National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

George Washington Memorial Parkway

Natural Resource Condition Assessment

Natural Resource Report NPS/GWMP/NRR—2016/1121

ON THE COVER
Photograph of Great Falls in Great Falls Park, Virginia.
Photograph courtesy of Brent Steury, National Park Service.

George Washington Memorial Parkway

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Natural Resource Report NPS/GWMP/NRR—2016/1121

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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

George Washington Memorial Parkway (GWMP) was developed as a scenic parkway to help preserve the Potomac River Gorge and shoreline while serving as a memorial to the first President of the United States, George Washington. The Potomac Gorge is one of the most significant natural areas in the United States, and is home to hundreds of occurrences of many rare species and communities. The park also houses several unique habitats, including a major river system with numerous tributaries, noteworthy stands of upland forest, seeps and springs harboring rare groundwater fauna, and abundant wetlands (Allen and Flack 2001). Today, GWMP occupies more than 2,954 hectares (7,300 acres) of land, connecting some of the most important historic, natural, and cultural sites from Mount Vernon to Great Falls Park, and providing a sanctuary for many rare and unique plant and animal species in the urbanized Washington, D.C. metropolitan area (NPS 2014a). GWMP runs 45 km (28 mi) along the western shore of the Potomac River through the District of Columbia and portions of northern Virginia. Within the park there are 27 sites associated with George Washington’s life, and the nation he helped establish. The parkway is a key transportation artery in northern Virginia, providing access to Washington, D.C., Arlington County, Fairfax County, and the City of Alexandria. Many local residents consider the parkway a commuter route, however from its inception, the parkway was established as a recreational and environmental conservation area (NPS 2008).

Significant natural areas occur throughout GWMP and are extremely rich both in biodiversity and in historical context. The park provides islands of refuge for many rare and unique plant and animal species in the highly urbanized Washington, D.C. metropolitan area, protecting a variety of cultural and natural resources, including plant community types found nowhere else on earth. Finding species new to science is a regular occurrence within the park, and in the ten years of conducting its all taxa biotic index, 5,289 species have been documented, including 74 species new to science, 3 species new to North America, 84 new to Virginia, and 105 listed as rare in Virginia or Maryland. Additionally, GWMP provides opportunities for the public to foster awareness of the importance of species preservation, biological diversity, natural systems and processes, and the value of natural open space in an urban environment.

The natural resources of GWMP are challenged by multiple regional and local stressors. 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. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available to native flora and fauna. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion. Adverse recreational use within the park can lead to the trampling and loss of vegetation, potential introduction of non-native species, and disturbance or displacement of flora and fauna. Exotic and invasive plants compete with native species, while insects and other pests cause damage to forest trees. Exotic plants are prevalent with the park. Excessive numbers of white-tailed deer use the park as a refuge; resulting in overgrazing of native flora, particularly tree seedlings.

Natural Resource Condition Assessment

Assessment of natural resource condition within GWMP was carried out using the Inventory and Monitoring (I&M) program vital signs ecological monitoring framework. Twenty-five metrics were synthesized 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 justified ecological threshold values.

Overall, the natural resources of George Washington Memorial Parkway were in degraded condition.

Ecological monitoring framework

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

All air quality metrics were evaluated to be in conditions of significant concern, except particulate matter, which was in moderate condition.

Water resources were in good condition overall. Specific conductance, physical habitat index, total phosphorus, and benthic index of biotic integrity were in degraded to very degraded condition, while pH, dissolved oxygen, water temperature, and acid neutralizing capacity were in very good condition, similar to results found in parks throughout the region.

George Washington Memorial Parkway had variable results for biological integrity. The park scored as very good condition for presence of forest pest species and basal area of exotic trees and saplings within the NPS Inventory & Monitoring plots; degraded condition for stocking index, fish index of biotic integrity (FIBI), and bird community index (BCI); and very degraded condition for cover of exotic herbaceous species and deer density.

Landscape dynamics were in very degraded condition overall. Impervious surface at the park scale was very good, however it was in very degraded condition at the 5x park area scale. Forest interior area, forest cover, and road density were all very degraded at both the park scale, and the 5x park area scale.

Recommendations and data gaps

Air quality was in 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.

Water resources were in good condition overall, with 60% attainment of reference conditions. However, total phosphorus was in very degraded condition, which is similar to results found in parks throughout the region. Benthic Index of Biotic Integrity (BIBI) is currently in very degraded condition while the Physical Habitat Index is in moderate (degraded) condition. The majority of water inflows to the park originate from outside the park in developed/urban areas. It would be informative to monitor water as it enters and then leaves 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 upon cooler water.

Biological integrity was in a degraded condition overall, although results for individual metrics were variable. Deer density, fish index of biological integrity, and cover of exotic herbaceous species were all 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 to include efforts to model 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, the introduction and spread of exotic species and forest pests and diseases.

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

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

Conclusions

Natural resources in GWMP are in degraded condition overall and are under threat from surrounding land use, regionally poor air quality, and overpopulation of deer. Climate change is predicted to negatively affect many of the natural resources of the park, including increasing ozone levels and particle pollution, raising water temperature, changing forest composition, and affecting exotic species and forest pests and disease. Despite the degraded conditions, species new to science are regularly found in GWMP and the park provides habitat for over 100 rare species.

Acknowledgments

Geoff Sanders, John Paul Schmit, Jim Pieper, Marian Norris, and NPS National Capital Region Inventory & Monitoring, who provided data support. Alex Romero, Superintendent at George Washington Memorial Parkway and GWMP Acting Biologist Ryan Tietjen. 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 project scoping, initiation, and 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:

- 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.

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource

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

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

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

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.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

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

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

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 decisionmaking, planning, and partnership activities.

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

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

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

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

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

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

NRCA Reporting Products…

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

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations ***(near-term operational planning and management)***

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values ***(longer-term strategic planning)***

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public

Introduction and Resource Setting

George Washington Memorial Parkway (GWMP) was developed as a scenic parkway to help preserve the Potomac River Gorge and shoreline while serving as a memorial to the first President of the United States, George Washington. The Potomac Gorge is one of the most significant natural areas in the United States, and is home to hundreds of occurrences of many rare species and communities. The park also houses several unique habitats, including a major river system with numerous tributaries, noteworthy stands of upland forest, seeps and springs harboring rare groundwater fauna, and abundant wetlands (Allen and Flack 2001). Today, GWMP occupies more than 7,300 acres of land, connecting some of the most important historic, natural, and cultural sites from Mount Vernon to Great Falls Park, and providing a sanctuary for many rare and unique plant and animal species in the urbanized Washington, D.C. metropolitan area (NPS 2014a). GWMP runs 45 km (28 mi) along the western shore of the Potomac River through the District of Columbia and portions of northern Virginia. Within the park there are 27 sites associated with George Washington's life, and the nation he helped establish. The parkway is a key transportation artery in northern Virginia, providing access to Washington, D.C., Arlington County, Fairfax County, and the City of Alexandria. Many local residents consider the parkway a commuter route, however from its inception, the parkway was established as a recreational and environmental conservation area (NPS 2008).

The Capper-Cramton Act of May 29, 1930 (46 Stat. 482) allowed for the acquisition, establishment, and development of GWMP along the Potomac River from Mount Vernon and Fort Washington to Great Falls, Virginia (NPS 2014a). This act also provided for the acquisition of lands in the District of Columbia, Maryland, and Virginia, which were constructed from 1935 to 1965. The parkway was built in stages between 1929 and 1970. Originally known as the Mount Vernon Memorial Highway (MVMH), construction on the MVMH portion of the new roadway was completed in three years, opening in 1932 for the bicentennial of Washington's birth. The longest section, between Spout Run and Langley, Virginia, was officially opened by President Dwight Eisenhower in 1959. The final portion of the road, between Chain Bridge (Little Falls) and the Maryland border, was opened in 1970. In 1989, the Maryland portion of the road was renamed Clara Barton Parkway in honor of the founder of the American Red Cross, whose home is preserved near the parkway. Nearby Glen Echo Park, in Montgomery County, Maryland was founded in 1891 as a National Chatauqua Assembly to promote education and intellectual discourse in the science, arts, languages and literature. The Chatauqua evolved into an amusement park which served the Washington area until 1968. The NPS acquired Glen Echo Park in 1971, and today the park's historic buildings house a diversity of public arts education programs (Allen and Flack 2001).

Since its inception, the parkway has served as a grand entryway to the nation's capital and as a steward to the Potomac River and its watersheds (Robinson and Associates 2011). GWMP comprises 27 sites within Virginia, Maryland, and the District of Columbia replete with natural and cultural resources. While some of these sites were included in the original parkway authorization, others such as Theodore Roosevelt Island and Arlington House, the Robert E. Lee Memorial were separately legislated and incorporated under the administration of GWMP. Additionally, a number of other small parks, natural areas, and marinas (operated by concessioners) are also administered by the parkway. Also grouped with the parkway for NPS administration are Great Falls Park in Virginia, Columbia Island (Lyndon B. Johnson Memorial Grove), Clara Barton National Historic Site, Clara Barton Parkway, Glen Echo Park, and adjoining land along the Chesapeake and Ohio (C&O) Canal on the Maryland shore of the Potomac River. In 2005, the U.S. Department of Transportation designated George Washington Memorial Parkway as an All-American Road in the National Scenic Byways Program. This program recognizes selected roadways throughout the U.S. based on their archeological, cultural, historic, natural, recreational, and scenic qualities and seeks to protect them (NPS 2005).

