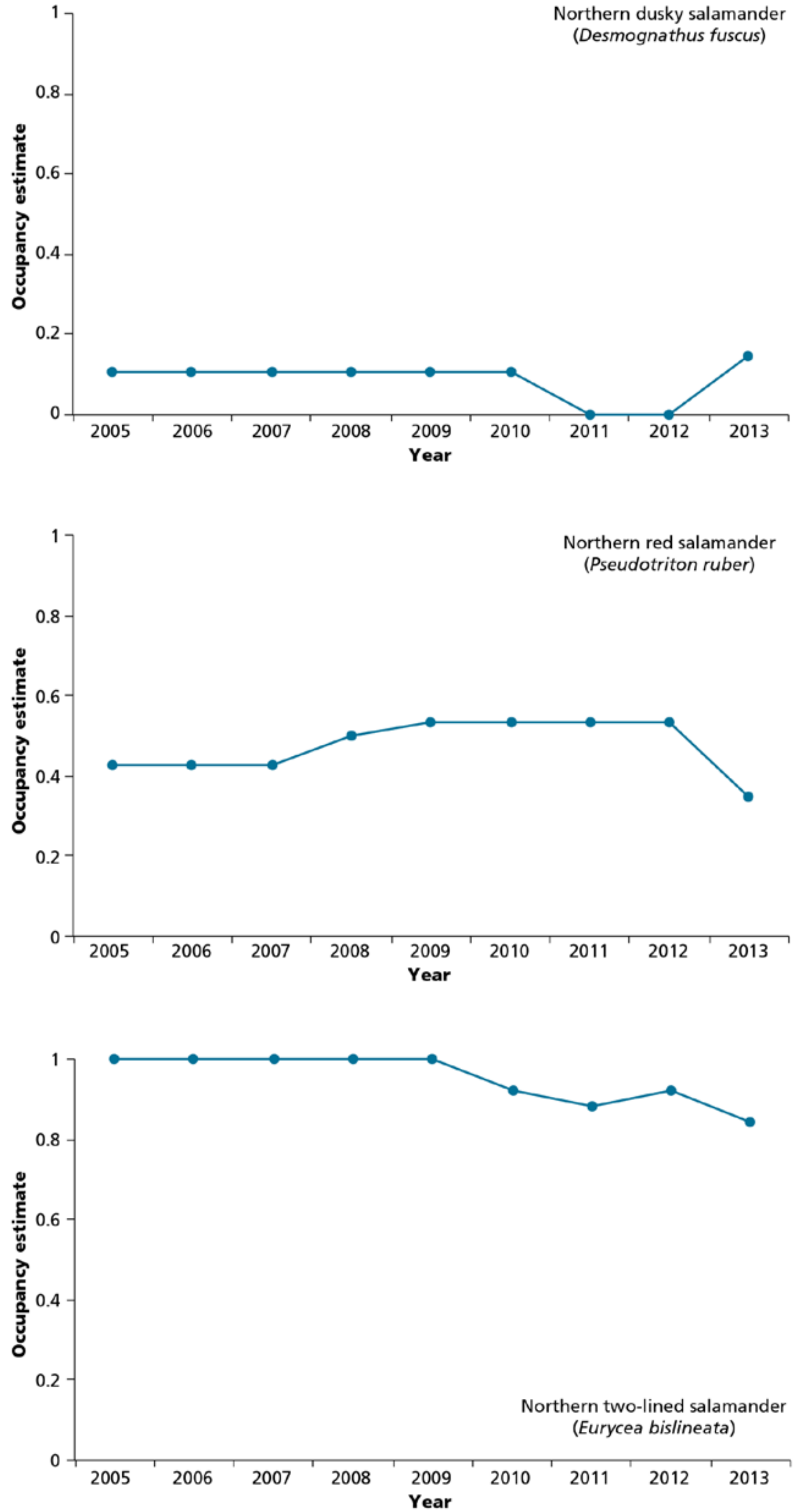

Figure 4-55 Occupancy estimate for three salamander species within PRWI.

Landscape dynamics

Four indicators were used to assess landscape dynamics in PRWI—forest interior area, forest cover, impervious surface, and road density (measured at two different scales) (Table 4-15). Data from the 2011 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 2010b, 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 an 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 of land use immediately surrounding the park on ecosystem processes.

Reference conditions were established for each indicator (Table 4-16) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that indicator (Table 4-16). This resulted in an overall landscape dynamics condition attainment of 77.5%, or good condition (Table 4-17).

Table 4-20 Ecological monitoring framework data for Landscape Dynamics provided by agencies and specific sources included in the assessment of PRWI.

Landscapes 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 2010a
Road density (within park + 5x buffer)	NPS NPScape	NPS 2010a

Table 4-21 Landscape Dynamics reference conditions for PRWI.

Landscape dynamics indicator	Sites	Samples	Period	Reference condition	Percent 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%	

Table 4-16 (continued) Landscape Dynamics reference conditions for PRWI.

Landscape dynamics indicator	Sites	Samples	Period	Reference condition	Percent attainment applied
Impervious surface (within park + 5x buffer)	Park	1	2011	< 10%	0-100% Scaled linearly
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 4-22 Summary of resource condition assessment of Landscape Dynamics in PRWI.

Landscapes dynamics indicator	PRWI result	Percent attainment	Condition assessment	Overall landscapes dynamics condition
Forest interior area (within park)	77.5	78	Good	65% Good
Forest interior area (within park + 5x buffer)	40.4	40	Moderate	
Forest cover (within park)	95.6	100	Very good	
Forest cover (within park + 5x buffer)	68.5	100	Very good	
Impervious surface (within park)	0.2	100	Very good	
Impervious surface (within park + 5x buffer)	16.0	0	Very degraded	
Road density (within park)	0.9	100	Very good	
Road density (within park + 5x buffer)	3.3	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).

Higher rates of nest predation occur in forest edges. In addition, forest edges provide access to the interior for avian predators such as blue jays, crows, grackles, and mammalian predators that include foxes, raccoons, squirrels, dogs, and cats. These predators eat eggs and young birds still in the nest. They tend to be abundant near areas of human habitation and can be detrimental to nesting success (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 4-15) 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 PRWI at the scale of the park and at the scale of the park plus the 5x buffer was 77.5% and 40.4%, respectively (Table 4-18, Figure 4-36). This indicated good condition at the scale of the park, and moderate condition at the 5x area scale. Note: forest interior area at an additional scale (park boundary plus a 30 km buffer) is also shown Table 4-18 for reference but was not included in the current assessment. No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-23 Forest interior area (%) in PRWI.

Area	Forest Interior area (%)
Park	77.5
Park + 5x area	40.4
Park + 30 km	19.5

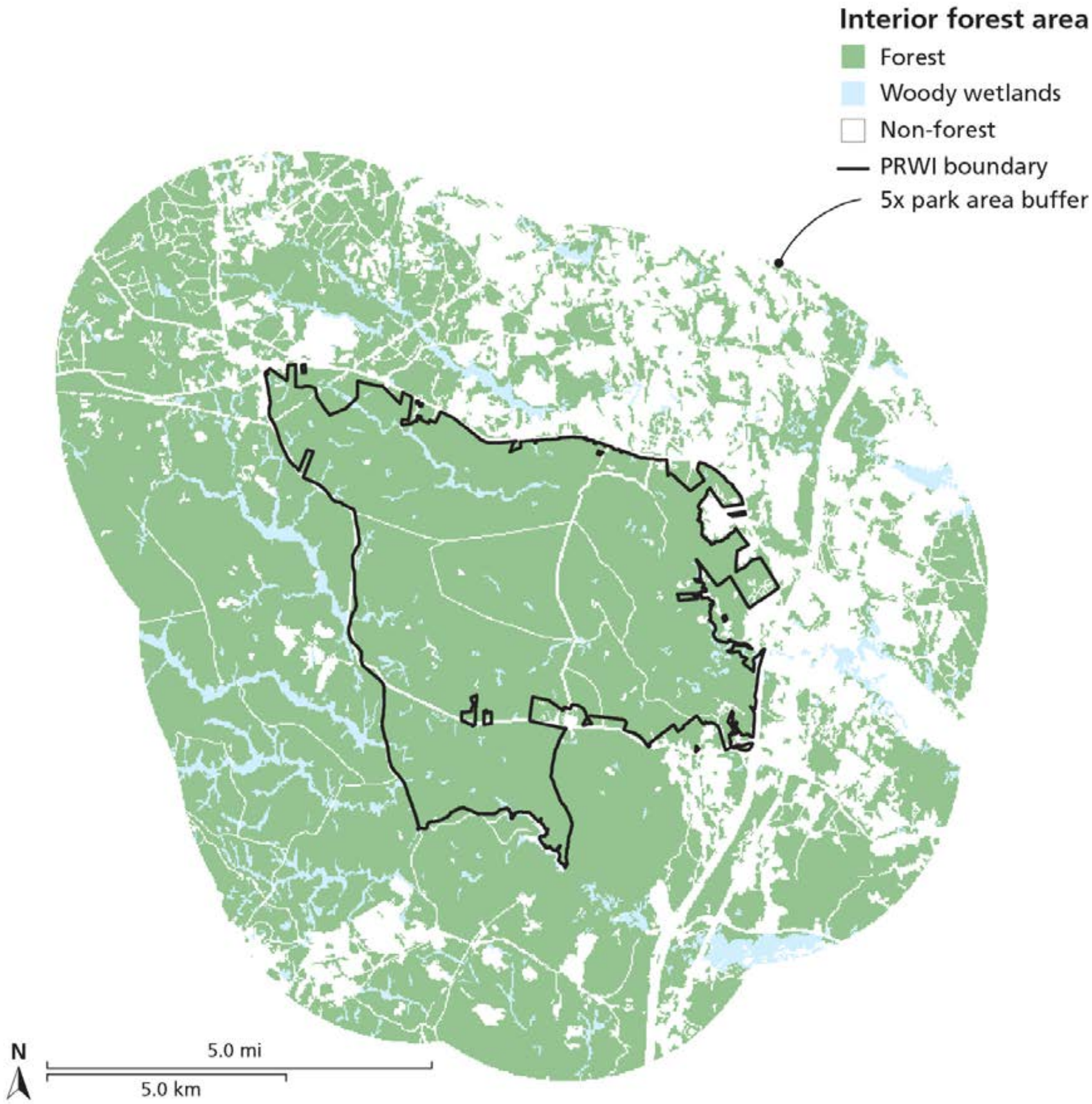

Figure 4-56 Extent of forest interior area within and around PRWI. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

Forest cover

Description

Forest is the dominant historical land use in the region surrounding PRWI and is still the dominant land use within the park itself (Figure 4-36). As intact and connected forest provides habitat, wildlife corridors, and ecosystem services, forest cover was chosen as a Landscape Dynamics indicator.

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 4-15). The source 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 (Table 4-16). The purpose of this analysis was to assess the influence of land use immediately surrounding the park on ecosystem processes. The park was given a rating of either 100% or 0% attainment based on the result of the one-off calculation.

Condition and Trend

At the scale of the park, forest cover in PRWI was 95.6%, which is above the reference condition of 59%. This resulted in 100% attainment and very good condition (Table 4-17). When a buffer of five times the park was added, forest cover dropped to 68.5%, also above the reference condition of 59%, resulting in 100% attainment of the reference condition and indicating very good condition (Table 4-19, Figure 4-37). Note: forest cover 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. No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-24 Forest cover in PRWI.

Area	Forest cover (%)
Park	95.6
Park +5x	68.5
Park + 30km	49.2

Figure 4-57 Extent of forest and non-forest landcover within and around PRWI. 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.

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 and loss of biodiversity when impervious surface covers more than 10% of the land area (Arnold and Gibbons 1996, Lussier *et al.* 2008). A study of nine metropolitan areas in the United States demonstrated measurable effects of impervious surface on stream invertebrate assemblages at impervious surface cover of 5% (Cuffney *et al.* 2010). 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 2010a, b, Jin *et al.* 2014) (Table 4-15).

Ecosystem components such as floral and faunal communities show considerable impact when impervious surface comprises 10% or more of habitat area, therefore the reference condition was for total impervious surface to be less than 10% (Arnold and Gibbons 1996, Lussier *et al.* 2008; Table 4-16).

An impervious surface reference condition of < 10% was used in this assessment and data used in this assessment represents 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. 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 PRWI at the scale of the park and the scale of the park plus the 5x buffer was 0.19% and 6.55%, respectively (Figure 4-38, Table 4-20). These were both below the reference condition of 10% impervious surface, resulting in 100% attainment and very good condition at both scales (Table 4-17). Note: impervious surface at an additional scale (park boundary plus a 30 km buffer) is also shown in Table 4-20 for reference but was not included in the current assessment. No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-25 Impervious surface (%) in PRWI.

Area	Impervious surface (%)
Park	0.19
Park + 5x area	6.55
Park + 30km	6.53

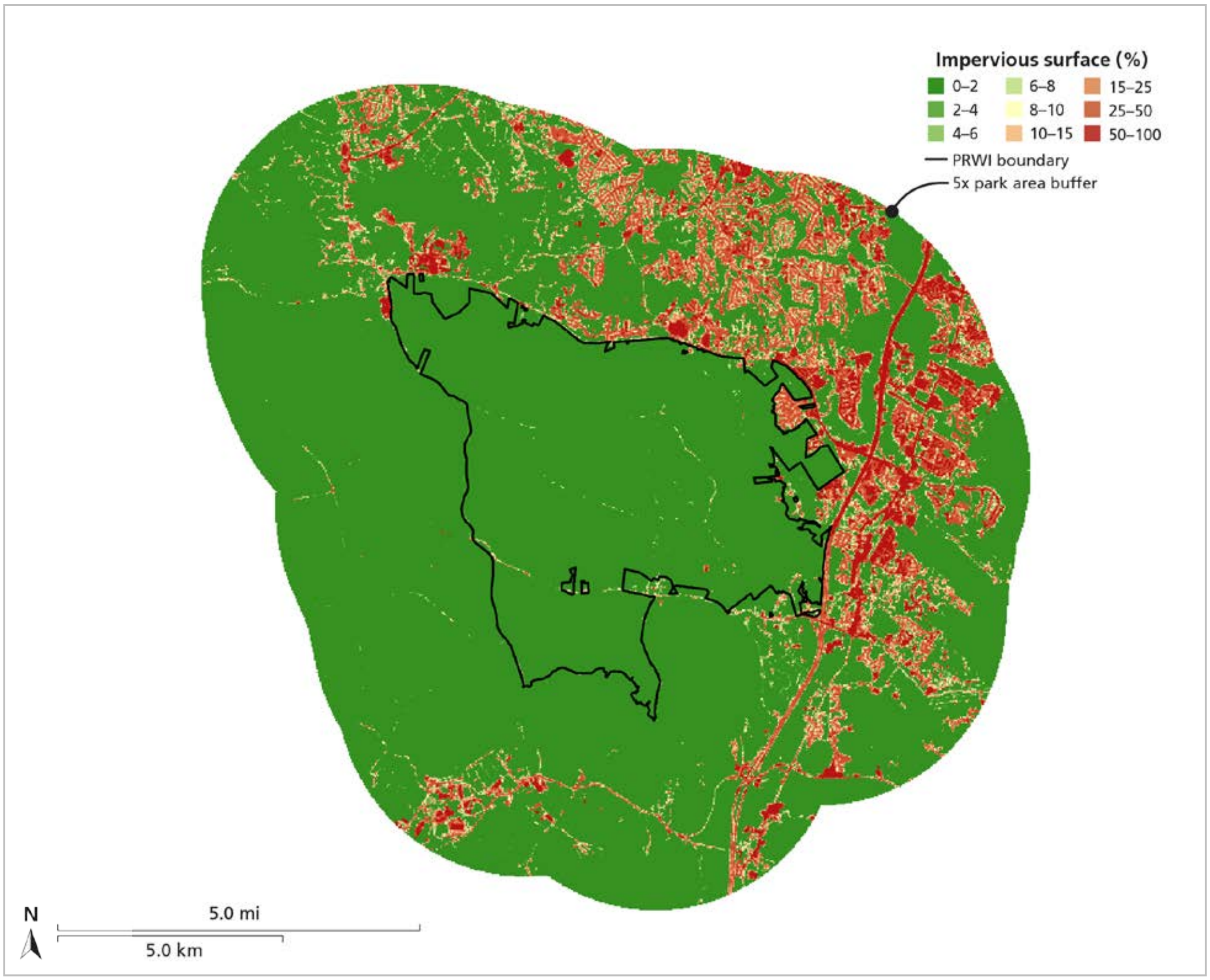

Figure 4-58 Percent impervious surface within and around PRWI. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

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 Indicators Processing SOP (NPS 2010) for the park and buffered areas (Table 4-15). 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/km2 have been shown to impact turtle populations, while densities higher than 0.6 km/km2 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 < 1.5 km/km2 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 (Table 4-16). The purpose of this analysis was to assess the influence of land use immediately surrounding the park on ecosystem processes. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation (Table 4-17).

Condition and trend

At the scale of the park, road density in PRWI is 0.9 km/km2, which is below the reference condition of 1.5 km/km2, resulting in 100% attainment and very good condition. At the scale of the park plus the 5x buffer road density in PRWI was 3.3 km/km2 (Figure 4-39,

Table 4-21). This value exceeded the reference condition of 1.5 km/km2, resulting in 0% attainment and very degraded condition (Table 4-17). No trend analysis was possible with the current data set.

Sources of expertise

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

Table 4-26 Road density (km/km^2) in PRWI.

Area	Road density (km/km^2)
Park	0.9
Park + 5x	3.3*
Park + 30km	3.2*

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

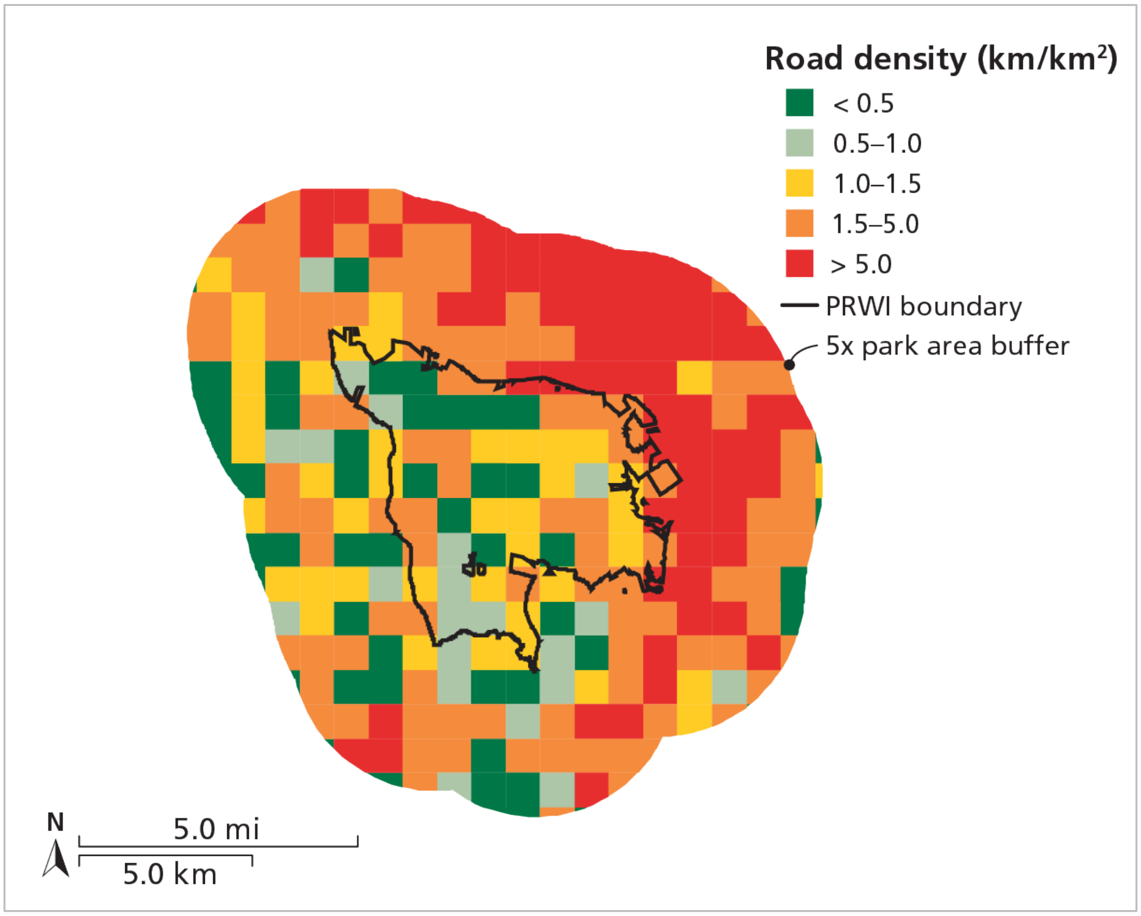

Figure 4-59 Road density within and around PRWI. The 5x area buffer is an area five times the total area of the park, evenly distributed as a ‘buffer’ around the entire park boundary.