Approximately nine million visitors use the parks of GWMP annually, including the national and international monuments and memorials, natural and recreational areas, trails, a living history farm, and historic homes. These sites, while each possessing a distinct history and individual merits, are united by the parkway and together represent broad themes in the nation’s history (Robinson and Associates 2011).

Legislated Park Units Managed by George Washington Memorial Parkway

- Arlington House, The Robert E. Lee Memorial
- Clara Barton National Historic Site
- George Washington Memorial Parkway
- Lyndon Baines Johnson Memorial Grove on the Potomac
- Theodore Roosevelt Island
- Non-legislated Park Sites Managed by George Washington Memorial Parkway
- Arlington Ridge Park
- Netherlands Carillon
- U.S. Marine Corps War Memorial
- Belle Haven Park and Marina
- Claude Moore Colonial Farm
- Collingwood Picnic Area
- Daingerfield Island
- Dyke Marsh Wildlife Preserve
- Fort Hunt Park

- Fort Marcy
- Glen Echo Park
- Gravelly Point
- Great Falls Park
- Jones Point Park and Lighthouse
- Lady Bird Johnson Park
- Memorial Avenue/Arlington Memorial Bridge
- Mount Vernon Trail
- Navy and Marine Memorial
- Riverside Park
- Roaches Run Waterfowl Sanctuary
- Turkey Run Park
- Women in Military Service for America Memorial

Park enabling legislation

The enabling legislation is the specific piece of legislation through which Congress created the park and declared its intent for the park. Based on enabling legislation, the mission of George Washington Memorial Parkway is to develop, manage, and preserve the park, parkway and playground system of the National Capital area; protect and preserve a wide variety of individual cultural, natural, recreational, and scenic resources throughout the parkway; and promote opportunities for the public to learn about and experience parkway resources. Several laws and documents guide natural resource management for GWMP—the National Park Service Organic Act of 1916 ("Organic Act," Ch. 1, 39 Stat 535) and the federal legislation passed June 30, 1944 to establish the park.

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"*.

Public Law 69-158 (June 6, 1924) provided for a comprehensive development of the park and playground system of the Nation's capital. The law constituted the National Capital Park

Commission *“to prevent pollution of Rock Creek and the Potomac and Anacostia Rivers, to preserve forests and natural scenery in and about Washington, and to provide for the comprehensive systematic, and continuous development of the park, parkway, and playground system of the National Capital”.*

The legislation authorizing construction of George Washington Memorial Parkway is Public Law 493. Its formal title is "*An act to authorize and direct the survey, construction, and maintenance of a memorial highway to connect Mount Vernon, in the State of Virginia, with the Arlington Memorial Bridge across the Potomac River at Washington".*

In 1930, Congress enacted the "Act of May 29, 1930" (46 Stat. 482)—more commonly known as the Capper-Cramton Act—to establish George Washington Memorial Parkway. Its formal title is *“An Act providing for the comprehensive development of the park and playground system of the National Capital”* allowed for the appropriation of funds for the development of *“the George Washington Memorial Parkway along the shores of the Potomac, and adjacent lands, from Mount Vernon and from Fort Washington to the Great Falls, and to provide for the acquisition of lands in the District of Columbia and the States of Maryland and Virginia, and including the protection and preservation of the natural scenery of the Gorge and the Great Falls of the Potomac”*.

Public Law 89-255 (October 10, 1965) authorized the Secretary of the Interior to acquire 783.6 acres of land in the Great Falls area of Virginia from the Potomac Electric Power Company (PEPCO) in exchange for 391 acres of NPS land in Blue Ponds in Prince George’s County, Maryland, and a sum not to exceed $1,000,000 from appropriated funds to make up the difference in value of the two properties.

Geographic Setting

Park description

GWMP runs 45 km (28 mi) along the western shore of the Potomac River through the District of Columbia and portions of northern Virginia (Figure 1), totaling 7,600 acres (11.88 sq. mi). Parklands that are administered by, or accessed by GWMP include Arlington House, the Robert E. Lee Memorial, Arlington National Cemetery, Clara Barton National Historic Site, Clara Barton Parkway, Claude Moore Colonial Farm, Collingwood Picnic Area, Dyke Marsh Wildlife Preserve, Fort Hunt Park, Fort Marcy, Glen Echo Park, Great Falls Park, Lyndon Baines Johnson Memorial Grove on the Potomac, Mount Vernon Estates and Gardens, Mount Vernon Trail, Potomac Heritage National Scenic Trail, Riverside Park, Roaches Run Waterfowl Sanctuary, Theodore Roosevelt Island, Turkey Run Park, U.S. Marine Corps War Memorial, and Netherlands Carillon (Southworth and Denneny 2009) (**Figure 2-1**).

Land Use

George Washington Memorial Parkway lies within the Potomac River watershed. Land area in the Potomac River watershed is approximately 58% forest, 32% agriculture, 5% water and wetlands, and 5% developed (ICPRB 2012). The basin’s major industries include: agriculture 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). The proportions of land use within the 30 km (18.64 mi) boundary of GWMP are predominately mixed intensity development (**Figure 2-3**), and have remained relatively stable since 2001

Figure 2-4). Lands adjacent to the park are predominately privately owned, and protected areas within a 30 km (18.64 mi) radius of GWMP are mainly National Park Service lands, with some regional parks and protected areas (**Figure 2-5**). These protected areas serve as vital habitat and wildlife corridors for native flora and fauna.

Population

George Washington Memorial Parkway passes through the City of Alexandria, Arlington County, and Fairfax County in the Commonwealth of Virginia, and Montgomery County in the state of Maryland. Approximately 6.11 million people (2010 estimated census) live within the Potomac River watershed, of which almost three-quarters (approximately 5.36 million people) live within the Washington, D.C. metropolitan area (**Figure 2-6Figure 2-7**). This metropolitan area has grown at a constant high pace for the past several decades, particularly Fairfax and Arlington Counties in Virginia that have grown 11.5% and 9.6%, respectively, between 2000 and 2010. Fairfax County's population growth has made it the most populous jurisdiction in both Virginia and the Washington, D.C. metropolitan area (Fairfaxcounty.gov). Clara Barton Parkway runs through Montgomery County, Maryland, the most populous county in the state of Maryland. In 2010, the population of Montgomery County was 971,777, an increase of 11% from the 2000 U.S. Census (U.S. Census Bureau 2014) (**Figure 2-7**).

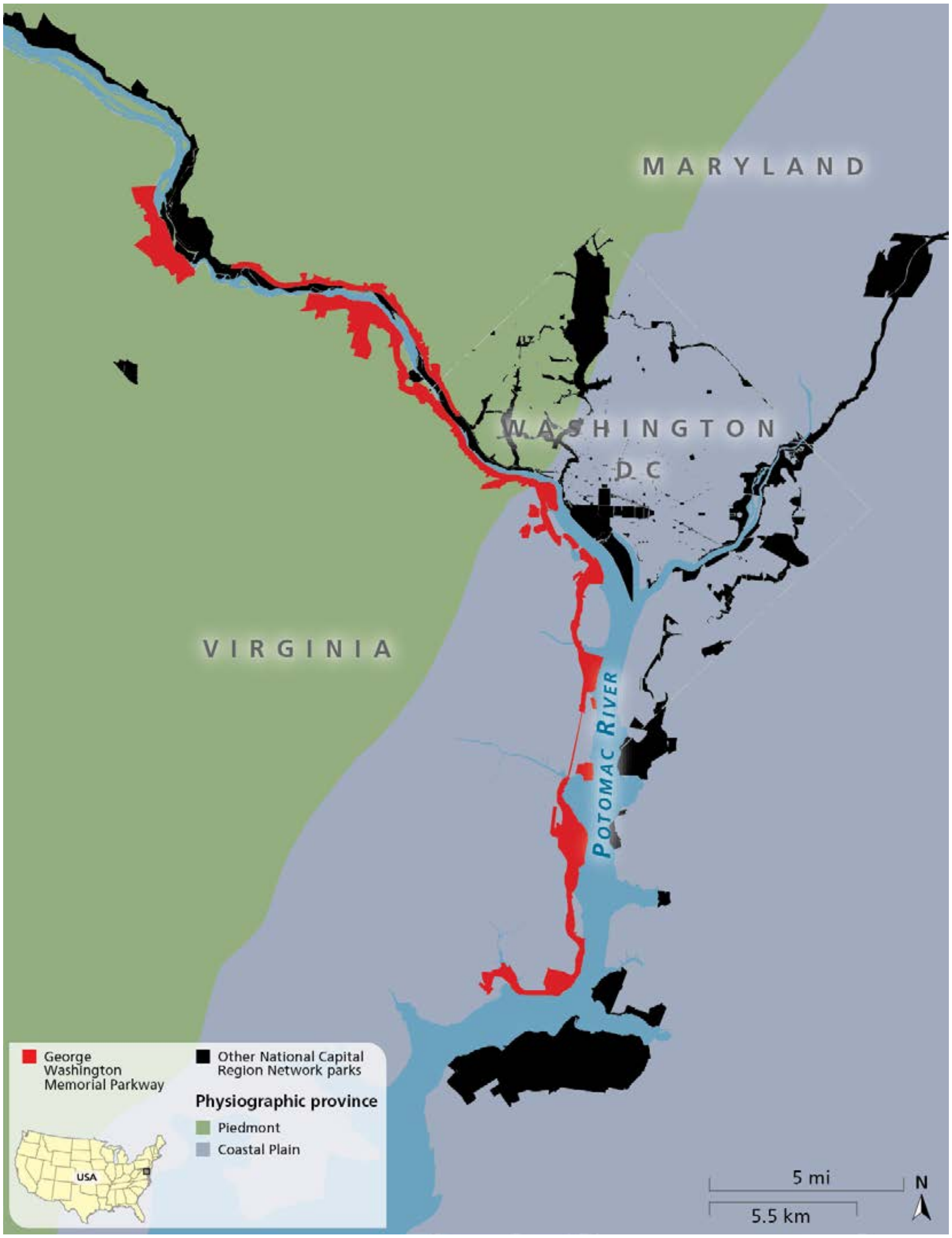

Figure 2-1 Location of GWMP in the greater Washington, D.C. Metropolitan region.

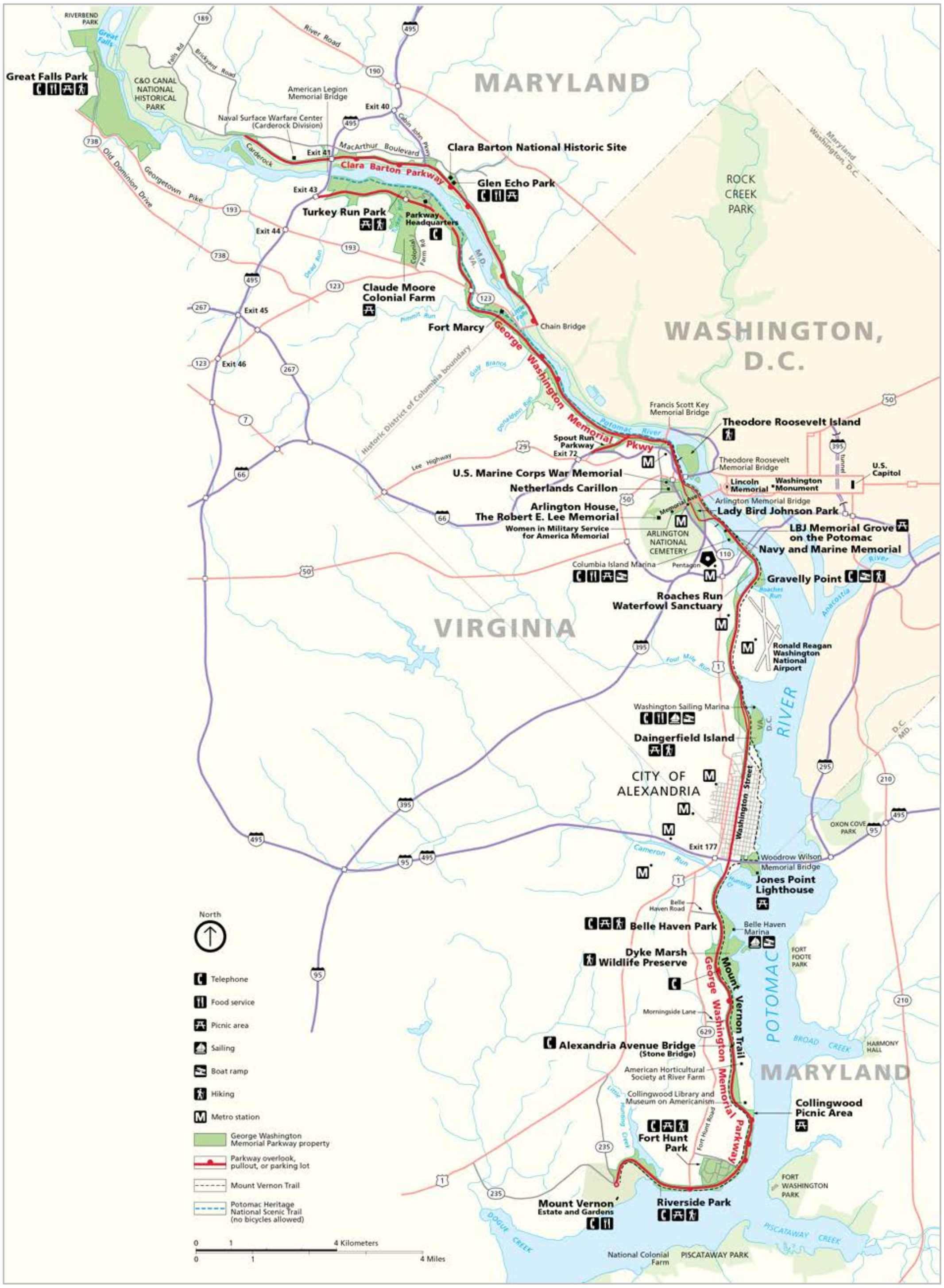

Figure 2-2 National Park Service map of George Washington Memorial Parkway (NPS).

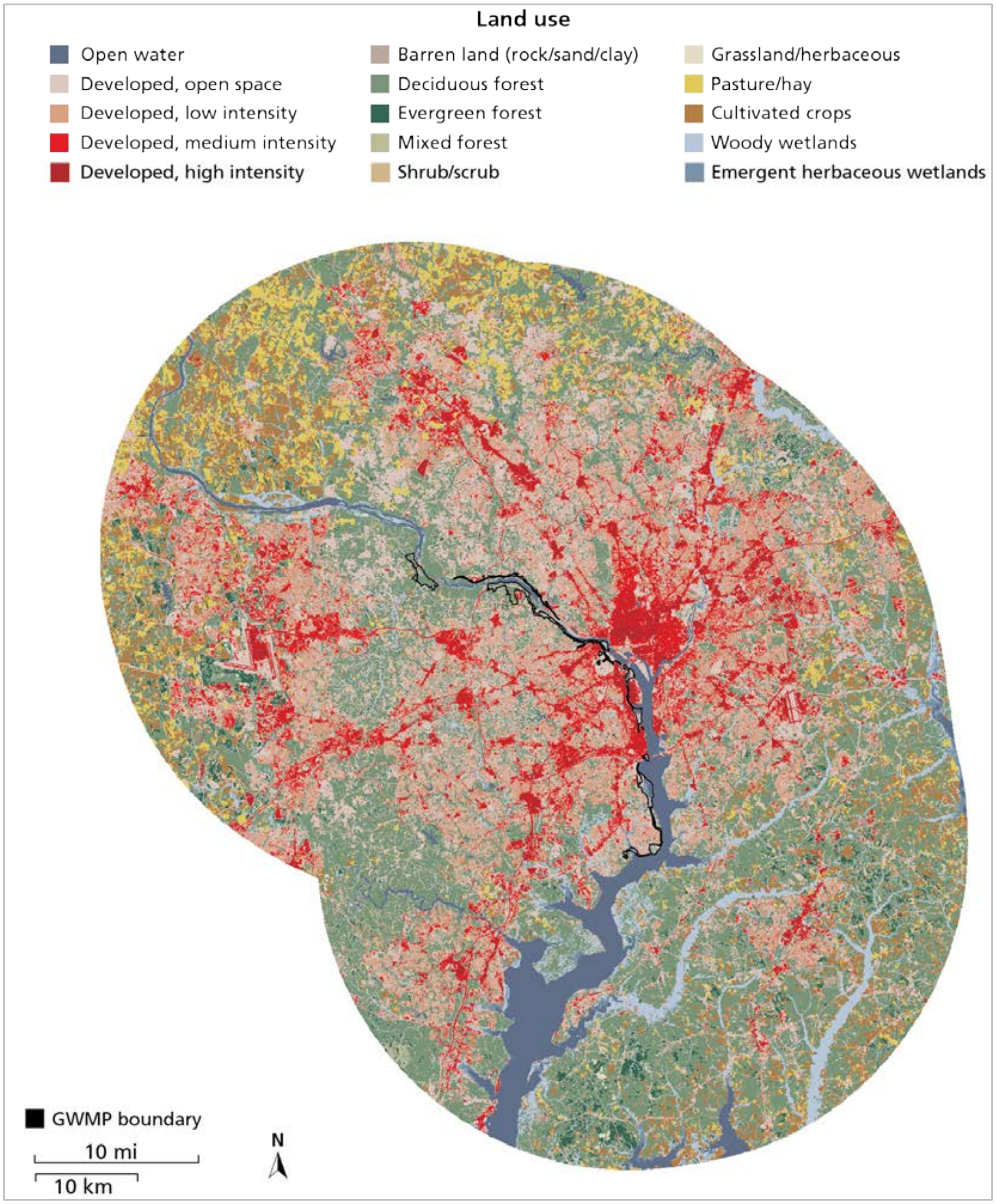

Figure 2-3 Adjacent land use within a 30 km area surrounding GWMP in 2011 (Jin *et al.* 2013; NPS 2011a).