Figure 4-60 Map of the roads and streets in and around PRWI. This is the base map from which the Figure 4-39 was generated.

Air quality

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). The U.S. EPA has established standards for six common air pollutants, and these standards define levels of air quality that are necessary to protect against adverse effects on human health and the environment. These six air pollutants, referred to as "criteria" pollutants, include ozone, particle pollution, lead, nitrogen dioxide, carbon monoxide, and sulfur dioxide (U.S. EPA 2013).

Five indicators were used to assess air quality in Prince William Forest Park (PRWI)—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 4-22). 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 boundary (Figure 4-41). Data for the other two indicators (particulate matter and mercury deposition) were obtained from the national monitoring network sites (Table 4-22).

Table 4-27 Ecological monitoring framework data for Air Quality provided by agencies and specific sources included in the assessment of PRWI.

Indicator	Agency	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

Reference conditions were established for each of the five indicators (Table 4-23) and the data were compared to these reference conditions to obtain the percent of attainment and converted to the condition assessment for that indicator (Table 4-25). Multiple reference condition categories were used in accordance with the NPS ARD documentation (NPS ARD 2011) (Table 4-23).

Figure 4-61 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 mean concentrations for PRWI.

Table 4-28 Air Quality reference conditions for PRWI.

Indicator	Reference conditions	Sites	Samples	Period
Wet sulfur deposition (kg/ha/yr)	< 1; 1-3; >3	Whole park	N/A*	2006-2010
Wet nitrogen deposition (kg/ha/yr)	< 1; 1-3; >3	Whole park	N/A*	2006-2010
Ozone (ppb)	≤ 60; 60.1-75; >75	Whole park	N/A*	2006-2010
Ozone (W126; ppm-hrs)	< 7; 7-13; >13	Whole park	N/A*	2006-2010
Visibility (dv)	<2; 2-8; >8	Whole park	N/A*	2006-2010
Particulate matter (PM2.5; µg/m3)	≤12; 12.1-15; >15	2	1974	2002-2012
Mercury deposition (ng/L)	N/A	2		2002-2012

* One interpolated value represents a five-year average of weekly measurements at multiple sites.

Table 4-29 Categorical ranking of the reference condition attainment categories for Air Quality indicators.

Indicator reference condition					Percent attainment	Natural resource condition
S & N deposition (kg/ha/yr)	Ozone (ppb)	Ozone (W126)	Visibility (dv)	Particulate matter (µg/m3)		
< 1	≤ 60	< 7	< 2	≤ 12	100%	Good
1-3	60.1-75	7-13	2-8	12.1-15	0-100% (scaled)	Moderate
> 3	> 75	> 13	> 8	> 15	0%	Significant concern

To assess trends, data from the NPS ARD were used where possible (NPS ARD 2011). Otherwise, monitoring sites closest to PRWI from the National Atmospheric Deposition Program (NADP) and Interagency Monitoring of Protected Visual Environments (IMPROVE) program (Table 4-22).

PRWI scored 0% attainment (or a condition of significant concern) for all air quality indicators except particulate matter (82.8% attainment). This resulted in an overall air quality condition attainment of 14%, or very degraded condition (Table 4-25).

Table 4-30 Summary of resource condition assessment of Air Quality in PRWI.

Indicator	Result	Reference conditions	Percent attainment	Condition	Air quality condition
Wet sulfur deposition (kg/ha/yr)	4.7	< 1; 1-3; >3	0	Significant concern	13.4% Very degraded
Wet nitrogen deposition (kg/ha/yr)	4.2	< 1; 1-3; >3	0	Significant concern	
Ozone (ppb)	77.5	≤ 60; 60.1-75; >75	0	Significant concern	
Ozone (W126; ppm-hrs)	13.7	< 7; 7-13; >13	0	Significant concern	
Visibility (dv)	12.6	<2; 2-8; >8	0	Significant concern	
Particulate matter (PM2.5; μg/m3)	12.6	≤12; 12.1-15; >15	82.76	Very good	
Mercury deposition (ng/L)		N/A	N/A	N/A	

Wet Sulfur Deposition

Description

Emissions of sulfur dioxide (SO_2) in the U.S increased from nine million indicator tons in 1900 up to 28.8 million indicator tons by 1973, with 60% of these emissions coming from electric utilities. Geographically, 41% came from the seven Midwest states centered on the Ohio Valley (Driscoll *et al.* 2001). Largely as a result of the Clean Air Act, emissions of SO_2 had reduced to 17.8 million indicator tons by 1996 and while large areas of the eastern U.S. had annual sulfur wet deposition loads >30 kg/ha/yr over the period 1983-1985, these areas were mostly < 25 kg/ha/yr by the period 1995-1997 (Driscoll *et al.* 2001). 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 is significant in the eastern parts of the United States (Figure 4-42).

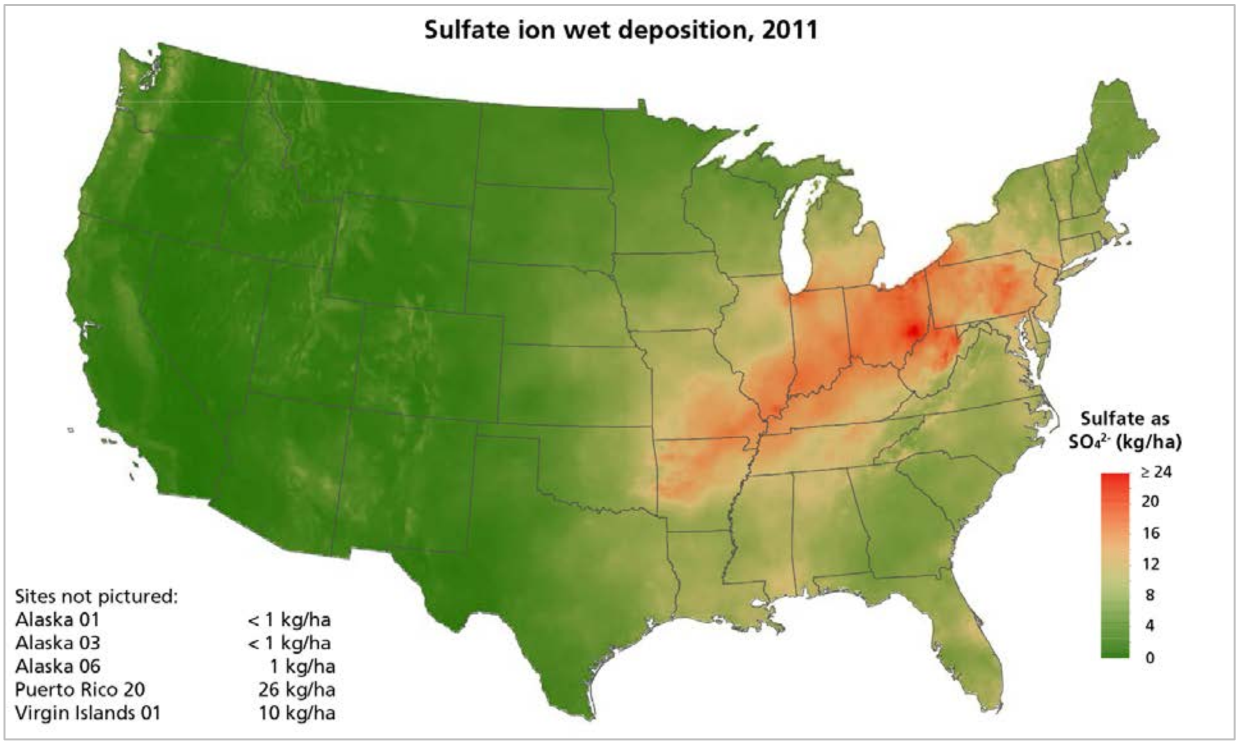

Figure 4-62 Total wet deposition of sulfate (SO_4^{2-}) for the continental United States in 2011 (NADP/NTN 2013).

Data and Methods

The reference condition for total sulfur wet deposition is ecological. Natural background total wet and dry sulfur deposition in the east of the U.S. is 0.5 kg/ha/yr, which equates to a wet deposition of approximately 0.25 kg/ha/yr (Porter and Morris 2007, NPS ARD 2011). NPS ARD has established wet sulfur deposition guidelines as < 1 kg/ha/yr indicating good condition (or 100% attainment of reference condition) and > 3 kg/ha/yr indicating significant concern (or 0% attainment) (Table 4-23). Concentrations of 1-3 kg/ha/yr were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Table 4-26). For the current assessment, the reported wet deposition value was assessed against these guidelines (NPS ARD 2011).

Table 4-31 Wet sulfur deposition categories, percent attainment, and condition assessment.

Wet sulfur deposition (kg/ha/yr)	Percent attainment	Condition
< 1	100%	Good
1-3	0-100% (scaled)	Moderate
> 3	0%	Significant Concern

The wet sulfur deposition data used for this assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2012) (Table 4-22). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for PRWI was taken from the interpolation at the park centroid, which is a location near the center of the park.

The analysis meant that there was only one value reported for wet sulfur deposition for PRWI, so this value was assessed against the three reference condition ranges described above.

Because there are no air quality monitoring sites within PRWI to assess trends, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to PRWI were used. These included sites VA00 (Charlottesville) and VA28 (Shenandoah National Park-Big Meadows) in Virginia, and site MD99 (Beltsville, Prince Georges County) in Maryland.

NPS ARD assessments identified ecosystems and resources in national parks at risk for acidification and excess nitrogen enrichment. They present a relative risk assessment of acidification and nutrient enrichment impacts from atmospheric nitrogen and sulfur deposition. If park ecosystems are ranked very high in sensitivity compared to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b), the park's risk category is adjusted to the next worse level (NPS 2013).

<u>Condition and trend</u>
Interpolated wet sulfur deposition between 2006 and 2010 for PRWI was 4.7 kg/ha/yr, which resulted in 0% attainment of reference condition, or a condition that is of significant concern (NPS ARD 2012) (Table 4-25, Figure 4-43, Figure 4-44).

In a national assessment to identify ecosystems and resources in national parks at risk for acidification and excess nitrogen enrichment, PRWI did not rank as a NPS unit with very high ecosystem sensitivity ranking for acidification impacts (Sullivan et al. 2011a; NPS 2013).

<u>Sources of expertise</u>

- Air Resources Division, National Park Service
  http://www.nature.nps.gov/air/

- National Atmospheric Deposition Program
  http://nadp.sws.uiuc.edu/

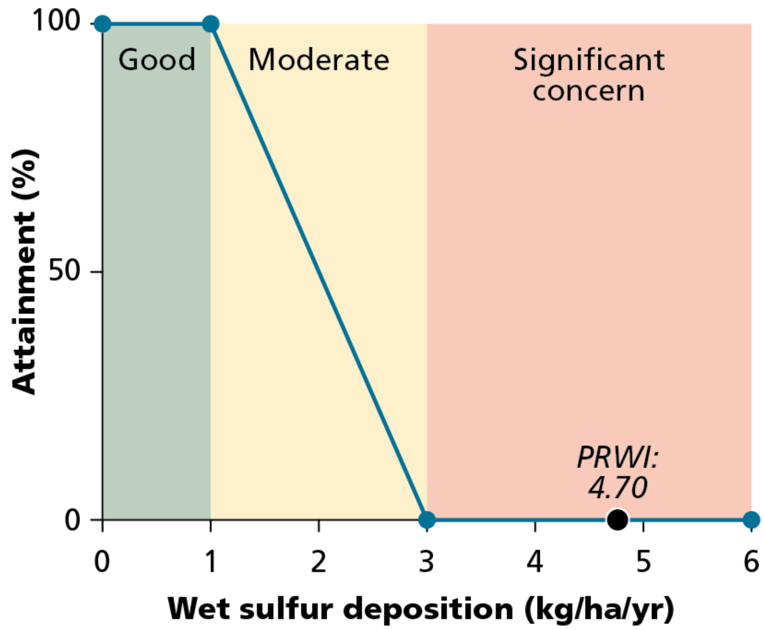

Figure 4-63 Application of the percent attainment categories to the wet sulfur deposition at PRWI was 4.70 kg/ha/yr which equated to 0% attainment of the reference condition.

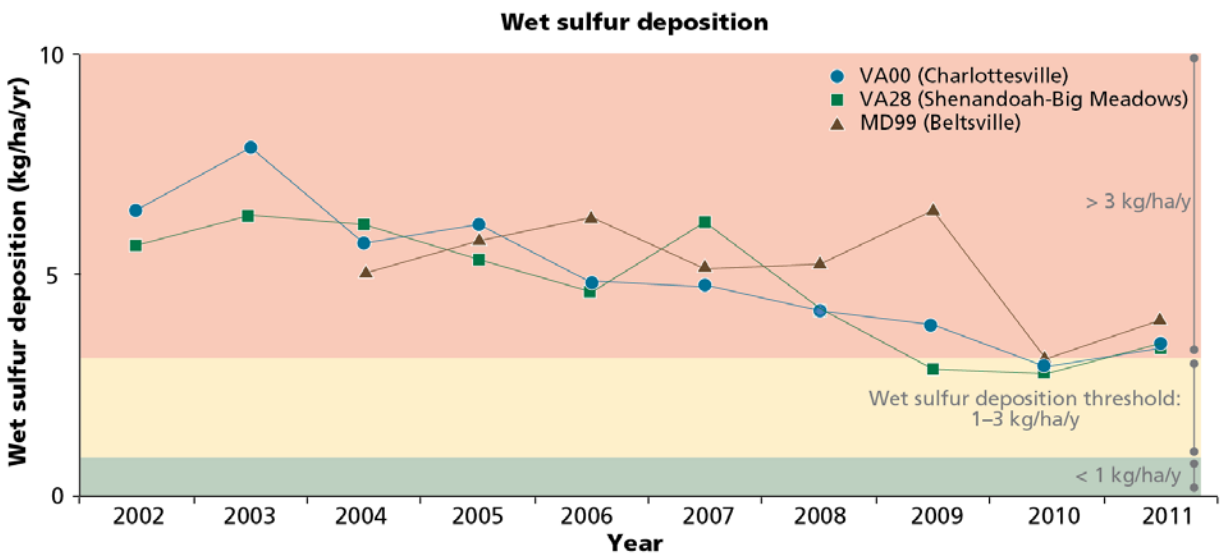

Figure 4-64 Annual wet deposition of sulfate (kg/ha/yr) at the three sites closest to PRWI. Data were reported as SO_4 deposition; these data were converted to total S deposition using atomic weights (multiplying by 0.333). Reference conditions are shown in green.

Wet nitrogen deposition

Description

During the 1940s and 1950s, it was recognized in the United States and Great Britain that emissions from coal burning and large-scale industry such as power plants and steel mills were causing severely degraded air quality in major cities. This resulted in severe human health impacts and, by the early 1970s, the U.S. Environmental Protection Agency had established the National Ambient Air Quality

Standards (NAAQs) (Porter and Johnson 2007). In addition to human health effects, it has been increasingly recognized that there are significant ecosystem impacts of atmospheric nitrogen deposition, including acidification and nutrient fertilization of waters and soils (NPS ARD 2011a). These impacts included such measurable effects as the disruption of nutrient cycling, 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 parts of the United States (Figure 4-45).

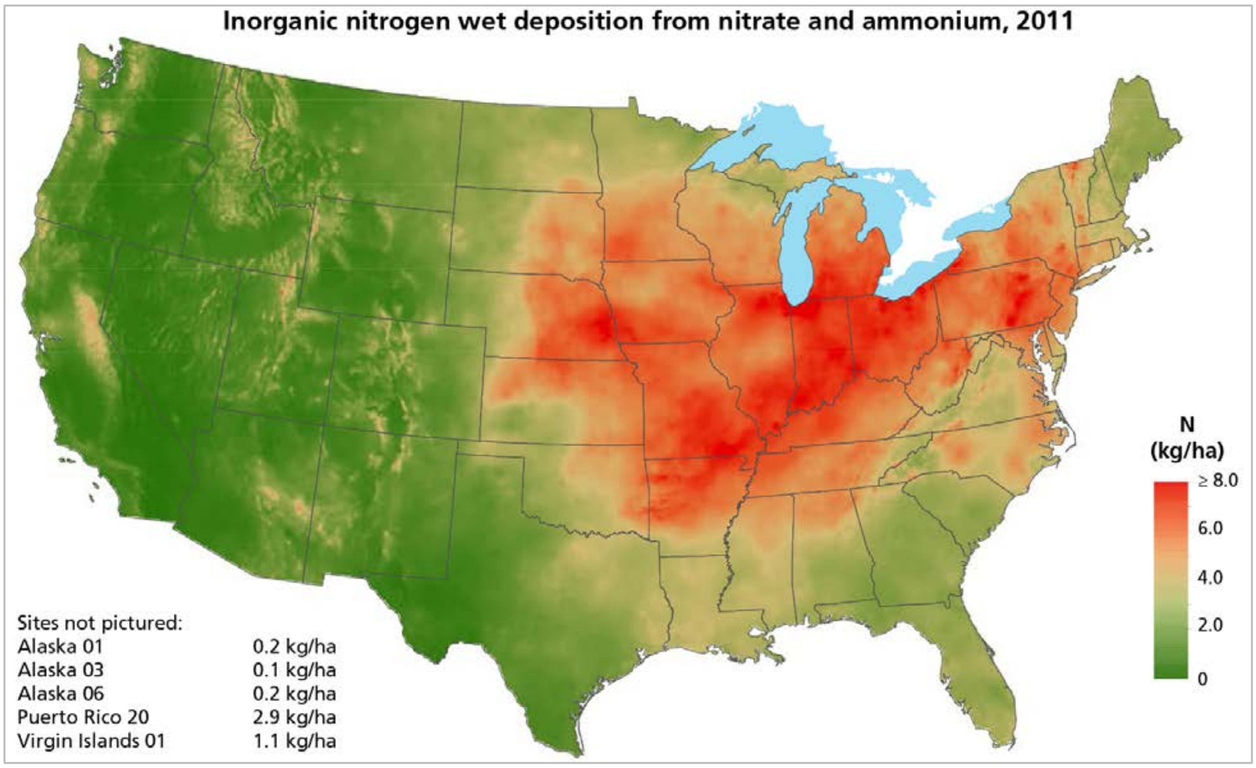

Figure 4-65 Total wet deposition of nitrate (NO_3^-) and ammonium (NH4+) (kg/ha) for the continental United States in 2011 (NADP/NTN 2013).

Data and Methods

The reference condition for total nitrogen wet deposition is ecological. Natural background total nitrogen deposition in the east of the U.S. is 0.5 kg/ha/yr, which equates to a wet deposition of approximately 0.25 kg/ha/yr (Porter and Morris 2007, NPS ARD 2011a). Some sensitive ecosystems, such as coastal and estuarine waters and upland areas, show responses to wet nitrogen deposition rates of 1.5 kg/ha/yr, while there is no evidence of ecosystem harm at deposition rates less than 1 kg/ha/yr (Fenn *et al.* 2003). NPS ARD has established wet nitrogen deposition guidelines as < 1 kg/ha/yr indicating good condition (or 100% attainment of reference condition) and > 3 kg/ha/yr indicating significant concern (or 0% attainment). Concentrations of 1-3 kg/ha/yr were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points. For the current assessment, the reported wet deposition value was assessed against these guidelines (Table 4-27).

Table 4-32 Wet nitrogen deposition categories, percent attainment, and condition assessment.

N deposition (kg/ha/yr)	Percent attainment	Condition
< 1	100%	Good
1-3	0-100% (scaled)	Moderate
> 3	0%	Significant Concern

The wet nitrogen deposition data used for this assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2011) (Table 4-22). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for PRWI was taken from an interpolation at the park centroid, which is a location near the center of the park.

This analysis meant that there was only one value reported for wet nitrogen deposition for PRWI, so this value was assessed against the three reference condition ranges described above.

To assess trends, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to PRWI were used. These included sites VA00 (Charlottesville) and VA28 (Shenandoah, Big Meadows) in Virginia, and site MD99 (Beltsville, Prince Georges County) in Maryland.

National assessments identified ecosystems and resources in national parks at risk for acidification and excess nitrogen enrichment. The reports provide a relative risk assessment of acidification and nutrient enrichment impacts from atmospheric nitrogen and sulfur deposition. If park ecosystems are ranked very high in sensitivity to all Inventory & Monitoring parks (Sullivan et al. 2011a; Sullivan et al. 2011b), the condition category is adjusted to the next worse condition category (NPS 2013).

Condition and trend

Interpolated wet nitrogen deposition between 2006 and 2010 for PRWI was 4.2 kg/ha/yr which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2012) (Figure 4-46, Figure 4-47, Table 4-25).