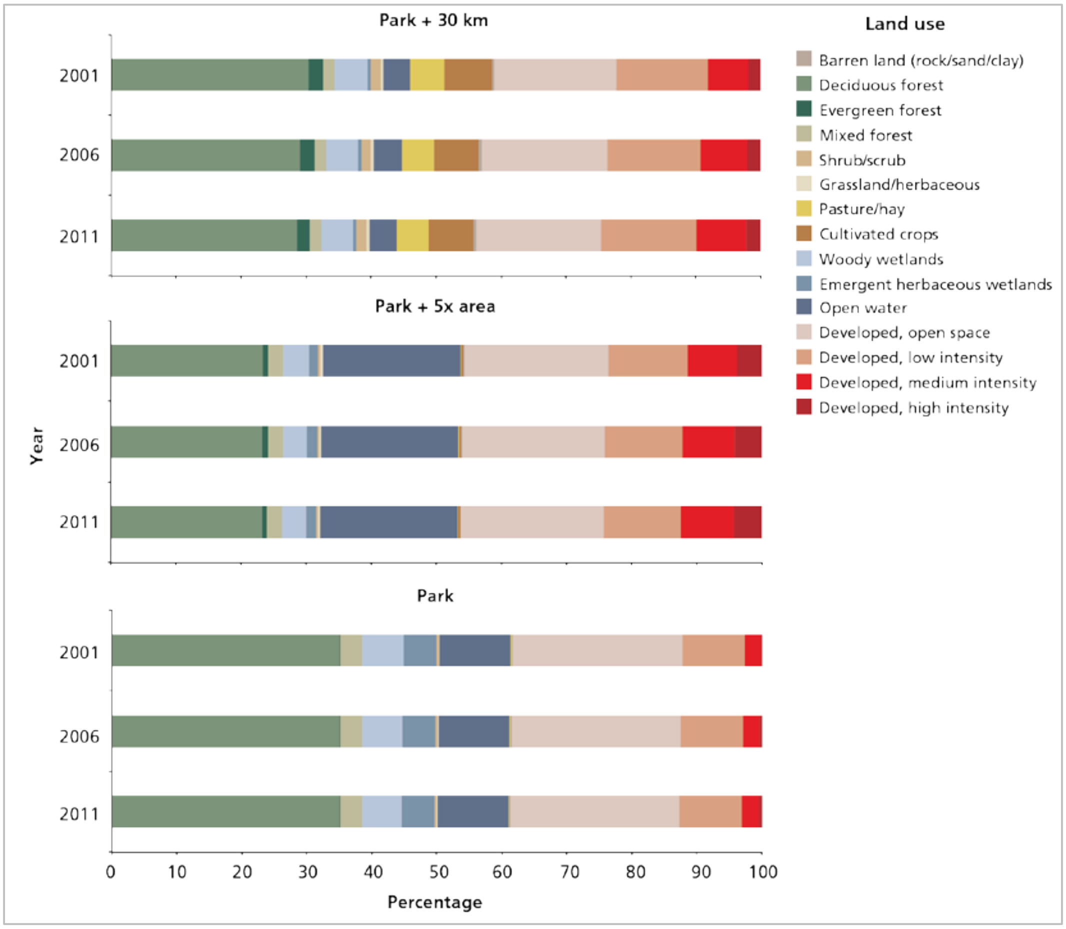

Figure 2-4 Changes in land use from 2001 to 2011 at three scales (Park + 30 km, Park + 5x area, Within Park) surrounding GWMP (Jin *et al.* 2013; NPS 2011a).

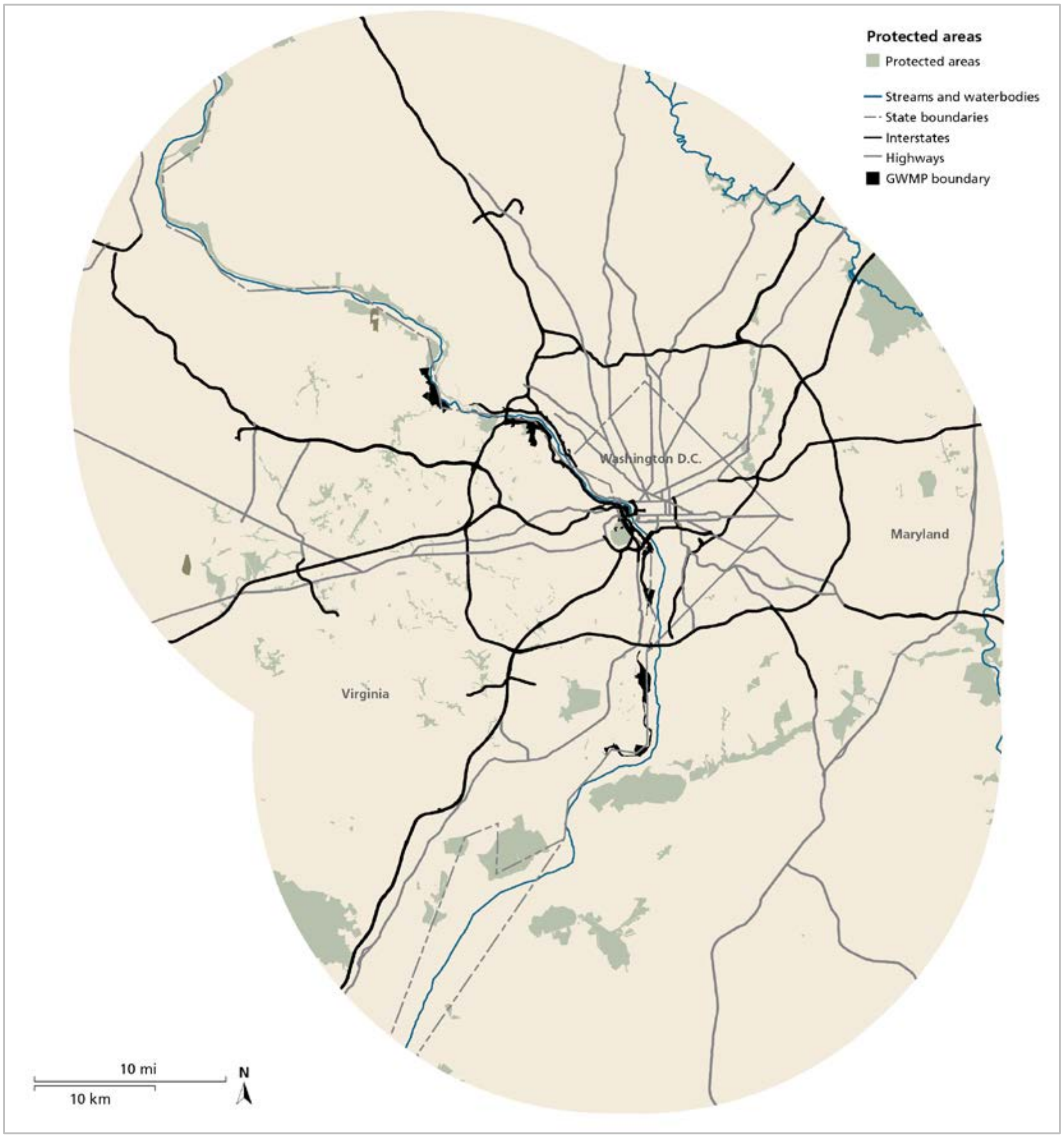

Figure 2-5 Protected areas within a 30-km area surrounding GWMP in 2011 (NPS 2011a).