In a national assessment to identify ecosystems and resources in national parks at risk for acidification and excess nitrogen enrichment, PRWI did not rank as a NPS unit with very high ecosystem sensitivity for acidification impacts (Sullivan et al. 2011a; NPS 2013).

Sources of expertise

- Air Resources Division, National Park Service
  http://www.nature.nps.gov/air/

- National Atmospheric Deposition Program
  http://nadp.sws.uiuc.edu/

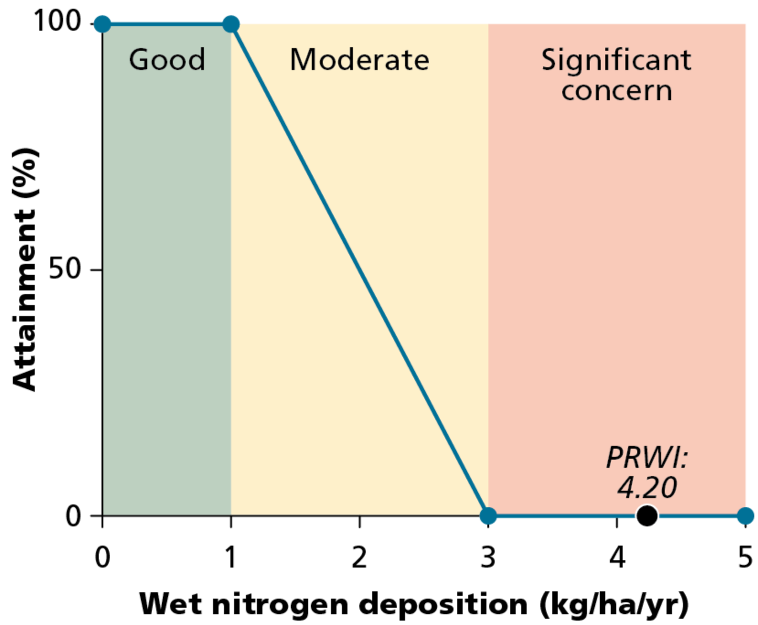

Figure 4-66 Application of the percent attainment categories to the wet nitrogen deposition value categories. Wet nitrogen deposition at PRWI was 4.20 kg/ha/yr which equated to 0% attainment of the reference condition.

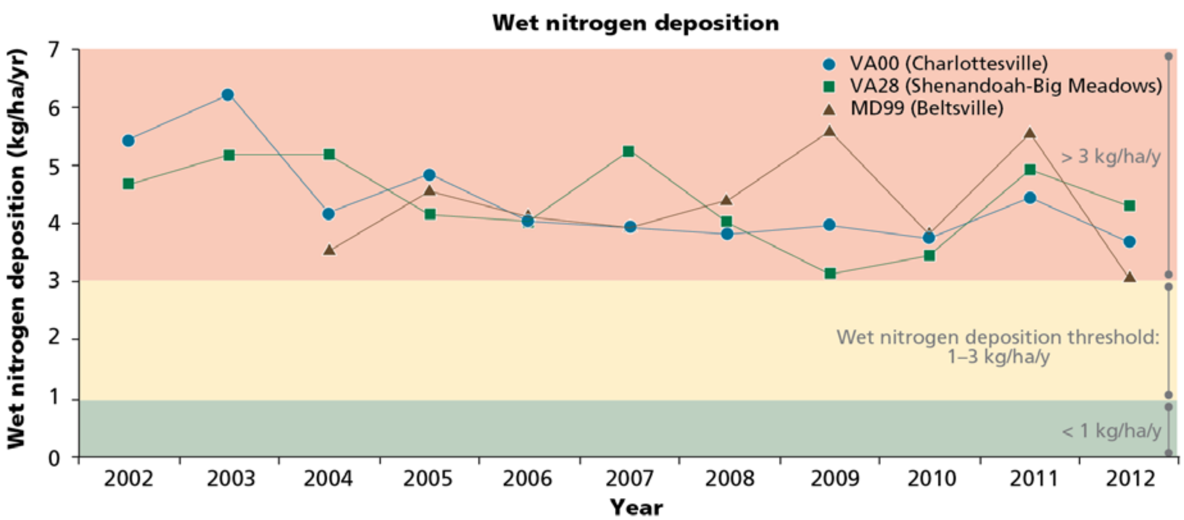

Figure 4-67 Annual wet deposition of total nitrogen (kg/ha/yr) at the three sites closest to PRWI. Reference conditions are shown in green.

Ozone

Description

Ozone is a secondary atmospheric pollutant, meaning it is not directly emitted; rather it 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 hospitalization. Although adverse health effects can occur in very sensitive groups at levels below 60 ppb, the U.S. EPA's 2007 review of the standard concluded that levels between 60 and 70 ppb would likely be protective of most of the population (U.S. EPA 2007). In 2010, the U.S. EPA proposed strengthening the primary standard to a value in the range of 60-70 ppb to protect human health, and establishing a separate secondary standard to protect vegetation based on an ecologically relevant indicator, 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.

Data and methods

Ground-level ozone is regulated under the Clean Air Act and the U.S. EPA is required to set standard concentrations for ozone (U.S. EPA 2004). The current National Ambient Air Quality Standards (NAAQS) standard is 75 ppb, based on the three-year average annual fourth-highest daily maximum eight-hour ozone concentration at a monitor (NAAQS). Both the NAAQS standard and the plant exposure indicator, the W126, are incorporated into the benchmarks to assess ozone condition within National Park units by the National Park Service Air Resources Division (NPS ARD 2011).

NPS ARD has established ozone concentration (three-year average fourth-highest daily maximum eight-hour ozone concentration, averaged over five years) guidelines as ≤ 60.0 ppb (set as 80% of the current standard of 75 ppb) indicating good condition and > 75 ppb indicating significant concern (or 0% attainment) (U.S. EPA 2007, NPS ARD 2011). Concentrations of 60.1-75.0 ppb were considered moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points. For the current assessment, the reported visibility value was assessed against these guidelines (Table 4-28).

Table 4-33 Ozone deposition categories, percent attainment, and condition assessment.

Ozone (ppb)	Ozone (W126 in ppm-hrs)	Percent attainment	Condition
≤ 60	< 7	100%	Good
61-75	7-13	0-100% (scaled)	Moderate
≥ 76	> 13	0%	Significant concern

The ozone concentration data used for the assessment of current condition were taken from the NPS ARD Air Quality Estimates (NPS ARD 2011) (Table 4-22). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for PRWI was taken from the interpolation at the park centroid, which is a location near the center of the park.

This analysis meant that there was only one value reported for ozone concentration for PRWI, so this value was assessed against the three reference condition ranges described above (Table 4-28).

An NPS ARD risk assessment rated parks at low, moderate, or high risk for ozone injury to vegetation, based on presence of sensitive plant species, ozone exposures, and environmental conditions, i.e., soil moisture (Kohut 2007). If parks were evaluated at high risk for ozone injury to vegetation, the condition category is adjusted to the next worse condition category.

NPS ARD has also used the W126 standard to assess the risk for ozone-induced foliar damage to sensitive plants. W126 provides an index of the cumulative ozone exposure to plants during daylight hours. The W126 weights higher ozone concentration more heavily because they are more likely to cause injury. Values less than 7 parts per million-hour (ppm-hrs) are considered safe for sensitive plants (or 100% attainment of reference condition) and > 13 ppm-hrs is considered a significant concern for very sensitive plant species (or 0% attainment). Values of 7-13 ppm-hrs represent a moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (NPS ARD 2010, 2011) (Table 4-23).

Condition and trend

Interpolated fourth-highest daily maximum eight-hour ozone concentration between 2006 and 2010 for PRWI was 77.5 ppb, which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2012) (Figure 4-48, Table 4-25). PRWI is located in an EPA designated 8-hour ozone nonattainment county (Figure 4-50), and therefore, the overall air quality condition is automatically placed in the Warrants Significant Concern category (NPS 2013).

Interpolated W126 value between 2006 and 2010 for PRWI was 13.7 ppm-hrs, which resulted in 0% attainment of reference condition, or conditions of significant concern (Figure 4-48, Table 4-25). PRWI was evaluated at high risk for ozone injury to vegetation (Kohut 2007).

Sources of expertise

- Drew Bingham, Geographer, NPS Air Resources Division.
- Ellen Porter, NPS Air Resources Division.
- Holly Salazer, NPS Air Resources Coordinator for the Northeast Region.
- Air Resources Division, National Park Service
  http://www.nature.nps.gov/air/
- National Atmospheric Deposition Program
  http://nadp.sws.uiuc.edu/

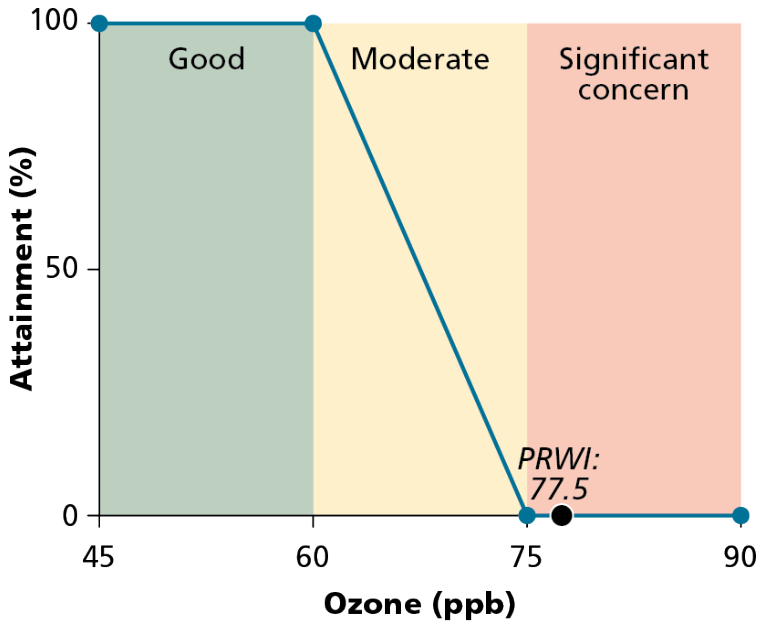

Figure 4-68 Application of the percent attainment categories to the ozone (ppb) value categories. Ozone at PRWI was 77.5 ppb, which equated to 0% attainment of the reference condition.

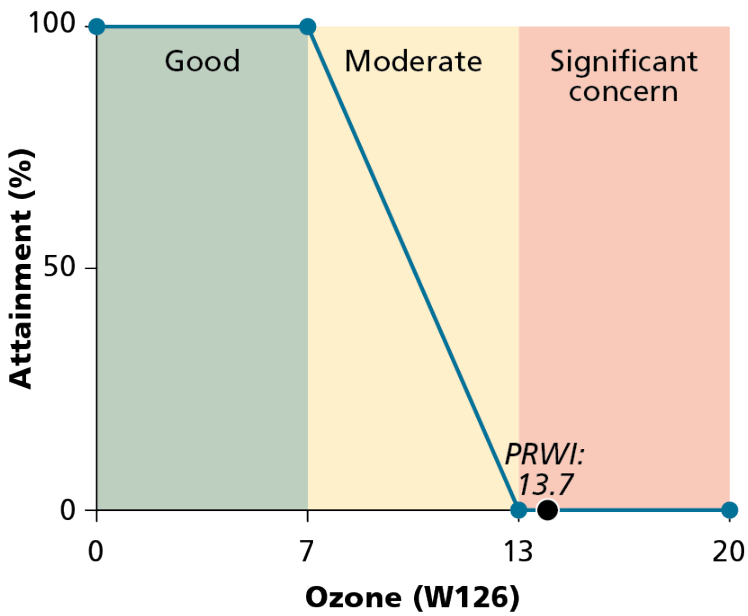

Figure 4-69 Application of the percent attainment categories to the ozone (W126 in ppm-hrs) value categories. W126 at PRWI was 13.7 ppm, which equated to 0% attainment of the reference condition.

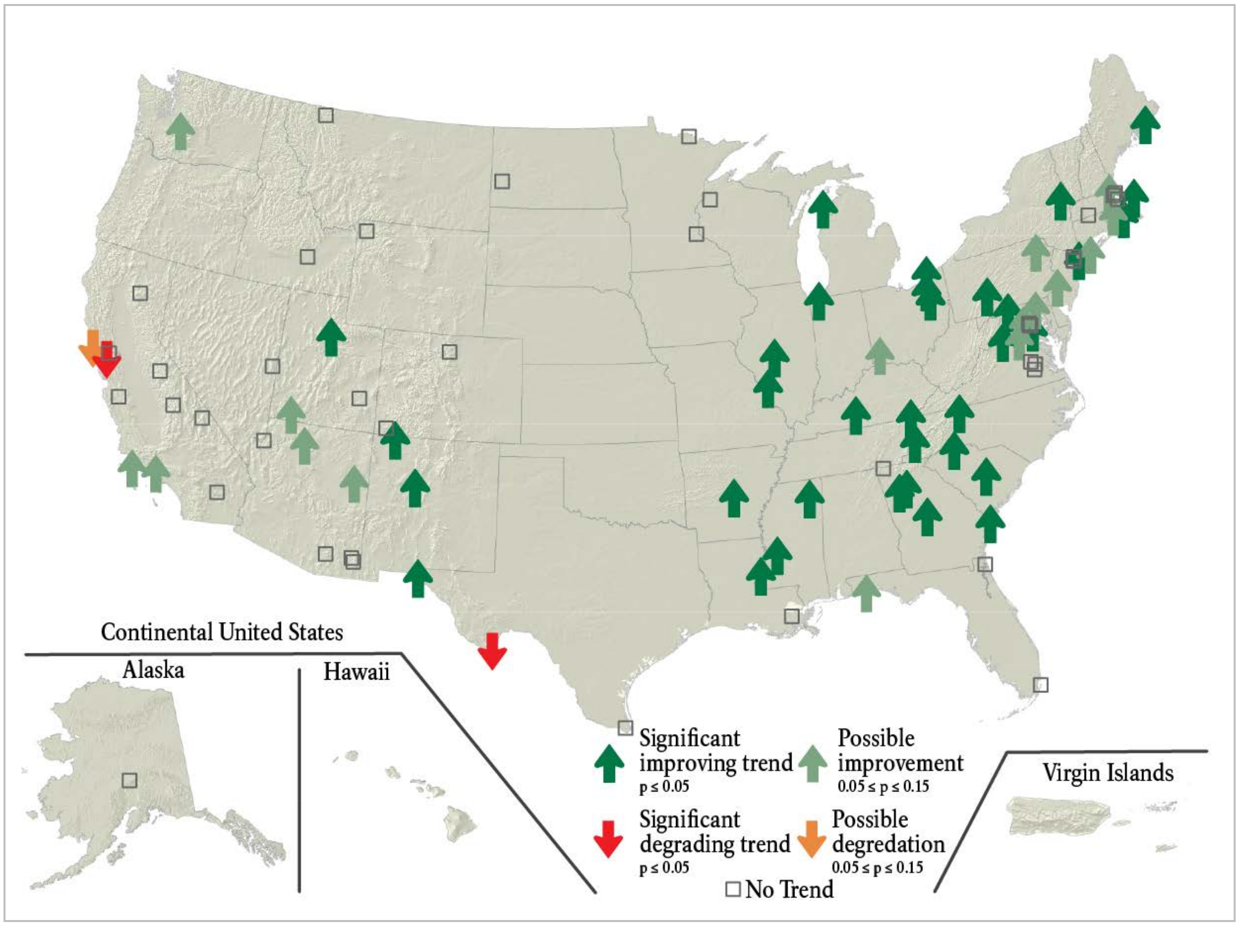

Figure 4-70 Trends in annual fourth-highest eight-hour ozone concentration in ppb, 2000-2009 (NPS ARD 2013).

Visibility

Description

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 2004).

Data and Methods

Air pollution causes haze and reduces visibility. Visibility is measured using the Haze Index in deciviews (dv). As the Haze Index increases, the visibility worsens. Conditions for visibility are based on five-year average visibility minus estimated average natural visibility, where average visibility is the mean of visibility between 40th and 60th percentiles. Interpolated 5-year averages are used within the contiguous U.S. The visibility condition is expressed as:

Visibility condition = average current visibility – estimated average natural visibility

Natural visibility conditions represent the long-term degree of visibility that is estimated to exist in a given mandatory Federal Class I area in the absence of human-caused impairment. Natural visibility conditions are calculated on the average or best visibility (20% least haziest) days monitored over several years.

The reference condition for visibility is based on the national goal of restoring natural visibility. The Regional Haze Rule requires remedying existing and preventing any future visibility impairment in the nation's largest parks and wilderness areas, known as the 'Class I' areas (NPS ARD 2010). NPS has adopted this goal for all parks, including PRWI and all others designated as Class II under the Clean Air Act.

The haze index data used for the assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2012) (Table 4-22). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for PRWI was taken from the interpolation at the park centroid, which is a location near the center of the park.

NPS ARD has established visibility guidelines as ≤ 2 dv above natural conditions indicating good condition (or 100% attainment of reference condition) and ≥ 8 dv above natural conditions indicating significant concern (or 0% attainment). Concentrations of 2-8 dv above natural conditions were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points. For the current assessment, the reported visibility value was assessed against these guidelines (NPS ARD 2011) (Table 4-29).

This analysis meant that there was only one value reported for the haze index for PRWI, so this value was assessed against the three reference condition ranges described above.

Table 4-34 Visibility categories, percent attainment, and condition assessment.

Average visibility (dv)	Percent attainment	Visibility condition
< 2	100%	Good
2 – 8	0-100% (scaled)	Moderate
> 8	0%	Significant concern

Condition and trend

Interpolated haze index between 2006 and 2010 for PRWI was 12.6 dv, which resulted in 0% attainment of reference condition, or a condition of significant concern (ARD 2012) (Table 4-25, Figure 4-51, Figure 4-52).

Sources of expertise

- Air Resources Division, National Park Service
  http://www.nature.nps.gov/air/

- National Atmospheric Deposition Program
  http://nadp.sws.uiuc.edu/

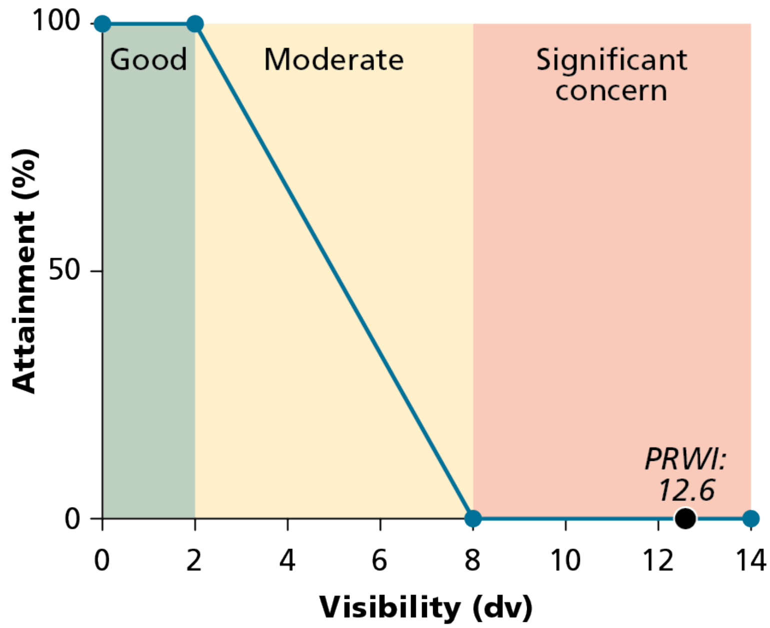

Figure 4-71 Application of the percent attainment categories to the visibility value categories. Visibility at PRWI was 12.6 dv, which equated to 0% attainment of the reference condition.

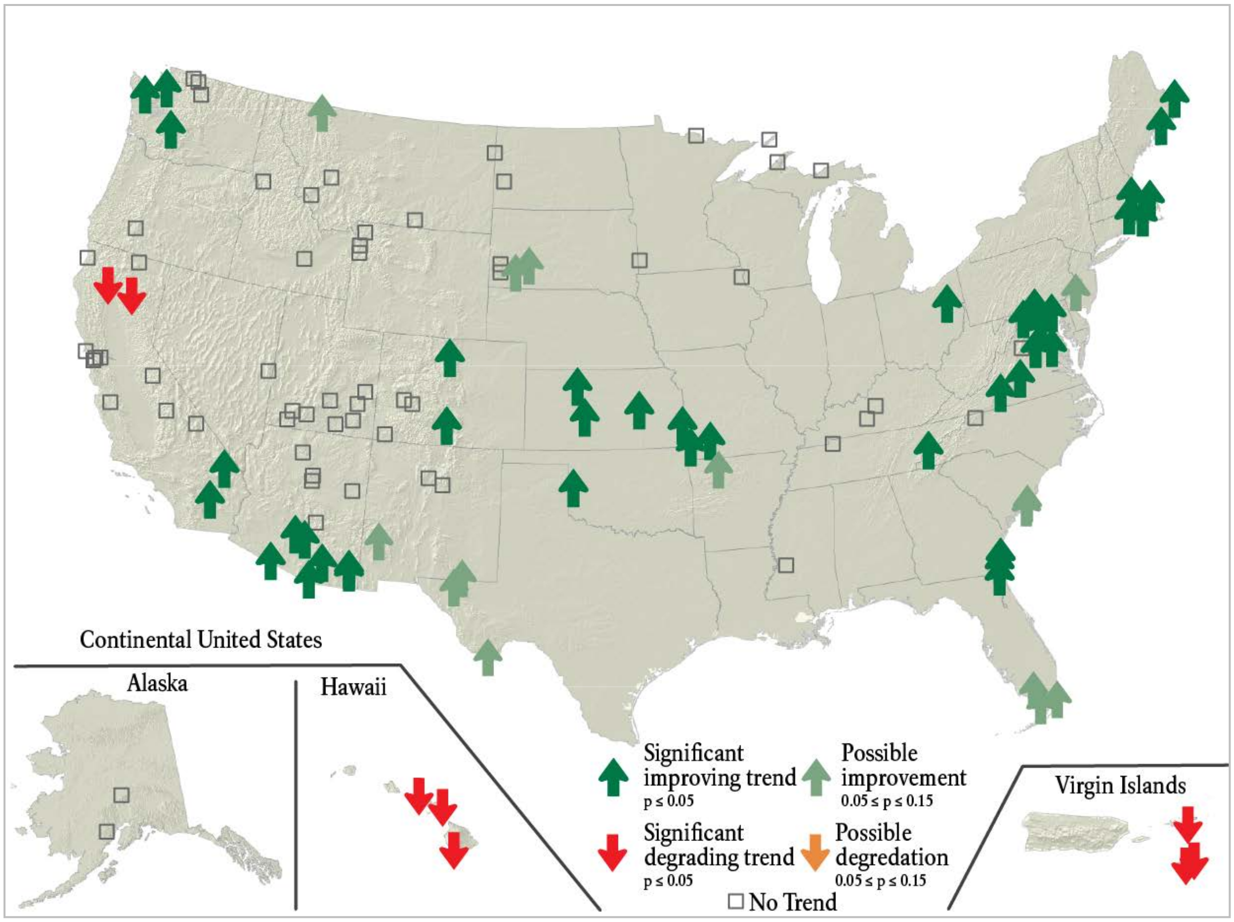

Figure 4-72 Visibility trends measured by the haze index (deciviews) on haziest days 2000-2009 (NPS ARD 2013).

Particulate Matter

<u>Description</u>

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 in the atmosphere to sulfate and nitrate particles. Fine particles (PM 2.5) are the main cause of reduced visibility (haze) in the United States (U.S. EPA 2012b). Haze is caused when sunlight encounters tiny pollution particles in the air, which reduce color and clarity. The federal government has been monitoring visibility in national parks and wilderness areas since 1988 (U.S. EPA 2012b). In addition, fine particles have multiple human health impacts and can aggravate lung disease and cause non-fatal heart and asthma attacks, acute bronchitis, respiratory infection, coughing, wheezing, shortness of breath, and changes in lung function (U.S. EPA 2006). In recognition of these significant health impacts, ground-level particulate matter is regulated under the Clean Air Act and the U.S. EPA is required to set standard concentrations for airborne particulates (U.S. EPA 2004). In the period between 2001 and 2010, national annual and 24-hour PM 2.5 concentrations have decreased by 24% (U.S. EPA 2012a).

Data and methods

Data was obtained from the Interagency Monitoring of Protected Visual Environments (IMPROVE) database (Table 4-22) through the U.S. EPA AirData interface for the two sampling locations closest to PRWI. These included sites 510590030 (Lee District Park) and 511071005 (Broad Run High School, VA).

The current National Ambient Air Quality Standards (NAAQS) particulate matter regulatory primary standard is an annual concentration of 15 $\mu g/m^3$ (NAAQS 2008). The annual standard is met (air condition is considered acceptable) when the three-year average of the annual mean concentration ≤ 15.0 $\mu g/m^3$. The annual standard (≤ 15.0 $\mu g/m^3$) was used as the reference condition in the current assessment (Table 4-23).

Data used in the analysis were 24-hour averages of PM 2.5. For each site, three-year averages of the annual mean concentrations were calculated. The median of all these values for two sampling sites was taken and assessed against the three reference condition ranges described above.

In keeping with the NPS ARD calculation of multiple reference conditions for ozone (NPS ARD 2011), good condition (or 100% attainment) for particulate matter presents 80% or less (or ≤ 12.0 $\mu g/m^3$) of the current standard. Values > 15 $\mu g/m^3$ indicated significant concern (or 0% attainment). Values of 12.0-15.0 $\mu g/m^3$ indicated moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Table 4-30).

Table 4-35 Particulate matter categories, percent attainment, and condition assessment.

Particulate matter ($\mu g/m^3$)	Percent attainment	Condition
≤ 12	100%	Good
12.1-15	0-100% (scaled)	Moderate
> 15	0%	Significant concern

Condition and trend

The two sites closest to PRWI had a median of 12.5 $\mu g/m^3$ between 2002 and 2012, with 82.76% attainment of the reference condition, or very good condition (Table 4-25).

Over the data range available, there appears to be a decreasing trend in PM 2.5 at both sites. Both sites showed a significant improving trend of particulate matter over the past decade (p value < 0.01) (Figure 4-53, Figure 4-54).

Sources of expertise

- Interagency Monitoring of Protected Visual Environments (IMPROVE).
- U.S. EPA PM Standards. http://www.epa.gov/airquality/particlepollution/

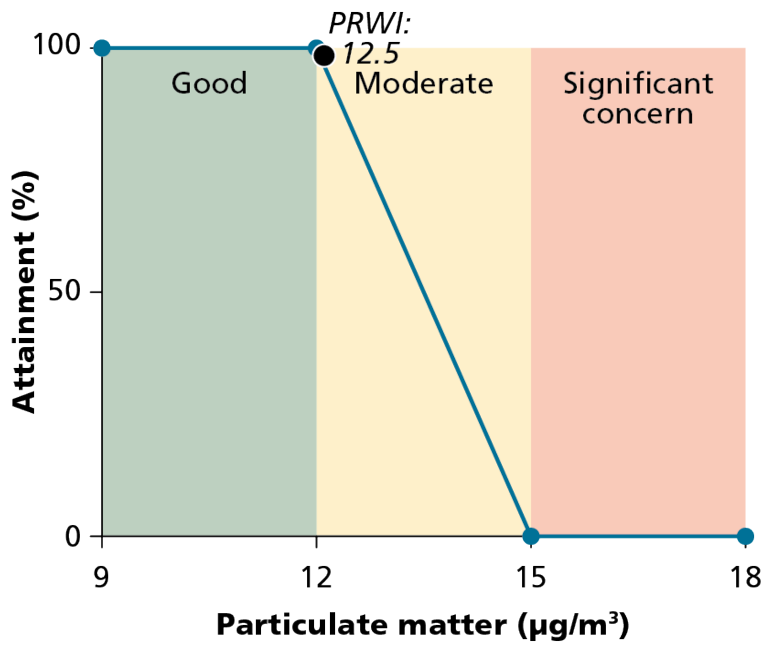

Figure 4-73 Application of the percent attainment categories to the particulate matter value categories. The median for particulate matter at PRWI was 12.5 µg/m^3 which equated to 100% attainment of the reference condition.

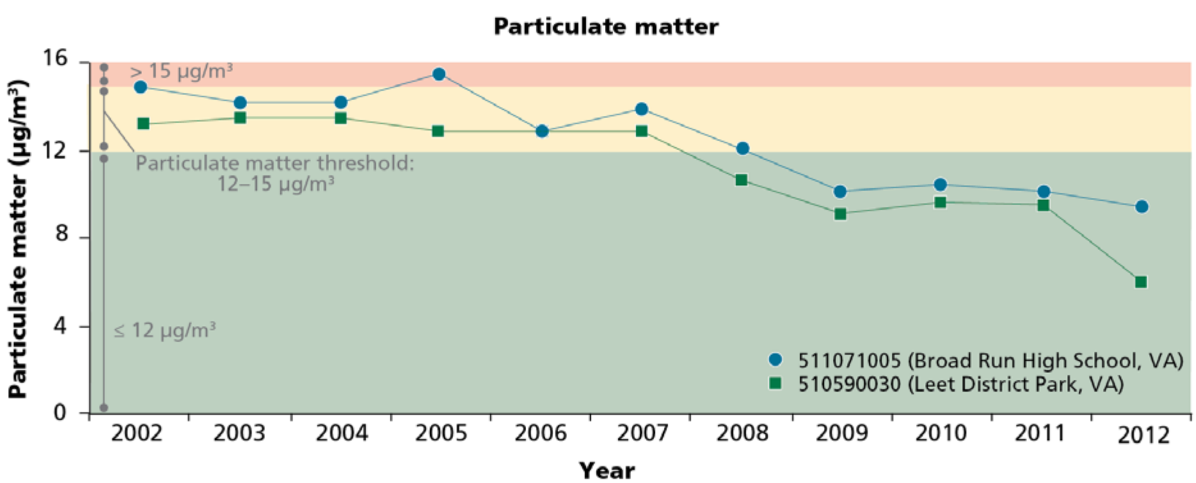

Figure 4-74 Particulate matter (µg/m^3) at the two sites closest to PRWI. Reference conditions are shown in green. Data shown are the annual mean concentrations.

Mercury deposition

Description

Atmospheric mercury (Hg) comes from natural sources, including volcanic and geothermal activity and geological weathering, and anthropogenic sources, such as burning of fossil fuels, processing of mineral ores, and incineration of certain waste products (UNEP 2008). At a global scale, annual anthropogenic emissions of mercury approximately equal all natural marine and terrestrial emissions, with anthropogenic emissions in North America being 153 indicator tons in 2005 (UNEP 2008).

Exposure of humans and other mammals to mercury *in utero* can result in mental retardation, cerebral palsy, deafness, blindness, and dysarthria (speech disorder), and exposure as adults can lead to motor dysfunction and other neurological and mental impacts (U.S. EPA 2001). Avian species' reproductive potential is negatively impacted by mercury, and measured trends in mercury deposition, from west to east across North America, can also be measured in the common loon (*Gavia immer*), and throughout North America in mosquitos (Evers *et al.* 1998, Hammerschmidt and Fitzgerald 2006). Mercury is also recorded to have a toxic effect on soil microflora, although no ecological depositional reference condition is currently established (Meili *et al.* 2003).

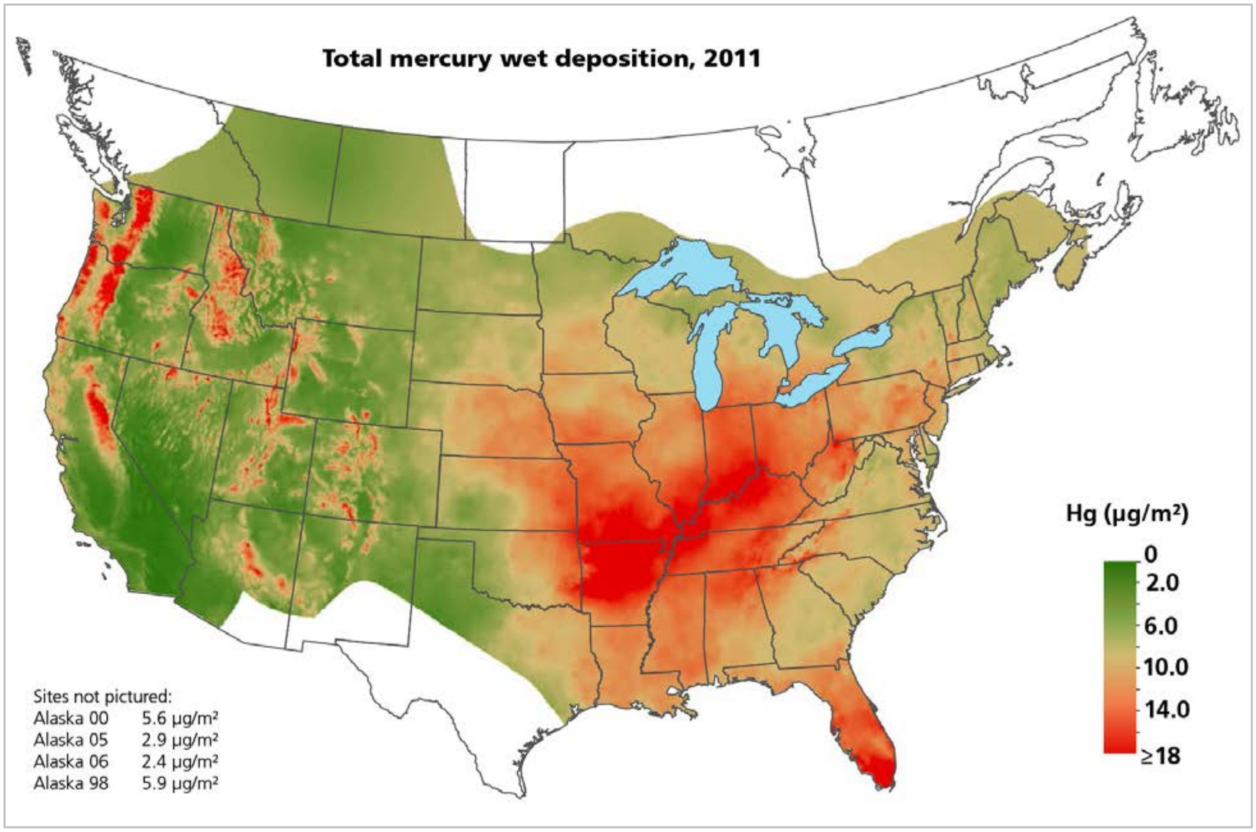

Figure 4-75 Total mercury wet deposition across the United States in 2011 (NADP/MDN 2013).

<u>Data and methods</u>

Data was obtained from the National Atmospheric Deposition Program, Mercury Deposition Network (Table 4-22) for two sites: MD99 (Beltsville, MD) and VA28 (Shenandoah-Big Meadows, VA). Samples are collected weekly within 24 hours of a precipitation event and analyzed for mercury concentration, measured in nanograms (ng) of Hg per liter. Annual mean mercury concentrations were calculated for each sampling site.

There are no published reference conditions for wet deposition of mercury, so this indicator was not included in the overall assessment of PRWI, but was included for informational purposes only.

Condition and trend

Annual median mercury concentrations in precipitation from two sites in the region of PRWI over the past decade range from ~4.97 to 12.56 ng/L (Figure 4-56), and the Mid-Atlantic region in general has relatively low levels of mercury deposition. If it is assumed that precipitation constitutes all of the flow in streams in the park, then it can be assumed that mercury concentrations would be comparable to the range observed in precipitation. The U.S. EPA does provide National Recommended Water Quality Criteria for the protection of aquatic life. Criteria for total dissolved mercury are 1400 ng/L (acute criteria) and 770 ng/L (chronic criteria) (U.S. EPA 2012). These criteria values are 1-2 orders of magnitude greater than what has been recorded in rainfall in the region, suggesting a low risk to aquatic life. However, because stream mercury concentration data within the region is not available, mercury has not been included in the overall assessment.

Over the data range available, no significant trend was present (p-value >0.01) (Figure 4-56).

Sources of expertise

- National Atmospheric Deposition Program, Mercury Deposition Network. http://nadp.sws.uiuc.edu/MDN

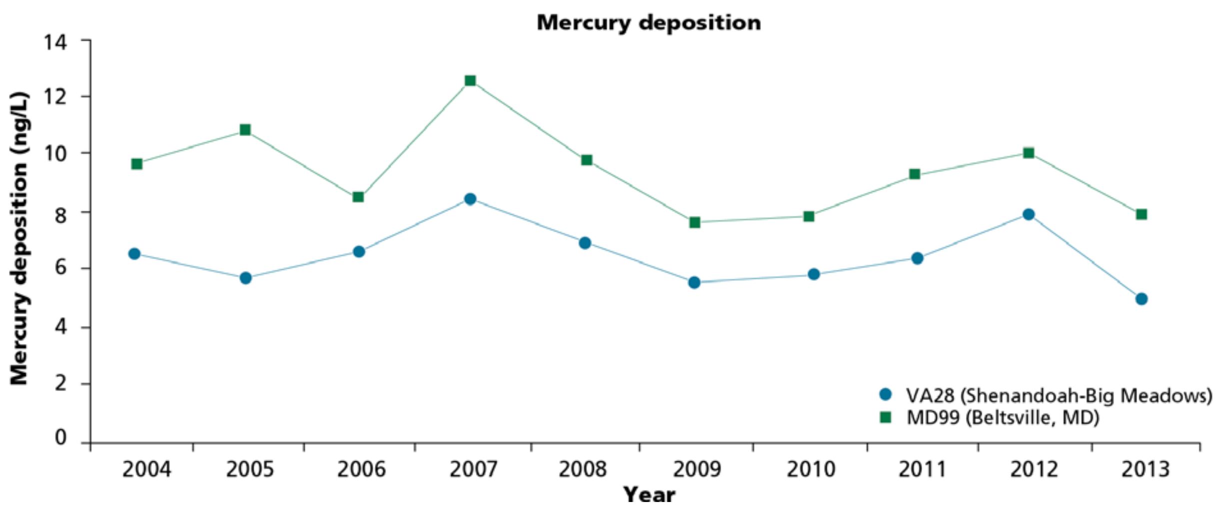

Figure 4-76 Median annual mercury concentrations (ng/L) in precipitation from two sites in the region of PRWI.

Park Natural Resource Condition

Overall, natural resources of Prince William Forest Park were classified as in ***moderate condition***, with 53% achievement of reference conditions. The good conditions of water resources and landscape integrity were offset by very degraded conditions for air resources (Table 5-1). The very degraded condition for air resources is driven by external forces and cannot be expected to be improved through management action within the park.

Table 5-1 Natural resource condition assessment of PRWI.

Vital sign	Reference attainment	Condition
Air quality	13%	Very degraded
Water resources	77%	Good
Biological integrity	57%	Moderate
Landscape dynamics	65%	Good
PRWI Overall	**53%**	**Moderate**

Water resources

Water resources within PRWI were in a good condition, with 77% attainment of reference conditions (Table 5-2). This is despite the majority of water inflows to the park originating from outside the park in developed/urban areas. The majority of water resource indicators were in a very good condition. A higher overall attainment was, however, offset by very degraded conditions for total phosphorus and degraded conditions for the Physical Habitat Index. Management implications and recommended next steps for water resources within PRWI are outlined in Table 5-3.

Table 5-2 Summary of water resources in PRWI.

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

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

Key findings	Management implications	Recommended next steps
Overall good water quality within streams in the park.	• NA	• Maintain integrity of watershed and stream-side vegetation.
• Very degraded condition for stream total phosphorus (Elevated phosphorus levels have been found in parks throughout the region and could be largely due to underlying geology (C*arruthers et al. 2009, Norris and Pieper 2010, Thomas et al.* 2011a, b, c).)	• Nutrient enrichment affects stream flora and fauna (eutrophication). • Visible signs of eutrophication reduces quality of visitor experience.	• Examine possibility of phosphorus enrichment from prolonged explosive usage at Marine Corps Base-Quantico. • Minimize soil disturbance • Implement best management practices such as riparian buffers and no-mow areas.
Degraded Physical Habitat Index		• 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.
• Known issues of low pH in Carter's Run (above pond) not reflected in I&M monitoring data.	• Lack of biological integrity reported in pond. • Reports of dead animals and lack of fish and benthic macroinvertebrates. • Believed that Carter's Pond was built using pyrite mine tailings now known to be acidic.	• Investigate options for adding a park-run monitoring site for Carter's Run above the pond.

Biological integrity

Biological integrity was in ***moderate condition***, with 57% attainment of reference conditions. A higher overall attainment was offset predominantly by very degraded conditions for deer density and their corresponding impact on seedling density (Table 5-4). Management implications and recommended next steps for biological integrity are outlined in Table 5-5.

Table 5-4 Summary of biological integrity in PRWI.