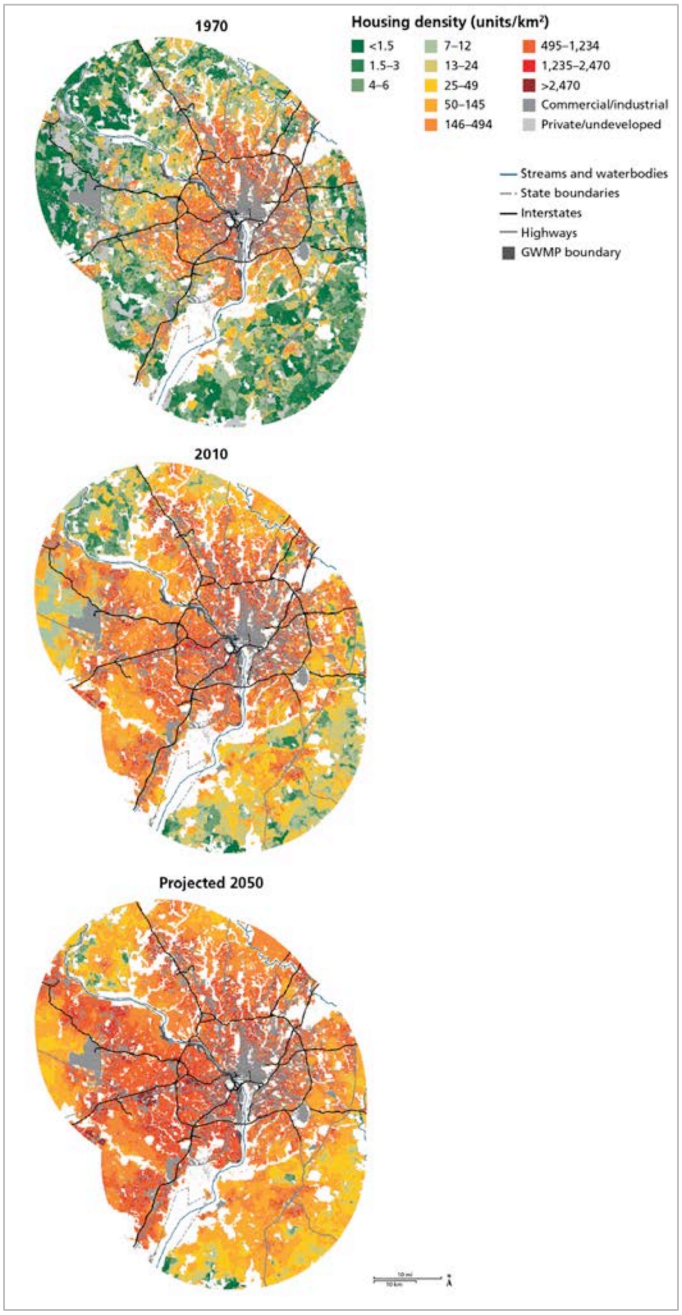

Figure 2-6 Housing density within a 30-km area surrounding GWMP in 1970, 2010, and projected for 2050 (NPS 2014; NPS 2011a).

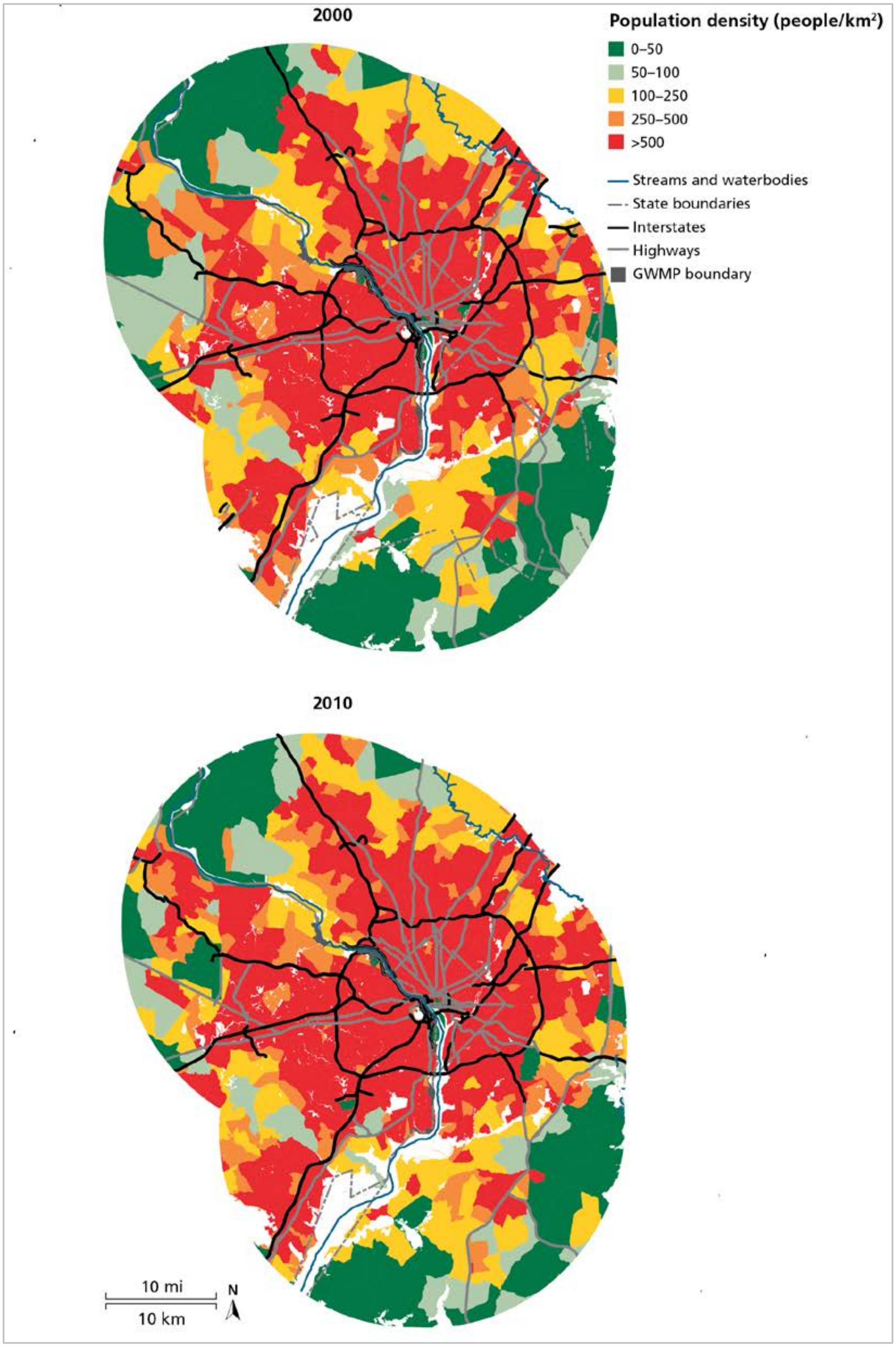

Figure 2-7 Population density around the park in 2000 and 2010 (NPS).

Climate

George Washington Memorial Parkway and the surrounding areas fall within the Mild Temperate Rainy Regional climate zone, and is characterized as having no distinct dry season, hot summers, and mild winters, with an annual average temperature of 14.6°C (58.2°F) (Steury et al. 2008; National Weather Service 2013a). Spring and fall are generally comfortable with some precipitation. Summers can be hot and humid with an average temperature of 25.4°C (77.7°F). 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 GWMP is 1 meter (39.74 inches) (National Weather Service 2013b), with an annual average total snowfall of 0.4 meters (15.8 inches) (National Weather Service 2013c). The wettest month is May and the driest month is February (Steury et al. 2008).

Occasional extreme precipitation events, such as tropical storms and hurricanes, are significant enough that they can impact the National Capital Region (NCR). Although wind damage can accompany these storms, the heavy precipitation and flooding is by far a more important disturbance factor for NCR ecosystems. Nor'easter storms during the winter months can also occasionally bring large snowfalls to the NCR (Davey et al. 2006). Major flooding of the Potomac River can result from heavy rains over the basin, often augmented with snowmelt, and above normal tides due to hurricanes or severe storms (Allen and Flack 2001). Potomac River floods exceeded the rim of the gorge within Great Falls Park in 1936, 1937, 1942, 1972, 1985 and 1996 (Steury et al. 2008).

Two weather/climate stations have been identified within the boundaries of GWMP (Davey et al., 2006). The NOAA ground-based GPS Meteorology site Turner-Fairbank Highway Research Center (McLean, VA) is an active site, while the other is a Cooperative Observer (COOP) network station (Great Falls) that operated between 1948 and 1950. There are 43 active COOP stations located within 10 km (6.21 miles) of GWMP. In addition, the NWS/FAA Surface Airways Observation Network (SAO) sites at the Dulles International Airport, Reagan National Airport, and Andrews Air Force Base provide near-real time climate observations for the area (Davey et al. 2006).

Visitation statistics

In addition to the thousands who use the parkway as a commuter route and transportation corridor daily, GWMP contains a diverse array of recreational opportunities such as hiking, biking, rock climbing, kayaking, fishing, picnicking, living history, visiting historical sites, cultural activities, wildlife and wildflower viewing, organized sports, and opportunities for solitude (NPS 2014a). These recreational opportunities are supported by a wide variety of amenities such as the Potomac Heritage National Scenic Trail (including the Mount Vernon Trail), multipurpose playing fields, playgrounds, picnic areas, boat launches, marinas, and expansive natural areas (NPS 2014a).

In 2013, approximately 7,360,392 people visited GWMP for recreational purposes while 33,910,598 non-recreation visitors were recorded (NPS Stats 2014). Low visitations coincide with cold weather months (lowest in January) and high visitations with summer months (highest in June and July) (**Figure 2-8**) (NPS Stats 2014).

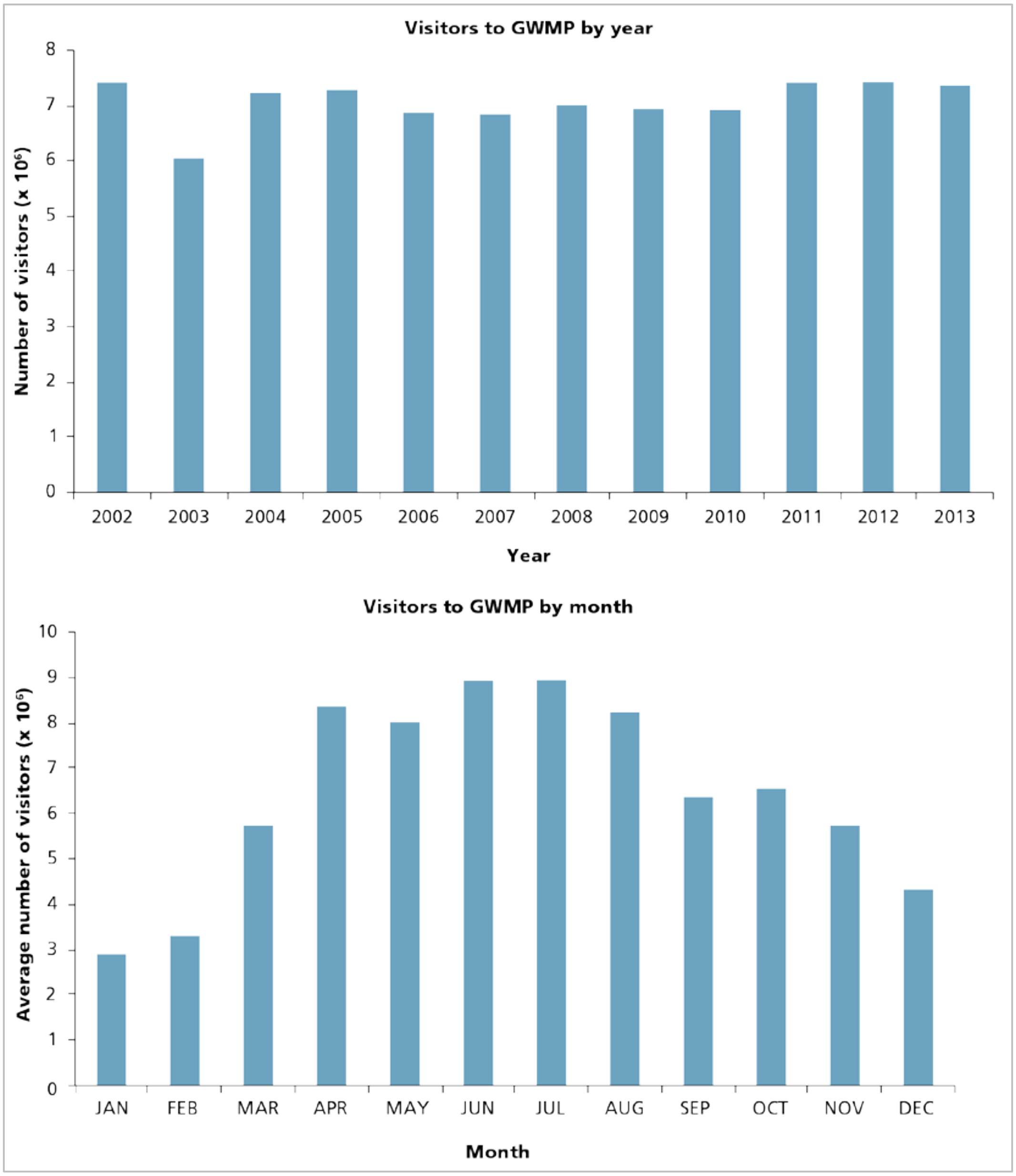

Figure 2-8 Visitors to GWMP over the past decade (2003-2013) by year (top) and by month (bottom) (NPS 2013c).

Natural resources

Significant natural areas occur throughout George Washington Memorial Parkway and are extremely rich in both biodiversity and in historical context. The park provides islands of refuge for many rare and unique plant and animal species in the highly urbanized Washington, D.C. metropolitan area, protecting a variety of cultural and natural resources, including plant community types found nowhere else on earth (Steury et al., 2008). Finding species new to science is a regular occurrence within the park, and in the ten years of conducting its All Taxa Biotic Index, 5,289 species have been documented, including 74 species new to science, 3 species new to North America, 84 new to

Virginia, and 105 listed as rare in Virginia or Maryland (Steury 2014b). Additionally, GWMP provides opportunities to foster public awareness of the importance of species preservation, biological diversity, natural systems and processes, and the value of natural open space in an urban environment.

Geology

GWMP transects the eastern Piedmont province (from Interstate Highway 495 at exit 14, just south of the American Legion Bridge) and the Coastal Plain province (from near Theodore Roosevelt Island south to Mount Vernon Estate and Gardens) (Southworth and Denenny, 2006).

The GWMP bedrock structure is complex. It consists of metamorphosed sedimentary rocks of the Sykesville Formation (a gray matrix of quartz and feldspar) that were locally intruded by Ordovician mafic and felsic igneous plutonic rocks (Southworth and Denenny, 2006). The last bedrock exposures are seen near Theodore Roosevelt Island. From there, south to Mount Vernon Estate and Gardens, the parkway follows alluvial and estuarine flood plains. Near Mount Vernon the parkway climbs onto terrace deposits of the dissected Coastal Plain upland where George Washington built Mount Vernon, in part, because of the view (Southworth and Denenny, 2006) (**Figure 2-9**)

The landscape of the parkway consists of rolling hills, river terraces, riverside marshes, and inlets. The topography is complex due to varied hydrological influences (**Figure 2-10**) (Thornberry-Ehrlich, 2009). This complexity, along with seasonal flooding, supports a diversity of habitats. In the northern reaches of the parkway, the Potomac River has cut a relatively linear gorge along faults and fractures through the deformed metamorphic crystalline rocks of the Potomac terrane (section of the Piedmont). The river widens below the “Fall Line” as it cuts through the unconsolidated sediments of the Atlantic Coastal Plain. The significant geologic features along the river administered by the parkway include Great Falls and Mather Gorge, Theodore Roosevelt Island, and Dyke Marsh. Because of its unusual hydrogeology, the Potomac Gorge is one of the country’s most biologically diverse areas, serving as a geographic meeting place for northern and southern species, Midwestern and eastern species, and montane and coastal species (Allen and Flack 2001).

Soils

Soils in the Piedmont are highly weathered, and generally well drained (Thornberry-Ehrlich, 2009). Ultisols, commonly known as red clay soils, dominate the soil type within GWMP (**Figure 2-11**). On the Coastal Plain, from the Fall Line east to the Chesapeake Bay and Atlantic Ocean, soils are commonly sandy or sandy loams that are well drained. This is typified by the soil texture found within GWMP (**Figure 2-12**).

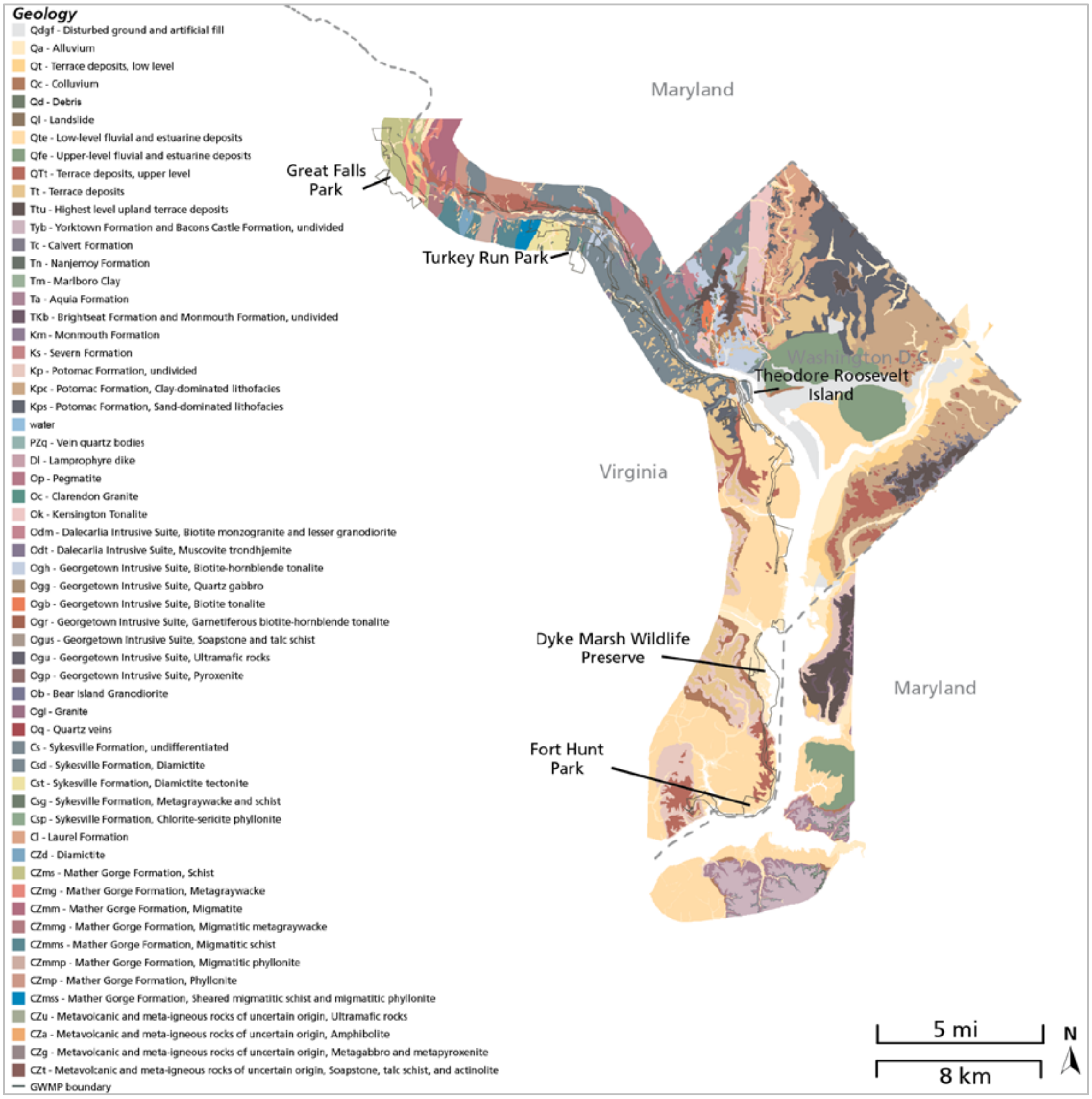

Figure 2-9 Geology of GWMP (Thornberry-Ehrlich 2009).