Indicator	Condition
Cover of exotic herbaceous species	Good
Area of exotic tree & saplings	Very good
Presence of forest pest species	Very good
Stocking index	Very degraded
Fish Index of Biological Integrity (FIBI)	Poor
Bird Community Index (BCI)	Very good
Deer density	Very degraded
Biological Integrity	**Moderate**

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

Key findings	Management implications	Recommended next steps
Overall forest community represented well by native plant species, though seedling regeneration is a potential problem.	• Future lack of forest regeneration and subsequent habitat. • Deer overbrowse can contribute to introduction of invasive species.	• Manage deer overbrowse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park). • Investigate deer density thresholds of action that relate to vegetation impacts (rather than solely on deer numbers). • Implement planting initiatives.
Overall very good bird community. However, potential problem near power line rights-of-way (tree clearing).	• Altered bird communities near forest edges.	• Agreement with power utility to move away from existing 5 year grow and clear cut pattern, and movement towards growth of shrubs and forbs underneath power lines. • Monitoring to measure before/after affects of tree management near power lines. • Monitoring for species of concern.
Fish index of biological integrity was in moderate condition.	• Fish population dominated by small fish species. • Effects of climate change on fish diversity unknown.	• Undertake study on potential climate change impacts to aquatic species diversity. • Continue monitoring for snakehead – presence will likely affect native fish

Key findings	Management implications	Recommended next steps
		populations. • Continue annual fish monitoring with Fairfax County. • Lowest score was identified in Carter's Run, likely a result of acidification from historic pyrite mine tailings.
Limited information on reptiles and invertebrates.	• Effects of changes in water quality on reptile and invertebrate species diversity unknown. • Effects of climate change on reptile and invertebrate species diversity unknown.	• Reptile and invertebrate bio-blitz. • Continued long-term monitoring of reptile, amphibian, and invertebrate species.

Landscape dynamics

Landscape dynamics are in ***good condition***, with 65% attainment of reference conditions (Table 5-6). A higher overall attainment was offset predominantly by very degraded conditions for impervious surfaces and road density, largely outside the park (Table 5-6). Management implications and recommended next steps for landscape dynamics are outlined in Table 5-7.

Table 5-6 Summary of landscape dynamics in PRWI.

Indicator	Condition
Forest interior area (within park)	Good
Forest interior area (within park + 5x buffer)	Moderate
Forest cover (within park)	Very good
Forest cover (within park + 5x buffer)	Very good
Impervious surface (within park)	Very good
Impervious surface (within park + 5x buffer)	Very degraded
Road density (within park)	Very good
Road density (within park + 5x buffer)	Very degraded
Landscape Dynamics	Good

Table 5-7 Key findings, management implications, and recommended next steps for landscape dynamics in PRWI.

Key findings	Management implications	Recommended next steps
PRWI highly susceptible to encroachment effects.	• Impacts from groundwater extractions outside the park boundary. • Introduction of pest species. • Altered stream flows (e.g. increased stormwater flows with pollutants).	• Monitor small wetlands and seeps for change. • Actively purchase lands near encroached areas. • Create easements along park boundary to increase buffer zones. • Continue discussions with Marine Corps Base-Quantico. • Outreach to homeowner associations about best management practices.

Air quality

Air quality conditions at PRWI were in a ***very degraded*** condition with 13% attainment of reference conditions (Table 5-8). 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. Management implications and recommended next steps for air resources are outlined in Table 5-9.

Table 5-8 Summary of air quality in PRWI.

Metric	Condition
Wet sulfur deposition	Very degraded
Wet nitrogen deposition	Very degraded
Ozone (ppb)	Very degraded
Ozone (W126)	Very degraded
Visibility	Very degraded
Particulate matter	Good
Overall Air Quality	**Very degraded**

Table 5-9 Key findings, management implications, and recommended next steps for air quality in PRWI.

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. • 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 and species within the park. (e.g. ozone damage to vegetation). • Continue participation in Climate Friendly Parks program (www.nps.gob/climatefriendlyparks). • Investigate effects of poor air quality on sensitive habitats and species within the park. • Continue previous bioindicator monitoring efforts (e.g. tolerant vs. non tolerant lichen species presence). • Stay engaged with the wider community in terms of air quality education and activities.
Lack of park-specific air quality data	• Air quality is only measured and interpolated on regional and national scales. • Unknown impact of traffic (specifically standing traffic) from I-95 near the western corner of the park.	• Use transport and deposition models to predict specific pollution effects by location. • 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.
Ecological references for mercury wet deposition are not available	• Mercury deposition is reported for PRWI but no reference exists for protection of species.	• Adopt standards once NPS Air Resources Division establishes mercury wet deposition reference.
Minimal soundscape information	• Traffic noise from I-95 corridor and weapon fire from Marine Corps Base-Quantico potentially affect bird distribution and recreational	• Noise/soundscape study. • Approach Virginia Department of Transport regarding feasibility of a noise containment wall.

Key findings	Management implications	Recommended next steps
	experience. • Effect greater in fall and winter when foliage not present to dampen noise.	

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Appendix A: Raw data

Table 0-10. Particulate matter (µg PM2.5/m^3). Site locations are shown in Figure 4-41 and thresholds are shown in Table 4-23 Air Quality reference conditions for PRWI..

Site	Years	3-year mean
510590030 (Lee District Park, Virginia)	2002-2004	13.4
	2003-2005	13.3
	2004-2006	13.1
	2005-2007	12.9
	2006-2008	12.2
	2007-2009	10.9
	2008-2010	9.8
	2009-2011	9.4
	2010-2012	8.4
511071005 (Broad Run High School, Virginia)	2002-2004	14.4
	2003-2005	14.6
	2004-2006	14.2
	2005-2007	14.1
	2006-2008	13.0
	2007-2009	12.0
	2008-2010	10.9
	2009-2011	10.2
	2010-2012	10.0

Table 0-11. Water quality data. Site locations are shown in Figure 4-1 and reference conditions are shown in Table 4-2.

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_BONE	10/18/10	6.34	9.2	13.5	*Present <QL	*Present <QL	0.7	0.1468
PRWI_BONE	11/15/10	6.5	9.5	10.8	*Present <QL	*Present <QL	1.3	0.0979
PRWI_BONE	12/13/10	6.79	12.1	4.1	*Present <QL	*Present <QL	0.7	0.0489
PRWI_BONE	2/9/11	6.72	13.8	9.6	*Present <QL	*Present <QL	0.4	0.1207
PRWI_BONE	4/11/11	6.59	8.3	18.3	*Present <QL	*Present <QL	0.3	0.1011
PRWI_BONE	5/4/11	6.48	9.5	12.9	*Present <QL	*Present <QL	0.6	0.1729
PRWI_BONE	6/13/11	6.48	7.3	19.2	*Present <QL	*Present <QL	0.8	0.0620
PRWI_BONE	7/18/11	6.53	5.9	22.4	*Present <QL	*Present <QL	0.7	0.1305
PRWI_BONE	8/17/11	6.71	6	21.6	*Present <QL	*Present <QL	0.7	0.1370
PRWI_BONE	9/20/11	6.46	8.3	17.1	*Present <QL	*Present <QL	0.8	0.3100
PRWI_BONE	10/18/11	6.55	7.5	15.1	*Present <QL	*Present <QL	0.9	0.2382
PRWI_BONE	11/15/11	6.37	7.7	13.6	*Present <QL	*Present <QL	0.6	0.1599
PRWI_BONE	12/13/11	6.64	9.4	7.9	*Present <QL	*Present <QL	0.6	0.0196
PRWI_BONE	1/17/12	6.65	11.5	7.8	*Present <QL	*Present <QL	0.8	0.0359
PRWI_BONE	2/16/12	6.56	10.3	6.7	*Present <QL	*Present <QL	0.7	0.0424
PRWI_BONE	3/15/12	6.6	9.3	14.8	*Present <QL	*Present <QL	0.6	0.0326
PRWI_BONE	4/19/12	6.63	8.6	15.2	*Present <QL	*Present <QL	0.7	0.0522
PRWI_BONE	5/17/12	6.65	8	15.9	*Present <QL	*Present <QL	0.6	0.0457
PRWI_BONE	6/20/12	5.65	6.7	20.6	*Present <QL	*Present <QL	0.9	0.0718
PRWI_BONE	7/11/12	6.43	6.1	22.3	*Present <QL	*Present <QL	0.5	0.0555
PRWI_BONE	8/14/12	6.78	5.1	22.6	*Present <QL	*Present <QL	0.4	0.1533
PRWI_BONE	9/20/12	6.34	7.8	15.8	*Present <QL	*Present <QL	0.6	0.1664
PRWI_BONE	10/9/12	6.85	7.9	12.2	*Present <QL	*Present <QL	0.5	0.0620
PRWI_BONE	11/19/12	7.15	9.4	10	*Present <QL	*Present <QL	0.4	0.0424
PRWI_BONE	12/11/12	6.71	9.7	9.9	*Present <QL	*Present <QL	0.5	0.2675
PRWI_BONE	1/15/13	6.68	11.2	7	*Present <QL	*Present <QL	0.5	0.1958
PRWI_BONE	2/20/13	7.06	10.3	4.8	*Present <QL	*Present <QL	0.6	0.0946
PRWI_BONE	3/11/13	6.91	9.8	10	*Present <QL	*Present <QL	0.7	0.0587
PRWI_BONE	4/8/13	6.51	7.6	15.8	*Present <QL	*Present <QL		
PRWI_BONE	5/6/13	6.78	8.9	15.5	*Present <QL	*Present <QL		
PRWI_CARU	1/15/07	6.09	9.21	10.3	*Present <QL	*Present <QL	0.7	0.5318
PRWI_CARU	2/15/07						1.3	
PRWI_CARU	3/26/07	6.3	8.04	14	*Present <QL	*Present <QL	0.7	0.0424
PRWI_CARU	5/1/07	5.89	8.29	17.1	*Present <QL	*Present <QL		0.0294
PRWI_CARU	5/25/07	6.09	7.14	18.05	*Present <QL	*Present <QL	0.4	0.0946
PRWI_CARU	6/21/07	6.12	6.78	19.7	*Present <QL	*Present <QL	0.3	0.1077

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_CARU	7/25/07						0.6	
PRWI_CARU	8/20/07						0.8	
PRWI_CARU	9/24/07						0.7	
PRWI_CARU	10/15/07						0.7	
PRWI_CARU	11/13/07	6.53	7.82	11.3	*Present <QL	*Present <QL	0.8	
PRWI_CARU	12/11/07	6.45	8.69	9	*Present <QL	*Present <QL	0.9	
PRWI_CARU	1/16/08		10.78	5.7	*Present <QL	*Present <QL	0.6	
PRWI_CARU	3/17/08	6.46	11	10.55	*Present <QL	*Present <QL	0.6	
PRWI_CARU	4/16/08	6.37	10.06	13.5	*Present <QL	*Present <QL	0.8	
PRWI_CARU	5/8/08	6.43	8.71	16.5	*Present <QL	*Present <QL	0.7	
PRWI_CARU	6/11/08	6.31	8.23	22.2	*Present <QL	*Present <QL	0.6	
PRWI_CARU	7/7/08	6.04	6.82	21.75	*Present <QL	*Present <QL	0.7	
PRWI_CARU	8/11/08	6.22	5.21	20.05	*Present <QL	*Present <QL	0.6	
PRWI_CARU	9/15/08	5.98	5.2	22.5	*Present <QL	*Present <QL	0.9	
PRWI_CARU	10/15/08	6.24	4.47	17.5	*Present <QL	*Present <QL	0.5	
PRWI_CARU	11/5/08	6.16	8	13.75	*Present <QL	*Present <QL	0.4	
PRWI_CARU	1/14/09	5.96		4.1	*Present <QL	*Present <QL	0.6	0.0522
PRWI_CARU	2/11/09	6.39	5.85	10.7	*Present <QL	*Present <QL	0.5	0.0392
PRWI_CARU	4/13/09	6.26	9.8	12.1	*Present <QL	*Present <QL	0.4	0.0359
PRWI_CARU	6/15/09	6.17	8.3	19.6	*Present <QL	*Present <QL	0.5	0.0718
PRWI_CARU	7/27/09	6.34	7	22.4	*Present <QL	*Present <QL	0.5	0.0848
PRWI_CARU	8/25/09	6.38	7.3	22.9	*Present <QL	*Present <QL	0.6	0.0750
PRWI_CARU	9/22/09						0.7	
PRWI_CARU	10/20/09	6.56	10.1	10.8	*Present <QL	*Present <QL		0.1142
PRWI_CARU	11/17/09	6.44	8.8	12.2	*Present <QL	*Present <QL		0.0326
PRWI_CARU	12/15/09	6.3	11.3	9	*Present <QL	*Present <QL	0.7	0.0359
PRWI_CARU	1/19/10	6.24	12.2	7.1	*Present <QL	*Present <QL	1.3	0.0489
PRWI_CARU	2/16/10						0.7	
PRWI_CARU	3/16/10	6.07	10.6	11.1	*Present <QL	*Present <QL		0.1697
PRWI_CARU	4/13/10	6.05	10.1	13.3	*Present <QL	*Present <QL	0.4	
PRWI_CARU	5/11/10	6.59	9.5	12.9	*Present <QL	*Present <QL	0.3	0.1044
PRWI_CARU	6/15/10	6.25	7.5	22	*Present <QL	*Present <QL	0.6	0.0816
PRWI_CARU	7/20/10	6.12	6.8	22.8	*Present <QL	*Present <QL	0.8	0.0587
PRWI_CARU	8/17/10	6.38	6.5	24.1	*Present <QL	*Present <QL	0.7	0.0620
PRWI_CARU	9/20/10						0.7	
PRWI_CARU	10/18/10	6	7.56	14.4	*Present <QL	*Present <QL	0.8	0.2088
PRWI_CARU	11/15/10	6.21	9.1	11.2	*Present <QL	*Present <QL	0.9	0.1272
PRWI_CARU	12/13/10	6.42	10.5	5.1	*Present <QL	*Present <QL	0.6	0.1827

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PRWI_CARU	1/10/11	6.88	12.5	10	*Present <QL	*Present <QL	0.6	0.0457
PRWI_CARU	2/9/11	6.64	13.1	9.8	*Present <QL	*Present <QL	0.8	0.0979
PRWI_CARU	4/11/11	6.31	8	17.2	*Present <QL	*Present <QL	0.7	0.1077
PRWI_CARU	5/4/11	6.19	8.7	15.5	*Present <QL	*Present <QL	0.6	0.1631
PRWI_CARU	6/13/11	6.53	7.8	20	*Present <QL	*Present <QL	0.7	0.0392
PRWI_CARU	7/18/11	6.8	6.5	22.6	*Present <QL	*Present <QL	0.6	0.1533
PRWI_CARU	8/17/11						0.9	
PRWI_CARU	9/20/11	6.42	8	17.7	*Present <QL	*Present <QL	0.5	0.1664
PRWI_CARU	10/18/11	6.42	7.7	15.8	*Present <QL	*Present <QL	0.4	0.1142
PRWI_CARU	11/15/11	6.12	7.6	13.3	*Present <QL	*Present <QL	0.6	0.0555
PRWI_CARU	12/13/11	6.26	10.6	7.8	*Present <QL	*Present <QL	0.5	0.0228
PRWI_CARU	1/17/12	6.54	10.6	7.3	*Present <QL	*Present <QL	0.4	0.0228
PRWI_CARU	2/16/12	6.31	10.2	7.1	*Present <QL	*Present <QL	0.5	0.0522
PRWI_CARU	3/15/12	6.19	9.5	14.5	*Present <QL	*Present <QL	0.5	0.0326
PRWI_CARU	4/19/12	6.42	9	15.5	*Present <QL	*Present <QL	0.6	0.0783
PRWI_CARU	5/17/12	6.5	8.5	17.4	*Present <QL	*Present <QL	0.7	0.0359
PRWI_CARU	6/20/12	6.67	6.4	21.5	*Present <QL	*Present <QL		0.0457
PRWI_CARU	7/11/12	6.52	7	22.4	*Present <QL	*Present <QL		0.0587
PRWI_CARU	8/14/12	6.43	7.4	22.6	*Present <QL	*Present <QL	0.7	0.1305
PRWI_CARU	9/20/12	6.6	8.2	16.8	*Present <QL	*Present <QL	1.3	0.1272
PRWI_CARU	10/9/12	6.54	8.5	13.3	*Present <QL	*Present <QL	0.7	0.0881
PRWI_CARU	11/19/12	6.67	9.5	10.2	*Present <QL	*Present <QL		0.0555
PRWI_CARU	12/11/12	6.81	9.9	10.1	*Present <QL	*Present <QL	0.4	0.1827
PRWI_CARU	1/15/13	6.83	11.7	7.5	*Present <QL	*Present <QL	0.3	0.1860
PRWI_CARU	2/20/13	6.86	11.1	5.7	*Present <QL	*Present <QL	0.6	0.1175
PRWI_CARU	3/11/13	6.91	10.7	9.8	*Present <QL	*Present <QL	0.8	0.0522
PRWI_CARU	4/8/13	6.42	8.4	15.6	*Present <QL	*Present <QL	0.7	
PRWI_CARU	5/6/13	6.82	9	15.2	*Present <QL	*Present <QL	0.7	
PRWI_MARU	4/16/08	6.84	11.07	9.65	*Present <QL	*Present <QL	0.7	
PRWI_MARU	5/8/08	7.25	8.9	14.75	254	254	0.4	
PRWI_MARU	6/11/08	6.74	7.15	18.35	*Present <QL	*Present <QL	0.7	
PRWI_MARU	7/7/08	6.24	5.66	17.8	202	202	0.3	
PRWI_MARU	8/11/08	6.54	4.96	16.95	*Present <QL	*Present <QL	0.7	
PRWI_MARU	9/15/08	6.25	4.85	19.25	*Present <QL	*Present <QL	0.5	
PRWI_MARU	10/15/08	6.34	5.24	15.55	212	212	0.6	
PRWI_MARU	11/5/08	6.16	4.29	13.25	226	226	0.5	
PRWI_MARU	2/11/09	5.99	11.6	9.65	*Present <QL	*Present <QL	0.7	0.0587
PRWI_MARU	4/13/09	6.24	9.68	9	*Present <QL	*Present <QL	0.9	0.0653

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PRWI_MARU	6/15/09	6.47	6.2	17.2	208	208	0.5	0.0522
PRWI_MARU	7/27/09	6.5	5.5	18.2	244	244	0.4	0.0620
PRWI_MARU	8/25/09	6.61	5.4	18.6	278	278	0.5	0.0750
PRWI_MARU	9/22/09	6.86	5.7	17.2	222	222	0.6	0.0489
PRWI_MARU	10/20/09	6.91	7.4	8.2	258	258	0.8	0.1468
PRWI_MARU	11/17/09	6.74	8	11.3	*Present <QL	*Present <QL	0.8	0.0392
PRWI_MARU	12/15/09	6.61	9.5	9.2	*Present <QL	*Present <QL	*Present <QL	0.0359
PRWI_MARU	1/19/10	6.83	11.3	6.2	*Present <QL	*Present <QL	0.7	0.0522
PRWI_MARU	3/16/10	6.71	11.4	8.7	*Present <QL	*Present <QL	0.5	0.1533
PRWI_MARU	4/13/10	6.61	10.1	11.7	*Present <QL	*Present <QL	1.2	0.0653
PRWI_MARU	5/11/10	7.22	10.4	11.3	*Present <QL	*Present <QL	0.5	0.1011
PRWI_MARU	6/15/10	6.47	6.4	17.8	366	366	1	0.0750
PRWI_MARU	7/20/10	6.61	6.8	19.2	*Present <QL	*Present <QL	1.2	0.0653
PRWI_MARU	8/17/10	6.55	6.3	19.6	220	220	1.2	0.0587
PRWI_MARU	9/20/10	6.9	6.4	17.4	238	238	1.7	0.1468
PRWI_MARU	10/18/10	7.08	6.9	12.4	308	308	0.8	0.1729
PRWI_MARU	11/15/10	6.8	7.9	10.4	*Present <QL	*Present <QL	1	0.1729
PRWI_MARU	12/13/10	7.34	10.1	4.9	*Present <QL	*Present <QL	1	0.1631
PRWI_MARU	1/10/11	7.42	13.4	9.3	*Present <QL	*Present <QL	1.2	0.0555
PRWI_MARU	2/9/11	7.44	13.5	7.1	*Present <QL	*Present <QL	0.7	0.1631
PRWI_MARU	4/11/11	6.95	8.6	13.4	*Present <QL	*Present <QL	0.5	0.1305
PRWI_MARU	5/4/11	7.05	8.5	12.4	*Present <QL	*Present <QL	0.6	0.1599
PRWI_MARU	6/13/11	6.75	6.3	16.6	218	218	1	0.0620
PRWI_MARU	7/18/11	6.7	5.8	18.9	230	230	1	0.2512
PRWI_MARU	8/17/11	7.31	7.1	19.8	216	216	0.5	0.1207
PRWI_MARU	9/20/11	6.71	7.2	15.9	204	204	0.6	0.2936
PRWI_MARU	10/18/11	6.68	6.2	14.2	202	202	0.9	0.1240
PRWI_MARU	11/15/11	6.55	8.2	12.8	*Present <QL	*Present <QL	0.6	0.1599
PRWI_MARU	12/13/11	6.89	10.2	7.4	*Present <QL	*Present <QL	0.5	0.0555
PRWI_MARU	1/17/12	7.36	10.7	7.5	*Present <QL	*Present <QL	0.9	0.0261
PRWI_MARU	2/16/12	6.88	9.8	7.5	*Present <QL	*Present <QL	0.4	0.0392
PRWI_MARU	3/15/12	6.45	9.3	11.5	*Present <QL	*Present <QL	0.7	0.0653
PRWI_MARU	4/19/12	6.63	8.7	13	200	200	0.9	0.0848
PRWI_MARU	5/17/12	6.83	8.2	15.1	202	202	0.5	0.0848
PRWI_MARU	6/20/12	6.49	7.5	17	206	206	0.9	0.0489
PRWI_MARU	7/11/12	6.48	5.7	18.3	246	246	0.4	0.1501
PRWI_MARU	8/14/12	6.74	5.1	19.8	706	706	0.5	0.1566
PRWI_MARU	9/20/12	6.55	6.7	13.8	290	290	0.3	0.1958