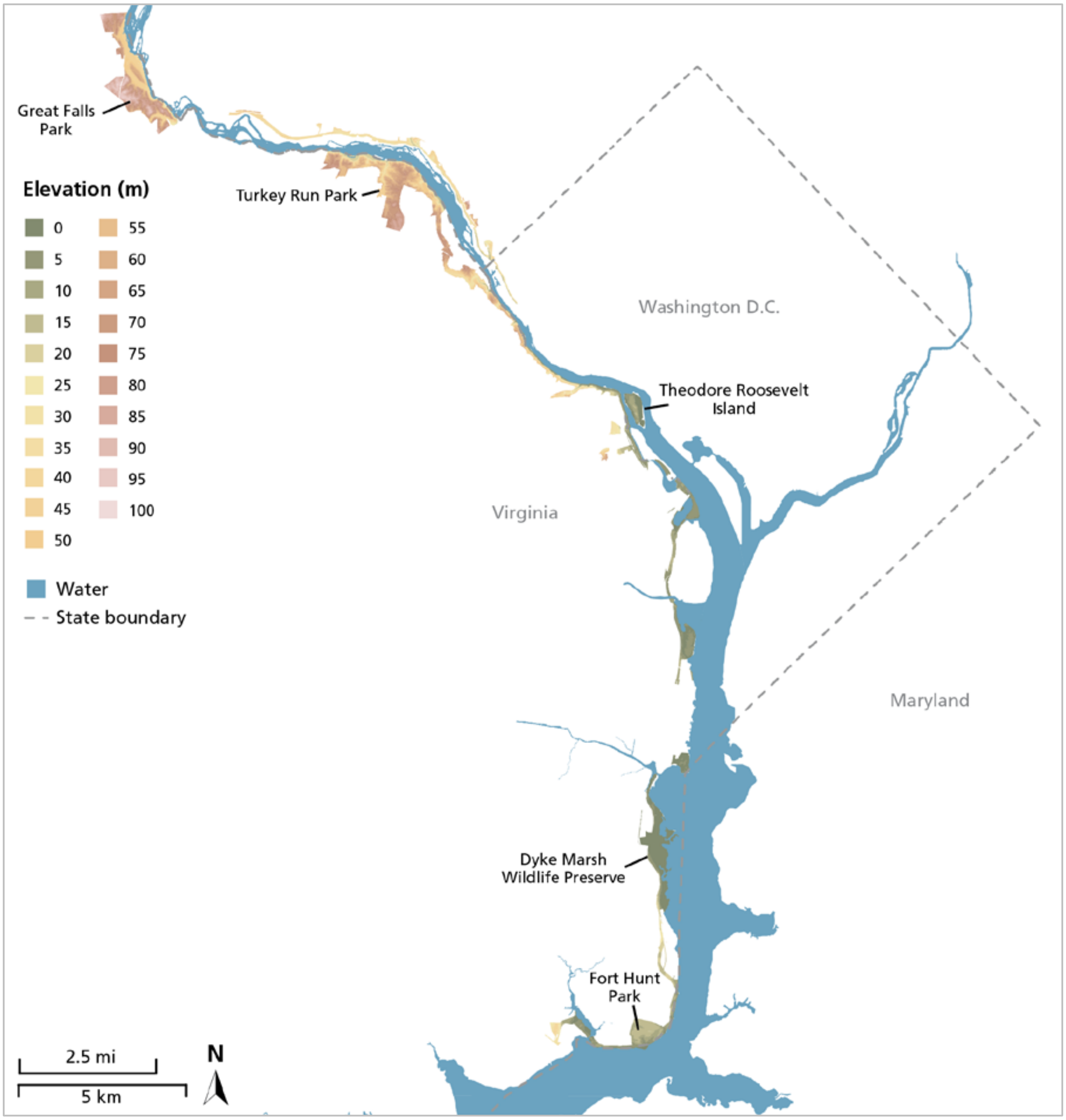

Figure 2-10 Topographic elevation of GWMP.

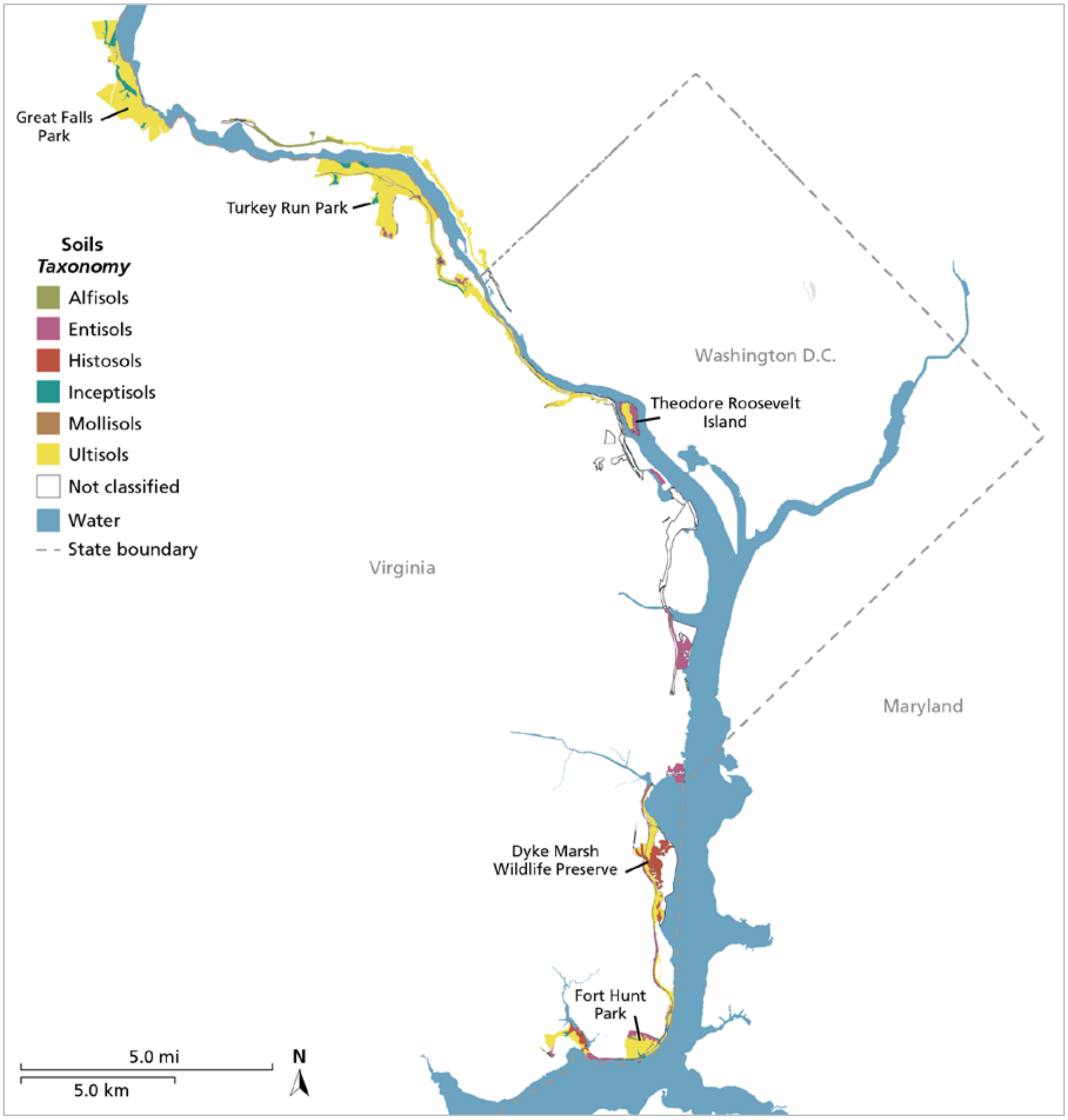

Figure 2-11 Soil taxonomy in GWMP.