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PRWI_MARU	10/9/12	7.11	7.1	11.5	300	300	0.5	0.1762
PRWI_MARU	11/19/12	7.35	8.1	9.6	204	204	0.4	0.0555
PRWI_MARU	12/11/12	7.68	8.4	9.6	218	218	0.7	0.2153
PRWI_MARU	1/15/13	7.46	10.4	7.8	*Present <QL	*Present <QL	0.5	0.1664
PRWI_MARU	2/20/13	7.9	10.4	5.7	*Present <QL	*Present <QL	0.5	0.1501
PRWI_MARU	3/11/13	6.59	10.1	7.9	*Present <QL	*Present <QL	0.4	0.1011
PRWI_MARU	4/8/13	7.22	8.7	11.7	216	216		
PRWI_MARU	5/6/13	7.28	9.3	12	206	206		
PRWI_MBBR	6/13/05	7.28	8.06	22.25	312	312	0.3	0.1827
PRWI_MBBR	7/14/05	7.16	6.4	21.45	210	210	*Present <QL	0.6917
PRWI_MBBR	10/18/05	6.46	8.82	12.7	392	392	*Present <QL	0.2186
PRWI_MBBR	11/15/05	6.87	4.83	12.9	344	344	*Present <QL	0.2153
PRWI_MBBR	12/20/05	6.75	6.54	2.78	*Present <QL	*Present <QL	*Present <QL	0.1077
PRWI_MBBR	2/2/06	6.58	10.04	7.85	212	212	*Present <QL	0.1794
PRWI_MBBR	3/2/06	6.83	8.65	5.65	212	212	*Present <QL	0.1468
PRWI_MBBR	3/27/06	7.1	4.86	11.5	272	272	0.2	0.0816
PRWI_MBBR	4/26/06	6.92	4.27	12.8	200	200	0.4	0.2675
PRWI_MBBR	5/30/06	7.11	2.88	18.2	376	376	0.4	0.6101
PRWI_MBBR	7/10/06	10.43	7.56	20.3	340	340	0.4	0.1175
PRWI_MBBR	7/27/06	7.01	5.37	24.2	396	396	0.5	0.3622
PRWI_MBBR	9/27/06		8.47	16.6	398	398	0.4	1.9152
PRWI_MBBR	10/24/06	7.19	6.2	9.2	350	350	0.5	0.4633
PRWI_MBBR	12/12/06	7.13	9.28	6	220	220	0.4	0.3850
PRWI_MBBR	1/16/07	7.14	9.48	10.15	*Present <QL	*Present <QL	1	0.2773
PRWI_MBBR	3/26/07	7.365	8.1	13.2	238	238	0.45	0.0359
PRWI_MBBR	5/1/07	7.125	8.155	16.85	304	304	0.17	0.0294
PRWI_MBBR	5/25/07	7.21	7.44	17.625	340	340	0.1	0.2708
PRWI_MBBR	6/21/07	7.21	6.23	18.9	482	482	0.3	0.1501
PRWI_MBBR	7/25/07	6.96	5.16	20.6	498	498	0.2	
PRWI_MBBR	11/13/07	7.23	8.4	10.4	472	472	0.8	
PRWI_MBBR	12/11/07	7.09	7.2	8.3	254	254	1.2	
PRWI_MBBR	1/16/08		9.92	2	412	412	0.6	
PRWI_MBBR	3/17/08	7.41	10.62	9.65	240	240	0.8	
PRWI_MBBR	4/16/08	7.39	10.42	11.8	388	388	0.7	
PRWI_MBBR	5/8/08	7.51	9.17	16	390	390	0.8	
PRWI_MBBR	6/11/08	7.28	9.32	21.2	388	388	0.7	
PRWI_MBBR	7/7/08	7.17	8.1	20.65	414	414	0.6	
PRWI_MBBR	8/11/08	7.35	7.87	18.9	468	468	0.7	

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PRWI_MBBR	9/15/08	7.22	7.45	22.1	326	326	0.6	
PRWI_MBBR	10/15/08	7	8.12	16.5	446	446	0.5	
PRWI_MBBR	11/5/08	6.93	8.51	13.3	462	462	0.6	
PRWI_MBBR	1/14/09	6.8	13.49	1.7	*Present <QL	*Present <QL	0.5	0.0326
PRWI_MBBR	2/11/09	7.13	10.8	10.2	*Present <QL	*Present <QL	0.7	0.0359
PRWI_MBBR	4/13/09	6.95	10.75	10.7	252	252	0.9	0.0294
PRWI_MBBR	6/15/09	7.17	8.9	18	378	378	0.8	0.0783
PRWI_MBBR	7/27/09	7.3	6.9	21.6	488	488	0.4	0.0750
PRWI_MBBR	8/25/09	7.28	6.6	21.8	488	488	0.8	0.0653
PRWI_MBBR	10/20/09	7.23	9.1	9.2	580	580	0.6	0.0848
PRWI_MBBR	11/17/09	7.23	9.8	11.7	308	308	*Present <QL	0.0261
PRWI_MBBR	12/15/09	7.04	11.8	8.5	*Present <QL	*Present <QL	0.5	0.0392
PRWI_MBBR	1/19/10	7.14	12.6	6.4	228	228	0.7	0.0359
PRWI_MBBR	3/16/10	7.23	11.5	10.3	*Present <QL	*Present <QL	0.8	0.1631
PRWI_MBBR	4/13/10	7.16	10.9	11.9	284	284	1.1	0.0718
PRWI_MBBR	5/11/10	7.37	11.5	10.3	342	342	0.6	0.1044
PRWI_MBBR	6/15/10	7.27	8.3	20.7	444	444	1.2	0.0653
PRWI_MBBR	7/20/10	7.21	7.1	22.7	384	384	1.1	0.0848
PRWI_MBBR	8/17/10	7.38	7.4	23	506	506	1	0.0587
PRWI_MBBR	10/18/10	6.78	7.81	13.3	414	414	0.8	0.2741
PRWI_MBBR	11/15/10	7.23	10.3	10.6	364	364	0.9	0.1664
PRWI_MBBR	12/13/10	7.3	12.7	3.7	284	284	0.7	0.0914
PRWI_MBBR	1/10/11	7.4	13.7	8.6	398	398	1.2	0.0457
PRWI_MBBR	2/9/11	7.17	12	9.6	278	278	0.4	0.1077
PRWI_MBBR	4/11/11	7.33	9.2	17.5	274	274	0.4	0.1142
PRWI_MBBR	5/4/11	7.08	9.7	13.7	294	294	0.7	0.1305
PRWI_MBBR	6/13/11	7.3	8.3	19.6	460	460	0.9	0.0457
PRWI_MBBR	7/18/11	7.47	7.8	22.4	578	578	0.6	0.0946
PRWI_MBBR	9/20/11	7.09	8.6	16.9	416	416	0.6	0.2055
PRWI_MBBR	10/18/11	7.16	8.6	14.6	380	380	1	0.0979
PRWI_MBBR	11/15/11	6.95	8.9	13	1608	1608	0.6	0.1305
PRWI_MBBR	12/13/11	6.81	11.3	6.1	272	272	0.6	0.0294
PRWI_MBBR	1/17/12	7.2	12.2	6.3	258	258	0.9	
PRWI_MBBR	2/16/12	7.23	11.7	6.1	306	306	0.6	0.0424
PRWI_MBBR	3/15/12	7.33	10.2	14.2	314	314	0.7	0.0392
PRWI_MBBR	4/19/12	7.3	9.9	14.9	438	438	0.7	0.0424
PRWI_MBBR	5/17/12	7.23	9	16.6	402	402	0.4	0.0522
PRWI_MBBR	6/20/12	7.49	8	20.4	438	438	0.6	0.0946

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_MBBR	7/11/12	7.35	6.9	22.4	604	604	0.4	0.1044
PRWI_MBBR	8/14/12	7.38	6.6	22.5	464	464	0.4	0.1240
PRWI_MBBR	9/20/12	7.3	7.7	16.2	520	520	0.3	0.2284
PRWI_MBBR	10/9/12	7.52	7.1	12.4	474	474	0.4	0.1109
PRWI_MBBR	11/19/12	7.71	8.9	9.8	450	450	0.4	0.0489
PRWI_MBBR	12/11/12	7.01	9.8	10.1	472	472	1.8	0.1403
PRWI_MBBR	1/15/13	7.83	11.7	6.8	382	382	0.5	0.1860
PRWI_MBBR	2/20/13	7.61	12.6	5	312	312	0.6	0.1370
PRWI_MBBR	3/11/13	7.29	10.9	9.2	236	236	0.6	0.0653
PRWI_MBBR	4/8/13	7.26	8.3	16.6	316	316		
PRWI_MBBR	5/6/13	7.13	10	15.1	382	382		
PRWI_NFQC	6/13/05	7.09	8.48	26.4	336	336	0.6	0.1240
PRWI_NFQC	7/14/05	7.25	8.08	26.3	330	330	*Present <QL	0.5024
PRWI_NFQC	8/16/05	7.03	6.19	24.7	744	744	0.1	
PRWI_NFQC	10/18/05	6.57	9.71	13.7	350	350	*Present <QL	0.1990
PRWI_NFQC	11/15/05	6.44	7.18	11.4	376	376	*Present <QL	
PRWI_NFQC	12/20/05	6.63	8.94	1.65	*Present <QL	*Present <QL	*Present <QL	
PRWI_NFQC	2/2/06	6.56	11.4	7.1	230	230	*Present <QL	1.9217
PRWI_NFQC	3/2/06	6.81	9.78	4.65	228	228	*Present <QL	0.1175
PRWI_NFQC	3/27/06	7.183	3.54	9.3	276	276	*Present <QL	0.0261
PRWI_NFQC	4/26/06	7.01	4.17	15.5	220	220	0.4	0.1827
PRWI_NFQC	5/24/06	7.06	4.22	16.6	364	364	0.3	0.3458
PRWI_NFQC	7/10/06	7.03	7.84	22.9	344	344	0.3	
PRWI_NFQC	7/27/06	7.14	6.16	27.6	394	394	0.4	0.0914
PRWI_NFQC	8/22/06	6.65	6.82	24.4	470	470	0.3	0.1925
PRWI_NFQC	9/27/06	6.99	8.26	19.1	324	324	0.4	1.6117
PRWI_NFQC	10/24/06	7.04	10.32	9.72	352	352	0.4	0.2969
PRWI_NFQC	12/12/06	6.92	10.2	3.833	236	236	0.4	0.4405
PRWI_NFQC	1/16/07	6.927	9.39	10.35	220	220	0.3	0.3622
PRWI_NFQC	3/22/07	7.158	8.903	11.3	212	212	0.61	0.0294
PRWI_NFQC	4/23/07	6.76	9.56	17	258	258	0.16	0.0457
PRWI_NFQC	5/25/07	7.04	7.433	21.5	330	330	*Present <QL	0.1272
PRWI_NFQC	6/21/07	6.98	6.42	24.2	456	456	0.1	0.0620
PRWI_NFQC	7/25/07	6.92	6.01	21.3	730	730	0.2	
PRWI_NFQC	8/20/07	7.11	7.08	21.5	770	770	*Present <QL	
PRWI_NFQC	9/24/07	7.01	7.92	17.4	572	572	0.4	
PRWI_NFQC	10/15/07	6.68	7.41	11.2	502	502	1.1	
PRWI_NFQC	11/13/07	6.9	8.86	10.1	444	444	1.1	

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_NFQC	12/11/07	7.06	10.4	7.6	332	332	1	
PRWI_NFQC	1/16/08		10.08	2.13	342	342	0.5	
PRWI_NFQC	3/17/08	6.92	10.96	9.47	346	346	0.9	
PRWI_NFQC	4/16/08	7.07	10.94	12.1	378	378	1.1	
PRWI_NFQC	5/8/08	7.09	8.66	18.4	430	430	0.6	
PRWI_NFQC	6/11/08	7	7.88	25.4	346	346	0.8	
PRWI_NFQC	7/7/08	7.08	7.9	24.2	430	430	0.5	
PRWI_NFQC	8/11/08	7.22	7.8	23.05			1	
PRWI_NFQC	9/15/08	6.81	7.33	24.47	292	292	0.8	
PRWI_NFQC	10/15/08	6.92	8.63	18.35	388	388	0.8	
PRWI_NFQC	11/5/08	6.82	8.93	13.92	384	384	0.6	
PRWI_NFQC	1/14/09	6.84	13.67	1.8	224	224	0.6	0.0457
PRWI_NFQC	2/11/09	7.02	15.22	7.65	220	220	0.6	0.0685
PRWI_NFQC	4/13/09	6.99	10.34	10.6	308	308	1.2	0.0522
PRWI_NFQC	6/15/09	6.94	7.9	20.65	450	450	0.7	0.0750
PRWI_NFQC	7/27/09	7.26	7.05	25.95	512	512	0.5	0.0685
PRWI_NFQC	8/25/09	7.22	7.35	25	474	474	0.9	0.0555
PRWI_NFQC	9/22/09	7.3	8.1	20	730	730	0.7	0.0457
PRWI_NFQC	10/20/09	7.12	10.9	9.7	302	302	0.7	0.1762
PRWI_NFQC	11/17/09	6.92	10.1	11.1	310	310	*Present <QL	
PRWI_NFQC	12/15/09	7.07	12.15	6.9	202	202	1.3	0.0392
PRWI_NFQC	1/19/10	7	13.1	5	220	220	0.6	0.0392
PRWI_NFQC	3/16/10	7.14	11.6	9.4	*Present <QL	*Present <QL	1.1	0.1566
PRWI_NFQC	4/13/10	6.94	10	13.4	284	284	1	0.0555
PRWI_NFQC	5/11/10	7.16	9.95	13.6	310	310	0.7	0.1566
PRWI_NFQC	6/15/10	7.12	8.5	24.6	408	408	1	0.0587
PRWI_NFQC	7/20/10	7.11	7.2	26.5	338	338	1.3	0.0587
PRWI_NFQC	8/17/10	7.05	6.75	26.5	364	364	1	0.0424
PRWI_NFQC	9/20/10	6.87	7.8	18.9	350	350	1.8	0.1044
PRWI_NFQC	10/18/10	6.54	9.28	14.4	394	394	1	0.2675
PRWI_NFQC	11/15/10	6.98	10.65	9.75	302	302	1.2	0.1240
PRWI_NFQC	12/13/10	7.26	13	2.77	222	222	0.8	0.0685
PRWI_NFQC	1/10/11	7.2	14	8.6	330	330	1.4	0.0489
PRWI_NFQC	2/9/11	6.87	12.1	8.7	240	240	0.5	0.1011
PRWI_NFQC	4/11/11	6.97	9.43	15.43	310	310	0.5	0.1142
PRWI_NFQC	5/4/11	6.91	8.8	16.4	306	306	0.8	0.0979
PRWI_NFQC	6/13/11	7.16	7.25	24.55	486	486	0.8	0.0457
PRWI_NFQC	7/18/11	7.2	7	27.1	494	494	1	0.0783

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_NFQC	8/17/11	6.76	7.5	24.1	396	396	0.7	0.0979
PRWI_NFQC	9/20/11	6.87	8.55	18	338	338	0.7	0.1892
PRWI_NFQC	10/18/11	6.76	8.7	15.4	396	396	1.1	0.1370
PRWI_NFQC	11/15/11	6.73	9.95	11.9	404	404	0.4	0.2382
PRWI_NFQC	12/13/11	6.72	11.65	4.9	286	286	0.6	0.0750
PRWI_NFQC	1/17/12	7.11	12.4	4.3	286	286	0.8	0.0228
PRWI_NFQC	2/16/12	7.08	11.85	5.4	346	346	0.6	0.0424
PRWI_NFQC	3/15/12	7.06	10.3	13.9	348	348	0.6	0.0359
PRWI_NFQC	4/19/12	7.3	9.5	16.9	446	446	0.6	0.0522
PRWI_NFQC	5/17/12	7.1	8.25	19.6	430	430	0.6	0.0555
PRWI_NFQC	6/20/12	7.3	7.65	24.55	462	462	0.8	0.0522
PRWI_NFQC	7/11/12	7.32	6.55	24.3	648	648	0.4	0.1272
PRWI_NFQC	8/14/12	7.26	6.3	25	716	716	0.4	0.1077
PRWI_NFQC	9/20/12	7.32	8.75	17.15	520	520	*Present <QL	0.1697
PRWI_NFQC	10/9/12	7.35	8.85	12.6	558	558	0.4	0.0522
PRWI_NFQC	11/19/12	7.02	11.6	9	392	392	0.4	0.0392
PRWI_NFQC	12/11/12	7.1	10.55	9.9	446	446	0.4	0.1599
PRWI_NFQC	1/15/13	7.02	12.4	6.7	358	358	0.7	0.1958
PRWI_NFQC	2/20/13	7.05	12.65	4.4	350	350	0.7	0.1403
PRWI_NFQC	3/11/13	7	11.35	8.6	240	240	0.5	0.0685
PRWI_NFQC	4/8/13	7.1	9.4	14.85	348	348		
PRWI_NFQC	5/6/13	7.3	9.2	14.5	410	410		
PRWI_ORRU	10/15/08	6.54	7.92	16.7	*Present <QL	*Present <QL	1.3	
PRWI_ORRU	11/5/08	6.44	7.78	13.65	*Present <QL	*Present <QL	0.7	
PRWI_ORRU	2/11/09	6.31	6.41	10.55	*Present <QL	*Present <QL	1.1	0.0653
PRWI_ORRU	4/13/09	6.27	8.58	11.2	*Present <QL	*Present <QL	1.1	0.0424
PRWI_ORRU	6/15/09	6.64	8.6	17.8	*Present <QL	*Present <QL	1.1	0.0783
PRWI_ORRU	7/27/09	6.8	7.1	22.4	*Present <QL	*Present <QL	0.6	0.0750
PRWI_ORRU	8/25/09	6.97	5.4	24.8	*Present <QL	*Present <QL	1	0.0979
PRWI_ORRU	10/20/09	6.98	9	10.6	*Present <QL	*Present <QL	0.6	0.1207
PRWI_ORRU	11/17/09	6.8	9.2	12.5	206	206	*Present <QL	0.0392
PRWI_ORRU	12/15/09	6.61	10.7	9.5	*Present <QL	*Present <QL	0.8	0.0522
PRWI_ORRU	1/19/10	6.54	10.6	7.6	*Present <QL	*Present <QL	0.9	0.0424
PRWI_ORRU	6/15/10	6.88	8.1	21.8	242	242	1.2	0.0881
PRWI_ORRU	7/20/10	6.82	7.3	23.8	*Present <QL	*Present <QL	1.3	0.0750
PRWI_ORRU	8/17/10	6.78	7.3	24.3	210	210	1.5	0.0881
PRWI_ORRU	10/18/10	6.21	8.89	14.2	222	222	0.7	0.1501
PRWI_ORRU	11/15/10	6.69	9.7	11	*Present <QL	*Present <QL	1	0.1892

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PRWI_ORRU	12/13/10	6.67	11.8	3.8	*Present <QL	*Present <QL	0.7	0.0979
PRWI_ORRU	2/9/11	6.49	12.6	10.9	*Present <QL	*Present <QL	0.5	0.1077
PRWI_ORRU	4/11/11	6.41	6.3	20.2	*Present <QL	*Present <QL	0.4	0.1142
PRWI_ORRU	5/4/11	6.5	7.8	14.2	*Present <QL	*Present <QL	0.7	0.1403
PRWI_ORRU	6/13/11	6.69	5.5	22.8	330	330	0.8	0.0881
PRWI_ORRU	7/18/11	6.81	5.9	25.5	350	350	0.8	0.1240
PRWI_ORRU	8/17/11	6.79	5.8	22.9	358	358	0.6	0.1501
PRWI_ORRU	9/20/11	6.53	8.3	17.6	228	228	0.9	0.1990
PRWI_ORRU	10/18/11	6.59	8.2	15.3	248	248	1.1	0.1501
PRWI_ORRU	11/15/11	6.27	7.7	13.6	250	250	0.6	0.1762
PRWI_ORRU	12/13/11	6.35	10.2	7.7	206	206	0.6	0.0326
PRWI_ORRU	1/17/12	6.7	11	7.5	*Present <QL	*Present <QL	1.1	
PRWI_ORRU	2/16/12	6.82	10.5	6.6	*Present <QL	*Present <QL	0.8	0.0555
PRWI_ORRU	3/15/12	6.76	9.1	15.8	224	224	0.7	0.0750
PRWI_ORRU	4/19/12	6.82	7.7	19.3	264	264	0.6	0.0783
PRWI_ORRU	5/17/12	6.83	8.3	17.7	270	270	0.6	0.0620
PRWI_ORRU	6/20/12	7.1	7.5	24.3	272	272	0.7	0.0718
PRWI_ORRU	9/20/12	6.96	8.5	18.6	228	228	0.6	0.1892
PRWI_ORRU	10/9/12	7.21	9.6	13.1	270	270	0.4	0.0555
PRWI_ORRU	11/19/12	6.75	9.7	10	234	234	0.6	0.0457
PRWI_ORRU	12/11/12	6.86	10.2	10	230	230	0.4	0.1305
PRWI_ORRU	1/15/13	7.03	11.1	6.8	*Present <QL	*Present <QL	0.6	0.1958
PRWI_ORRU	2/20/13	6.96	10.4	5.2	206	206	0.6	0.0816
PRWI_ORRU	3/11/13	6.7	9	11.1	*Present <QL	*Present <QL	0.7	0.0620
PRWI_ORRU	4/8/13	6.39	5.7	20.3	214	214		
PRWI_ORRU	5/6/13	7	9.4	12.7	258	258		
PRWI_SFQC	6/13/05	7.45	7.77	24.75	302	302	0.6	0.4111
PRWI_SFQC	7/14/05	7.54	7.63	24.4	262	262	*Present <QL	0.2349
PRWI_SFQC	10/18/05	6.8	9.98	13.1	*Present <QL	*Present <QL	*Present <QL	0.1403
PRWI_SFQC	11/15/05	6.53	7.21	11.4	294	294	*Present <QL	0.3361
PRWI_SFQC	12/20/05	6.64	8.97	1.25	200	200	*Present <QL	
PRWI_SFQC	2/2/06	6.72	11.09	6.1	224	224	*Present <QL	0.1175
PRWI_SFQC	3/2/06	7.11	10.02	4.8	224	224	*Present <QL	
PRWI_SFQC	3/27/06	7.44	5.79	9.12	280	280	*Present <QL	0.1305
PRWI_SFQC	4/26/06	7.12	4.05	15.1	*Present <QL	*Present <QL	0.2	0.0946
PRWI_SFQC	5/24/06	7.42	5.3	15	318	318	0.3	0.2904
PRWI_SFQC	7/10/06	7.1	7.54	21.8	280	280	0.3	0.0620
PRWI_SFQC	7/27/06	7.52	6.43	25.7	368	368	0.4	0.1697

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PRWI_SFQC	8/22/06	6.44	7.57	23.3	434	434	0.3	0.0131
PRWI_SFQC	9/28/06	13	8.71	16.95	320	320	0.4	1.6998
PRWI_SFQC	10/24/06	7.26	8.54	9.02	306	306	0.3	0.3687
PRWI_SFQC	12/12/06	7.223	10.197	3.65	210	210	0.4	0.3654
PRWI_SFQC	1/16/07	7.177	8.797	10.033	208	208	0.8	0.7863
PRWI_SFQC	3/22/07	7.308	8.993	11.3	206	206	0.51	0.0326
PRWI_SFQC	4/23/07	7.088	8.918	16.813	240	240	0.1	0.0457
PRWI_SFQC	5/25/07	7.33	6.35	19.488	316	316	0.1	0.0685
PRWI_SFQC	6/21/07	7.17	5.79	20.3	448	448	0.1	0.1077
PRWI_SFQC	7/25/07	7.23	7.01	21.4	508	508	0.1	
PRWI_SFQC	8/20/07	7.28	5.58	20.5	428	428	0.1	
PRWI_SFQC	9/24/07	7.28	6.59	17.9	446	446	0.3	
PRWI_SFQC	10/15/07	7.01	5.35	11.9	554	554	1	
PRWI_SFQC	11/13/07	7.17	6.63	9.5	384	384	1.2	
PRWI_SFQC	12/11/07	7.18	9.38	7.3	252	252	1.1	
PRWI_SFQC	1/16/08		11.79	1.75	328	328	0.9	
PRWI_SFQC	3/17/08	7.22	10.88	8.8	264	264	0.8	
PRWI_SFQC	4/16/08	7.34	10.82	11.13	344	344	0.8	
PRWI_SFQC	5/8/08	7.44	8.15	17.52	432	432	1	
PRWI_SFQC	6/11/08	7.29	7.93	23.94	350	350	0.9	
PRWI_SFQC	7/7/08	7.28	8.09	22.42	380	380	0.5	
PRWI_SFQC	8/11/08	7.41	7.73	20.42	402	402	0.6	
PRWI_SFQC	9/15/08	6.92	6.86	23.4	276	276	0.5	
PRWI_SFQC	10/15/08	7.1	7.75	16.34	404	404	0.7	
PRWI_SFQC	11/5/08	6.89	9.21	12.83	366	366	0.7	
PRWI_SFQC	1/14/09	7.09	14.03	1.1	234	234	0.4	0.0424
PRWI_SFQC	2/11/09	7.23	14.58	7.7	236	236	0.9	0.0718
PRWI_SFQC	4/13/09	7.25	10.82	10.33	294	294	0.9	0.0392
PRWI_SFQC	6/15/09	7.17	8.35	19.65	392	392	0.6	0.0914
PRWI_SFQC	7/27/09	7.45	7.35	23.7	458	458	0.5	0.0522
PRWI_SFQC	8/25/09	7.42	7.75	22.6	440	440	0.7	0.0522
PRWI_SFQC	9/22/09	7.42	7.55	19.4	440	440	0.5	0.0522
PRWI_SFQC	10/20/09	7.29	10.9	8.2	428	428	0.7	0.1403
PRWI_SFQC	11/17/09	7.11	10.17	10.9	294	294	0.5	0.0424
PRWI_SFQC	12/15/09	7.06	12.17	6.9	*Present <QL	*Present <QL	*Present <QL	0.0424
PRWI_SFQC	1/19/10	7.08	13.3	4.2	206	206	0.7	0.0620
PRWI_SFQC	3/16/10	6.98	11.5	9.1	*Present <QL	*Present <QL	0.9	0.1305

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_SFQC	4/13/10	7.18	10.38	13.1	276	276	1	0.0261
PRWI_SFQC	5/11/10	7.4	10.55	12.3	344	344	0.9	0.1109
PRWI_SFQC	6/15/10	7.37	7.5	23.3	358	358	0.9	0.0718
PRWI_SFQC	7/20/10	7.39	7.4	24.7	318	318	0.9	0.0587
PRWI_SFQC	8/17/10	7.34	7.4	24.5	380	380	1.1	0.0587
PRWI_SFQC	9/20/10	7.21	8.2	18.6	478	478		
PRWI_SFQC	10/18/10	7.04	9.58	12.9	362	362	0.9	0.1925
PRWI_SFQC	11/15/10	7.23	10.95	9.2	308	308	1.1	0.1631
PRWI_SFQC	12/13/10	7.31	13	2.85	270	270	0.9	0.0783
PRWI_SFQC	2/9/11	7.18	14.5	7.8	230	230	0.6	0.0783
PRWI_SFQC	4/11/11	7.22	9.55	15.5	296	296	0.5	0.1338
PRWI_SFQC	5/4/11	7.16	9.15	15.4	328	328	0.7	0.1240
PRWI_SFQC	6/13/11	7.52	7.95	22.5	442	442	0.8	0.0392
PRWI_SFQC	7/18/11	7.57	7.35	24.45	438	438	0.7	0.1207
PRWI_SFQC	8/17/11	7.43	7.35	23.5	534	534	0.5	0.1272
PRWI_SFQC	9/20/11	7.08	8.85	17.4	444	444	0.6	0.2055
PRWI_SFQC	10/18/11	6.92	8.85	14.65	364	364	1	0.0685
PRWI_SFQC	11/15/11	6.84	9.75	12.3	384	384	0.5	0.0750
PRWI_SFQC	12/13/11	6.63	11.8	4.6	384	384	0.7	0.0718
PRWI_SFQC	1/17/12	7.12	12.43	5	298	298	1	0.0392
PRWI_SFQC	2/16/12	7.32	11.8	5.5	462	462	0.4	0.0653
PRWI_SFQC	3/15/12	7.44	10.6	13.6	344	344	0.6	0.0620
PRWI_SFQC	4/19/12	7.48	9.55	15.4	440	440	0.6	0.0555
PRWI_SFQC	5/17/12	7.2	8.87	18.1	398	398	0.6	0.0457
PRWI_SFQC	6/20/12	7.5	8.17	22.23	424	424	0.9	0.0489
PRWI_SFQC	7/11/12	7.64	7.55	23.5	504	504	0.5	0.1272
PRWI_SFQC	8/14/12	7.64	7.85	24	522	522	0.4	0.1599
PRWI_SFQC	9/20/12	7.48	9.75	15.85	420	420	0.6	0.0914
PRWI_SFQC	10/9/12	7.46	9.7	12.3	504	504	0.5	0.0457
PRWI_SFQC	11/19/12	7.2	12.5	8.3	398	398	0.4	0.0489
PRWI_SFQC	12/11/12	7.14	11.2	9.8	406	406	0.2	0.2121
PRWI_SFQC	1/15/13	7.04	12.7	6.8	358	358	0.5	0.2480
PRWI_SFQC	2/20/13	7.14	12.9	3.9	328	328	0.7	0.1436
PRWI_SFQC	3/11/13	7.13	11.83	8.2	244	244	0.4	0.0718
PRWI_SFQC	4/8/13	7.44	9.6	15.1	310	310		
PRWI_SFQC	5/6/13	7.44	9.5	12.8	402	402		
PRWI_SORU	6/13/05	7.15	8.17	22.65	254	254	*Present <QL	0.1827
PRWI_SORU	7/14/05	7.02	7.76	21.35	232	232	*Present <QL	0.1338

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_SORU	8/16/05	7.02	7.31	22.85	680	680	0.2	0.1827
PRWI_SORU	10/18/05	6.55	8.92	13.3	298	298	*Present <QL	0.2806
PRWI_SORU	11/15/05	6.69	6.69	12.2	264	264	*Present <QL	0.2186
PRWI_SORU	12/20/05	6.75	7.44	2.15	*Present <QL	*Present <QL	*Present <QL	
PRWI_SORU	2/2/06	6.51	11.72	6.7	*Present <QL	*Present <QL	*Present <QL	1.0571
PRWI_SORU	3/2/06	6.76	9.03	5.6	*Present <QL	*Present <QL	*Present <QL	
PRWI_SORU	3/27/06	7.31	7.32	10.25	204	204	*Present <QL	0.0392
PRWI_SORU	4/26/06	6.92	3.35	13.7	*Present <QL	*Present <QL	0.3	0.0555
PRWI_SORU	5/30/06	6.96	1.38	18.3	288	288	0.3	0.3654
PRWI_SORU	7/10/06	6.85	7.12	19.9	248	248	0.5	0.0685
PRWI_SORU	7/27/06	7.02	5.9	23.1	300	300	0.5	0.0522
PRWI_SORU	8/22/06	6.55	6.74	20.7	298	298	0.5	0.4502
PRWI_SORU	9/27/06	7.01	9.1	15.6	232	232	0.3	1.6150
PRWI_SORU	10/24/06	7.18	11	8.5	546	546	0.3	0.3524
PRWI_SORU	12/12/06	7.04	9.895	3.775	*Present <QL	*Present <QL	0.4	0.3687
PRWI_SORU	1/15/07	6.56	8.365	10.05	*Present <QL	*Present <QL	0.7	0.3883
PRWI_SORU	3/22/07	7.315	8.96	10.3	*Present <QL	*Present <QL	0.59	0.0359
PRWI_SORU	4/23/07	6.635	8.81	14.2	*Present <QL	*Present <QL	0.15	0.0424
PRWI_SORU	5/25/07	6.845	7.855	15.4	232	232	0.1	0.0881
PRWI_SORU	6/21/07	6.96	7.46	17.5	782	782	0.2	0.1436
PRWI_SORU	7/25/07	6.99	7.51	19.2	354	354	0.2	
PRWI_SORU	8/20/07	7.04	6.86	19	302	302	0.1	
PRWI_SORU	9/24/07	6.85	6.7	15.9	356	356	0.4	
PRWI_SORU	11/13/07	7.15	8.56	9.5	324	324	1	
PRWI_SORU	12/11/07	6.98	10.1	7.9	338	338	1.2	
PRWI_SORU	1/16/08		13.32	1.2	280	280	0.8	
PRWI_SORU	3/17/08	7.08	12.15	7.3	244	244	1	
PRWI_SORU	4/16/08	7.4	10.68	9.6	314	314	1.1	
PRWI_SORU	5/8/08	7.4	7.5	16.4	302	302	0.8	
PRWI_SORU	6/11/08	7.18	7.95	21.2	382	382	1	
PRWI_SORU	7/7/08	7	8.25	20.6	298	298	0.6	
PRWI_SORU	8/11/08	7.17	6.94	18.1	282	282	0.8	
PRWI_SORU	9/15/08	6.97	7.25	21.8	262	262	0.5	
PRWI_SORU	10/15/08	6.97	8.48	16.05	314	314	0.7	
PRWI_SORU	11/5/08	6.86	9.31	13.1	340	340	0.5	
PRWI_SORU	1/14/09	7.52	14.37	1.1	210	210	0.5	0.0392
PRWI_SORU	2/11/09	7.09	15.66	9.3	208	208	0.8	0.0522
PRWI_SORU	4/13/09	7.02	10.61	9.2	204	204	0.5	0.0392

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_SORU	6/3/09	6.99	8.9	18	252	252	1.1	0.0750
PRWI_SORU	7/27/09	7.26	8.5	21.4	330	330	0.5	0.0587
PRWI_SORU	8/25/09	7.26	8	20.2	280	280	0.7	0.0653
PRWI_SORU	9/22/09	7.38	8.3	18.2	354	354	0.7	0.2186
PRWI_SORU	10/20/09	7.32	11.7	7.8	366	366	1.1	0.0718
PRWI_SORU	11/17/09	7.1	10.3	11	236	236	0.5	0.0489
PRWI_SORU	12/15/09	7.02	12	8.1	*Present <QL	*Present <QL	0.4	0.0392
PRWI_SORU	1/19/10	7.22	12.8	5.6	*Present <QL	*Present <QL	0.5	0.0489
PRWI_SORU	3/16/10	7.19	11.7	8.8	*Present <QL	*Present <QL	0.7	0.1305
PRWI_SORU	4/13/10	7.06	10.7	12.1	236	236	1.1	0.0620
PRWI_SORU	5/11/10	7.36	10.5	11.1	274	274	0.7	0.0783
PRWI_SORU	6/15/10	7.16	8.2	20.8	270	270	1.3	0.0750
PRWI_SORU	7/20/10	7.19	7.4	22.4	264	264	1.2	0.0555
PRWI_SORU	8/17/10	7.15	7.4	22.4	316	316	1	0.0555
PRWI_SORU	9/20/10	7.16	8	17.7	364	364	1.4	0.0816
PRWI_SORU	10/18/10	5.71	9.8	12.3	298	298	0.8	0.1403
PRWI_SORU	11/15/10	7.17	11	9.5	248	248	1.1	0.1011
PRWI_SORU	12/13/10	7.48	12.9	3.3	206	206	0.7	0.0653
PRWI_SORU	2/9/11	7.3	13	7.9	222	222	0.4	0.0457
PRWI_SORU	4/11/11	7.15	9.5	14.9	222	222	0.6	0.1272
PRWI_SORU	5/4/11	7.01	9.4	13.8	220	220	0.8	0.0881
PRWI_SORU	6/13/11	7.17	8.2	19.1	316	316	1	0.0685
PRWI_SORU	7/18/11	7.16	7.1	21.4	360	360	0.7	0.0750
PRWI_SORU	8/17/11	7.1	5.9	21.3	394	394	0.7	0.1468
PRWI_SORU	9/20/11	6.94	9	16.8	294	294	0.7	0.2284
PRWI_SORU	11/15/11	6.87	9.4	12.7	270	270	0.5	0.2055
PRWI_SORU	12/13/11	6.9	11.5	5.4	218	218	0.6	0.0457
PRWI_SORU	1/17/12	7.4	12.4	5.6	260	260	0.8	0.0228
PRWI_SORU	2/16/12	7	11.7	6.1	258	258	0.5	0.0326
PRWI_SORU	3/15/12	7.13	10.7	12.6	436	436	0.5	0.0326
PRWI_SORU	4/19/12	7.51	10	14.6	284	284	0.7	0.0489
PRWI_SORU	5/17/12	7.12	8.7	16.5	296	296	0.9	0.0555
PRWI_SORU	6/20/12	7.29	7.4	19.6	314	314	0.6	0.0555
PRWI_SORU	7/11/12	7.36	6.9	22	370	370	0.4	0.1729
PRWI_SORU	8/14/12	7.58	6.8	21.9	322	322	0.4	0.1207
PRWI_SORU	9/20/12	7.63	8.4	14.2	296	296	0.2	0.4046
PRWI_SORU	10/9/12	7.75	8.9	11.5	396	396	0.5	0.0653
PRWI_SORU	11/19/12	7.45	11.8	8.6	296	296	0.5	0.0424

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_SORU	12/11/12	7.49	11.3	9.7	304	304	0.3	0.2055
PRWI_SORU	1/15/13	7.31	12.5	7	238	238	0.5	0.1566
PRWI_SORU	2/20/13	7.86	12.6	3.7	238	238	0.7	0.1175
PRWI_SORU	3/11/13	7.07	11.8	7.5	*Present <QL	*Present <QL	0.7	0.0653
PRWI_SORU	4/8/13	7.39	9.8	12.5	262	262		
PRWI_SORU	5/6/13	7.33	9.7	12.5	300	300		
PRWI_TARU	1/15/07	6.94	8.82	9.8	*Present <QL	*Present <QL	0.39	0.6036
PRWI_TARU	3/22/07	7.25	8.39	12	218	218	0.53	0.0359
PRWI_TARU	4/23/07	6.81	9.76	15	276	276	0.32	0.0555
PRWI_TARU	5/25/07	6.93	8.08	14.8	398	398	0.1	0.2838
PRWI_TARU	6/21/07	6.89	6.91	17	598	598	0.2	0.1011
PRWI_TARU	7/25/07	7.09	6.05	18.9	932	932	0.1	
PRWI_TARU	11/13/07	7.15	8.5	9.9	694	694	1	
PRWI_TARU	12/11/07	7.06	10.92	8.3	282	282	1.1	
PRWI_TARU	1/16/08		10.28	1.5	466	466	0.8	
PRWI_TARU	3/17/08	7.03	11.84	7	316	316	1.1	
PRWI_TARU	4/16/08	7.29	10.75	9	398	398	1.2	
PRWI_TARU	5/8/08	7.35	9.19	15.65	434	434	0.9	
PRWI_TARU	6/11/08	7.1	8.21	19.9	384	384	0.9	
PRWI_TARU	7/7/08	6.89	9.36	19.7	490	490	0.7	
PRWI_TARU	8/11/08	7.03	7.36	17.75	480	480	0.6	
PRWI_TARU	9/15/08	6.96	6.75	21.1	354	354	0.5	
PRWI_TARU	10/15/08	6.87	7.23	15.75	498	498	0.9	
PRWI_TARU	11/5/08	6.79	8.48	12.9	494	494	0.5	
PRWI_TARU	2/11/09	6.94	16.2	9.45	226	226	0.9	0.0424
PRWI_TARU	4/13/09	6.86	10.65	9	262	262	0.6	0.0424
PRWI_TARU	6/3/09	6.9	8.8	16.7	330	330	1.1	0.0653
PRWI_TARU	7/27/09	7.15	7.4	20.6	592	592	0.7	0.0685
PRWI_TARU	8/25/09	7.12	7	19.8	642	642	0.7	0.0489
PRWI_TARU	9/22/09	6.97	3.6	17.7	664	664	0.5	0.0750
PRWI_TARU	10/20/09	7.27	10.4	7.7	604	604	0.7	0.0555
PRWI_TARU	11/17/09	7.07	9.8	10.9	366	366	*Present <QL	0.0457
PRWI_TARU	12/15/09	6.97	11.6	8.2	218	218	0.5	0.0424
PRWI_TARU	1/19/10	7.14	12.7	5.2	230	230	0.5	0.0620
PRWI_TARU	3/16/10	6.88	11.4	8.9	*Present <QL	*Present <QL	1.2	0.1175
PRWI_TARU	4/13/10	7.03	10.2	11.5	330	330	1	0.0685
PRWI_TARU	5/11/10	7.27	10	10.3	266	266	0.6	0.0522
PRWI_TARU	6/15/10	6.98	7.5	19.7	304	304	1.3	0.0750

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
PRWI_TARU	7/20/10	6.95	7	21.5	528	528	1.2	0.0816
PRWI_TARU	8/17/10	7.04	6.6	21.7	586	586	1.6	0.0783
PRWI_TARU	10/18/10	7.02	8.99	12.1	370	370	1.1	0.1109
PRWI_TARU	11/15/10	6.95	8.4	9.9	412	412	1	0.0522
PRWI_TARU	12/13/10	7.35	12.4	3.4	308	308	0.8	0.0914
PRWI_TARU	2/9/11	7.29	13.4	7.7	312	312	0.5	0.0489
PRWI_TARU	4/11/11	7.09	9.3	14.4	286	286	0.3	0.0979
PRWI_TARU	5/4/11	6.98	8.9	12.6	322	322	0.8	0.0816
PRWI_TARU	6/13/11	7.11	7.5	18.2	532	532	0.9	0.0522
PRWI_TARU	7/18/11	7.04	6.8	20.5	660	660	0.7	0.1044
PRWI_TARU	8/17/11	6.76	4.7	20.4	648	648	0.5	0.1827
PRWI_TARU	9/20/11	7.04	8.6	16.5	466	466	0.7	0.2219
PRWI_TARU	11/15/11	6.73	8.6	12.7	398	398	0.5	0.1468
PRWI_TARU	12/13/11	6.94	11.3	5.3	278	278	0.6	0.0228
PRWI_TARU	1/17/12	7.19	12.1	5.8	252	252	0.8	0.0228
PRWI_TARU	2/16/12	7.1	11.5	6.8	320	320	0.5	0.0816
PRWI_TARU	3/15/12	7.05	11	12.3	520	520	0.5	0.0424
PRWI_TARU	4/19/12	7.22	9.5	13.9	362	362	0.6	0.0685
PRWI_TARU	5/17/12	7.05	8.8	15.7	412	412	0.5	0.0555
PRWI_TARU	6/20/12	7.24	7.9	18.7	508	508	0.5	0.1011
PRWI_TARU	7/11/12	7.44	6.4	21.5	730	730	0.4	0.2316
PRWI_TARU	8/14/12	7.45	5.5	21.2	244	244	0.5	0.2316
PRWI_TARU	9/20/12	7.54	8.3	13.7	810	810	0.3	0.3067
PRWI_TARU	10/9/12	7.49	9	11.3	934	934	0.6	0.1501
PRWI_TARU	11/19/12	7.35	10.8	9.2	560	560	0.6	0.1175
PRWI_TARU	12/11/12	7.54	10.5	9.7	526	526	0.3	0.1925
PRWI_TARU	1/15/13	7.76	11.3	6.9	328	328	0.5	0.1925
PRWI_TARU	2/20/13	8.05	12.6	3.5	366	366	0.6	0.1370
PRWI_TARU	3/11/13	7.05	11.8	7.3	280	280	*Present <QL	0.0718
PRWI_TARU	4/8/13	7.27	10.4	12.1	342	342		
PRWI_TARU	5/6/13	7.24	9.8	11.7	430	430		

Table 0-12. Deer density (deer/km^2) in PRWI. Deer monitoring sites are shown in Figure 4-24.

Year	Density
2001	15.47
2002	13.09
2003	17.86
2004	11.7
2005	9.46
2006	11.03
2007	5.14
2008	11.7
2009	14.3
2010	5.89
2011	18.32
2012	17.1
2013	23.77
2014	5.91

Appendix B: Expanded Executive Summary

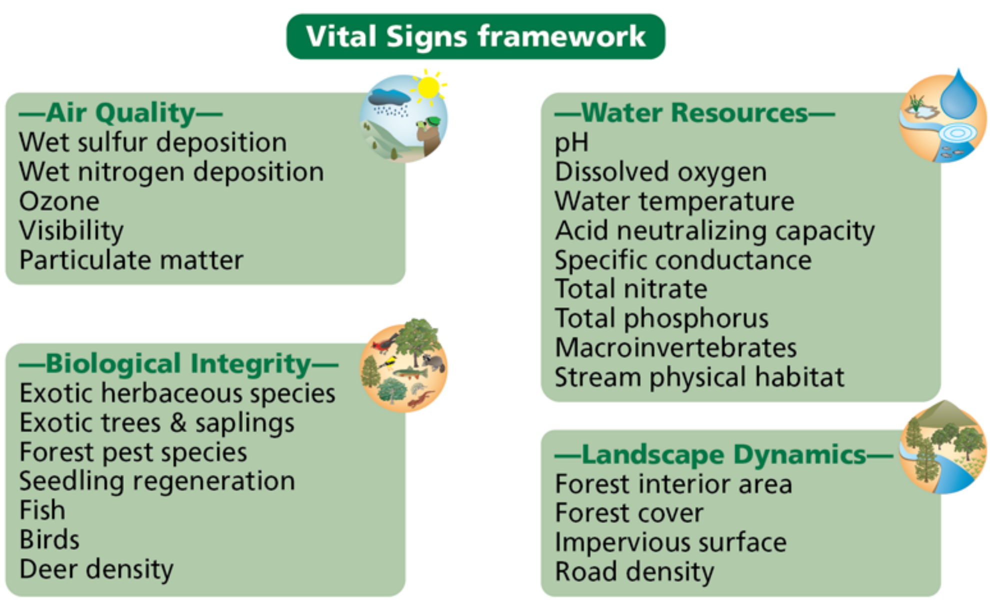
Background and context

Located approximately 35 miles south of Washington, D.C., Prince William Forest Park occupies 15,000 acres in Prince William County, Virginia. The park is the largest protected area in the region and is the third largest national park in the state of Virginia. It is also the largest example of a Piedmont forest in the national park system, and serves as a sanctuary for a diversity of plants and animals which are threatened by increasing development in northern Virginia.

Multiple regional and local stressors challenge Prince William Forest Park's natural resources. 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. 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

The vital signs framework was used to assess natural resource condition within Prince William Forest Park. Within each vital sign, indicators were identified that would inform the assessment and data was sourced for these indicators. 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 and data gaps were developed.



Features of Prince William Forest Park

Prince William Forest Park (PRWI) is located in the southeast corner of Prince William County, Virginia and the northern edge of neighboring Stafford County, Virginia. The park preserves approximately 15,000 acres, covering the Piedmont and the Coastal Plain physiographic provinces and straddles the southern and northern climates. The park is at a transition between the rolling Piedmont Plateau and the low-lying Atlantic Coastal Plain. The two zones meet within the park at the "fall line," where land level drops from the harder rocks of the Piedmont to the softer sedimentary rocks of the coastal plain, resulting in unique geological features such as waterfalls and rock outcroppings.

The 30 square-mile watershed of Quantico Creek is largely forested and protected as part of Prince William Forest Park and Marine Corps Base-Quantico. The headwaters of South Fork Quantico Creek lie within Marine Corps Base-Quantico, and 4 miles (downstream of PRWI) are in private ownership. The remaining 17 square of watershed lie within the park. South Fork Quantico Creek joins Quantico Creek proper near the eastern boundary of the park. These streams receive more than 90% of the runoff from park lands.

The park contains one of the few remaining intact forest ecosystems on the east coast, and is a sanctuary for native plants and animals in the midst of a rapidly developing region. Prince William Forest Park contains several rare plant communities—a seepage swamp, remote stands of eastern hemlock, and several populations of rare, and endangered plants including communities of the small-whorled pogonia (*Isotria medeoloides*), a federally threatened species. Because of the park's location between two physiographic provinces, several of the plant species found in PRWI are at the edge of their natural range.

Threats to Prince William Forest Park

Some areas of Prince William Forest Park are threatened by exotic invasive species that compete with native species. Several pests and diseases threaten forest resources, among them the gypsy moth (*Lymantria dispar)* and dogwood anthracnose (*Discula destructiva*). Excessive numbers of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available for native flora and fauna. Several manmade lakes exist within the park for recreational purposes, and these lakes are often closed to swimming after rainfall events due to bacterial levels. On a regional scale, degraded air quality associated with vehicular traffic affects aquatic habitats and sensitive species. Several streams within PRWI exhibit poor buffering capacity to acidic conditions.

Key findings, recommendations, and data gaps

Overall, the natural resources of Prince William Forest Park were in *moderate 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 good.

Vital sign category	Reference attainment	Condition
Air quality	13%	Very degraded
Water resources	76%	Good
Biological integrity	57%	Moderate
Landscape dynamics	65%	Good
PRWI Overall	**53%**	**Moderate**

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 amounts of particle pollution.

Air Quality. Key findings, management implications, and recommended next steps for air quality in Prince William Forest 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. • 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 and species within the park. (e.g. ozone damage to vegetation). • Continued participation in Climate Friendly Parks Program (www.nps.gob/climatefriendlyparks). • Investigate effects of poor air quality on sensitive habitats and species within the park. • Continue previous bioindicator monitoring efforts (e.g. tolerant vs. non tolerant lichen species presence). • Stay engaged with the wider community in terms of air quality education and activities.
Lack of park-specific air quality data	• Air quality is only measured and interpolated on regional and national scales. • Unknown impact of traffic (specifically standing traffic) from I-95 near the western corner of the park.	• Use transport and deposition models to estimate air quality indicator conditions. • 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.
Ecological references for mercury wet deposition are not available	• Mercury deposition is reported for PRWI but no reference exists for protection of species.	• Adopt standards once NPS Air Resources Division establishes mercury wet deposition reference.
Minimal soundscape	• Traffic noise from I-95 corridor and weapon fire	• Noise/soundscape study. • Approach Virginia Department of Transport

Key findings	Management implications	Recommended next steps
information	from Marine Corps Base-Quantico potentially affect bird distribution and recreational experience. • Effect greater in fall and winter when foliage doesn't dampen noise.	regarding feasibility of a noise containment wall.

Water Resources

Stream water resources were in good condition overall, with 76% attainment of reference conditions. The majority of water resource indicators were in a very good condition. A higher overall attainment was, however, offset by very degraded conditions for total phosphorus and degraded conditions for the stream Physical Habitat Index. The majority of water inflows to the park originate from outside the park in developed/urban areas. (It would be informative to monitor water as it enters the park.) 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 on cooler water.

Water Quality. Key findings, management implications, and recommended next steps for air quality in Prince William Forest Park.

Key findings	Management implications	Recommended next steps
Overall good water quality within streams in the park.	• NA	• Maintain integrity of watershed and stream-side vegetation.
• Very degraded condition for stream total phosphorus (Elevated phosphorus levels have been found in parks throughout the region and could also be largely due to underlying geology (C*arruthers et al. 2009, Norris and Pieper 2010, Thomas et al.* 2011a, b, c).)	• Nutrient enrichment affects stream flora and fauna (eutrophication). • Visible signs of eutrophication reduces quality of visitor experience.	• Examine possibility of phosphorus enrichment from prolonged explosive usage at Marine Corps Base-Quantico. • Minimize soil disturbance. • Maintain integrity of watershed and stream-side vegetation. • Implement best management practices such as riparian buffers and no-mow areas.
Degraded stream Physical Habitat Index	•	• Implement stream restoration and manage volume and velocity of water entering the park (e.g. swales, riparian buffers and no-mow

Key findings	Management implications	Recommended next steps
		areas). • Prepare education materials for immediate neighbors. • Implement monitoring to identify sources and patterns of pollution affecting stream biota and develop management actions.
Known issues of low pH in Carter's Run (above pond) not reflected in I&M monitoring data.	• Lack of biological integrity reported in pond. • Reports of dead animals and lack of fish and benthic invertebrates. • Believed that Carter's Pond was built using pyrite mine tailings now known to be acidic.	• Investigate options for monitoring Carter's Run pond specifically.

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 and as such, deer management should continue to be a top priority. Other monitoring recommendations include expanded 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 Prince William Forest Park.

Key findings	Management implications	Recommended next steps
Overall forest community represented well by native plant species, though seedling regeneration is a problem.	• Future lack of forest regeneration and subsequent habitat. • Deer overbrowse can contribute to introduction of invasive species.	• Manage deer overbrowse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park). • Investigate deer density thresholds of action that relate to vegetation impacts (rather than solely on deer numbers). • Implement planting

Key findings	Management implications	Recommended next steps
		initiatives.
Overall very good bird community. However, potential problem near power line rights-of-way (tree clearing).	• Altered bird communities near forest edges.	• Agreement with power utility to move away from existing 5-year grow and clear cut pattern, and movement towards growth of shrubs and forbs underneath power lines. • Monitoring to measure before/after affects of tree management near powerlines. • Monitoring for species of concern.
Fish index of biological integrity was in moderate condition.	• Fish population dominated by small fish species. • Effects of climate change on fish diversity unknown.	• Undertake study on potential climate change impacts to aquatic species diversity. • Continue monitoring for snakehead – presence will likely affect native fish populations. • Continue annual fish monitoring with Fairfax County. • Lowest score was identified in Carter's Run, likely a result of acidification from historical pyrite mine tailings.
Limited information on reptiles and invertebrates.	• Effects of changes in water quality on reptile and invertebrate species diversity unknown. • Effects of climate change on reptile and invertebrate species diversity unknown.	• Reptile and invertebrate bio-blitz. • Continued long-term monitoring of reptile, amphibian, and invertebrate species.

Landscape dynamics

Landscape dynamics were in good condition overall, with 65% attainment of reference conditions. A higher overall attainment was offset predominantly by very degraded conditions for impervious surfaces and road density – largely outside the park. Forest interior area and forest cover were both in moderate to very good condition.

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 Prince William Forest Park.

Key findings	Management implications	Recommended next steps
PRWI highly susceptible to encroachment effects.	• Impacts from groundwater extractions outside the park boundary.	• Monitor small wetlands and seeps for change. • Actively purchase lands

Key findings	Management implications	Recommended next steps
	• Altered stream flows (e.g. increased stormwater flows with pollutants). • Introduction of pest species.	near encroached areas. • Create easements along park boundary to increase buffer zones. • Continued discussions with Marine Corps Base-Quantico. • Outreach to homeowner associations about best management practices.

Conclusions

Natural resources in Prince William Forest Park are in moderate condition overall and are under threat from surrounding land use (increased development), regionally poor air quality, overpopulation of deer, and exotic species and pests. 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 allowing for the success of exotic species and forest pests and disease.

Appendix C: Resource Brief

Prince William Forest Park
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 Prince William Forest Park.

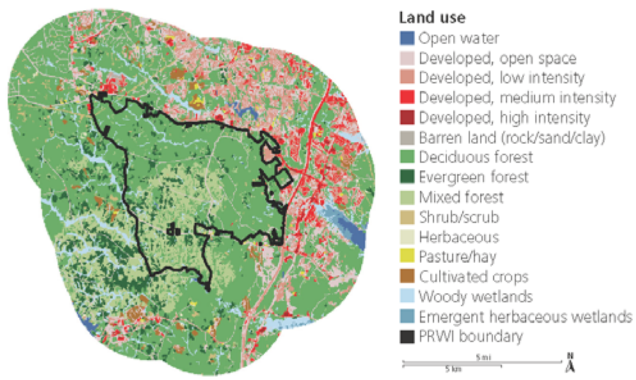
Prince William Forest Park (PRWI) contains one of the largest Piedmont forest ecosystems on the east coast, and is a sanctuary for native plants and animals in the midst of a rapidly developing region. PRWI contains several rare plant communities—a seepage swamp, remote stands of eastern hemlock, and several populations of rare, and endangered plants including communities of the small-whorled pogonia (*Isotria medeoloides*), a federally threatened species. Because of the park's location overlapping two physiographic provinces, several of the plant species found in PRWI are at the edges of their natural ranges.

Multiple regional and local stressors challenge Prince William Forest Park's natural resources. 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. On a regional scale, degraded air quality associated with vehicular traffic pollutes rain and snowfall that affects aquatic habitats and sensitive species. Several streams within PRWI exhibit poor buffering capacity to acidic conditions.

Some areas of Prince William Forest Park are threatened by exotic invasive plant species that compete with native species. Several pests and diseases threaten forest resources, among them the gypsy moth (*Lymantria dispar*) and dogwood anthracnose (*Discula destructiva*). Excessive numbers of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available for native flora and fauna. Several manmade lakes exist within the park for recreational purposes, and these lakes are often closed to swimming after rainfall events due to bacterial levels.

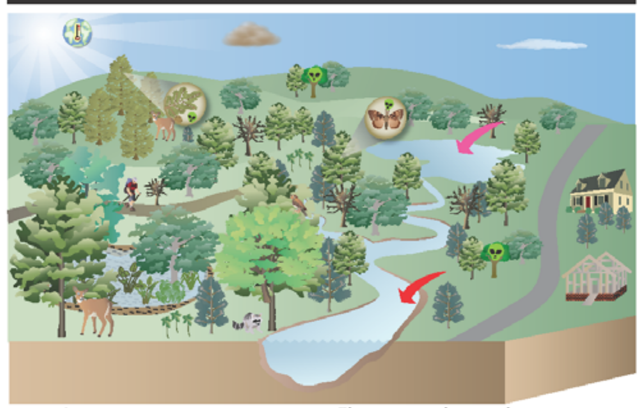
Natural resource condition in Prince William Forest Park

A total of 25 vital sign indicators were used to determine the natural resource condition of PRWI. Reference conditions (or ideal scenarios) were established as benchmarks for each indicator. Percentage scores were calculated for each indicator to represent where the state of the indicator was in comparison to reference conditions. Based on key vital sign findings, management recommendations were developed and data gaps were identified.



Adjacent land use within a 5 km area surrounding Prince William Forest Park in 2011 (Jin et al. 2013; NPS 2011b).

Prince William Forest Park Resources and Threats



Natural resources
- Native plant communities
- Seepage swamp
- Eastern hemlock stands
- Sustainable visitor use
- Rare plant communities (small whorled pogonia)
- Wildlife habitat

Threats to park natural resources
- Poor air quality
- Invasive exotic species (including gypsy moth, hemlock wooly adelgid and plant species)
- Deer overpopulation
- Exotic diseases and tree death
- Adjacent land use
- Nutrients
- Bacteria
- Stream bank erosion
- Global climate change

Features of, and threats to natural resources in Prince William Forest Park.

KEY FINDINGS AND RECOMMENDATIONS

Overall, the natural resources of Prince William Forest Park were in moderate condition.

Air Quality Air quality was in a very degraded condition. Degraded air quality is a problem throughout the eastern United States, the causes of which are out of the park's control. 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 in the air.

Water Resources Stream water resources were in good condition overall. The majority of water resource indicators were in a very good condition. A higher overall attainment was, however, offset by very degraded conditions for total phosphorus and degraded conditions for the stream Physical Habitat Index. 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 nutrient sources and sensitive organisms. An increase in stream water temperatures is one of the most immediate threats from climate change, as this could result in the loss of fish and other organisms that depend on cooler water.

Biological Integrity Biological integrity was in a moderate condition overall, although results for individual metrics were variable. Deer density and a measure of tree 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. 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.

Landscape Dynamics Landscape dynamics were in good condition overall. A higher overall attainment was offset predominantly by very degraded conditions for impervious surfaces and road density – largely outside the park. Forest interior area and forest cover were both in moderate to very good condition. Related 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.

Vital Signs Framework

Air Quality
- Wet sulfur deposition
- Wet nitrogen deposition
- Ozone
- Visibility
- Particulate matter

Biological Integrity
- Exotic herbaceous species
- Exotic trees & saplings
- Forest pest species
- Seedling regeneration
- Fish
- Birds
- Deer density

Water Resources
- pH
- Dissolved oxygen
- Water temperature
- Acid neutralizing capacity
- Specific conductance
- Total nitrate
- Total phosphorus
- Macroinvertebrates
- Stream physical habitat

Landscape Dynamics
- Forest interior area
- Forest cover
- Impervious surface
- Road density

The vital signs framework used to assess Prince William Forest Park.

Vital Sign	Reference condition attainment	Current condition
Air Quality	13%	Very degraded
Water Resources	77%	Good
Biological Integrity	57%	Moderate
Landscape Dynamics	65%	Good
PRWI	**53%**	**Moderate**

The overall reference condition attainment and current condition of each of the four vital signs within Prince William Forest Park.

CONCLUSIONS

Natural resources in Prince William Forest Park are in moderate condition overall and are under threat from surrounding land use (increased development), regionally poor air quality, overpopulation of deer, and exotic species and pests. 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 allowing for the success of exotic species and forest pests and disease.

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For more information, please visit the Park's Visitor Center or call (703) 221-4706.
Prince William Forest Park
National Park Service
www.nps.gov/prwi

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