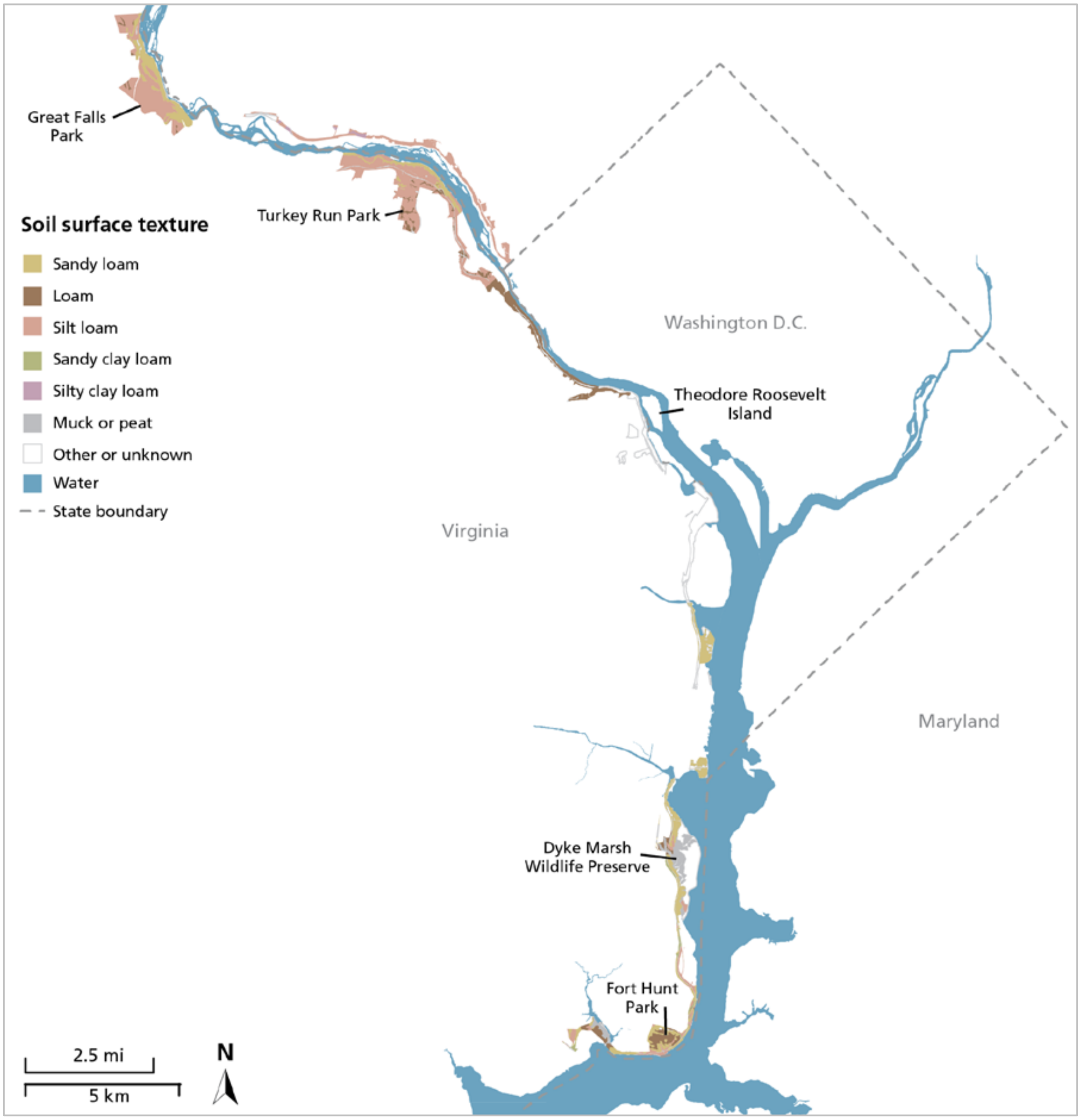

Figure 2-12 Soil texture at GWMP.

Watershed/Waterways

George Washington Memorial Parkway is located within the Potomac River Watershed that drains 37,995 sq. km (14,670 sq. mi) across Maryland, Virginia, West Virginia, Pennsylvania, and the District of Columbia (ICPRB 2012) (**Figure 2-13**). The river's mainstem flows from its headwaters at the Fairfax Stone in West Virginia to the Chesapeake Bay. 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). The Potomac River is the second largest tributary, after the Susquehanna River, to the Chesapeake Bay which is the largest estuary in the United States (Allen and Flack 2001, Chesapeake Bay Program 2013).

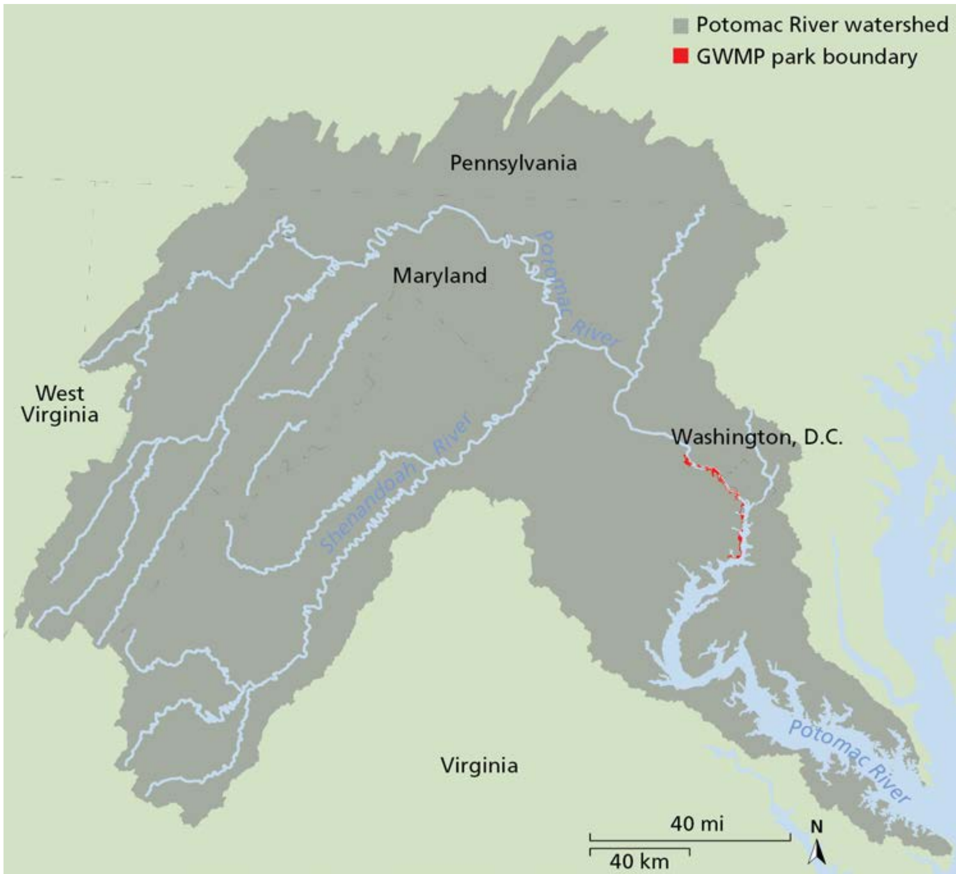

Figure 2-13 The Potomac River watershed.

The average water flow in the Potomac River at Washington, D.C. is approximately 26 billion liters (7 billion gallons) per day before water withdrawals, which account for approximately 1.84 billion liters (486 million gallons) per day as water supply for the Washington area (ICPRB 2012). Due to a combination of underlying geology and high precipitation, the Potomac River is subject to flashy hydrology with frequent flooding events (Allen and Flack 2001). Lowest flows occur in September, while the highest flows typically occur in March, primarily in response to snowmelt and occasionally from tropical storms (**Figure 2-14**).

Figure 2-14 Great Falls high water marks. Source: Doug Kerr (Wikimedia commons).

The Potomac River supplies 75% of the drinking water for the metropolitan Washington, D.C. area, and 100% of the drinking water for the District of Columbia itself (U.S. EPA 2004). Wastewater treatment plants located in Washington, D.C. (Blue Plains), Arlington VA, and Alexandria VA, discharge treated effluent into the river (U.S. EPA 2004).

A 1998 report from the National Water Quality Assessment (NAWQA) program disclosed several major issues discovered in the Potomac River basin including: nutrients and pesticides in streams and groundwater, organic contaminants and metals in streams, and radon in ground water (NPS 2007).

According to U.S. EPA data in 2004, the Potomac River was not impaired with respect to the designated uses within the vicinity of the park. However, 4.72 km (2.93 mi) of Difficult Run was impaired, including the 0.8 km (0.5 mi) portion that flows through the park (NPS 2007). The water body did not meet the state water quality standards for aquatic life use or recreation use.

Wetlands

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

The National Wetland Inventory has mapped approximately 174 ha (0.67 sq. mi) of wetland within GWMP (Tiner et al. 2000). About 300 discrete wetland units can be found within the Potomac Gorge area, rich in palustrine (non-flowing water) wetlands, such as vernal pools, permanent ponds, springs and seeps, wet floodplain forests, and seasonal riverbank wetlands (Allen and Flack 2001). Riverine wetlands of the Gorge are restricted to the shallow waters and scour bars within the Potomac River. The lacustrine (lake-associated) systems of the Gorge comprise the deep-water habitats of the dammed portion of the Potomac River, as well as the entire C&O Canal (Erdman et al. 2004)

Springs and seeps serve as habitat for rare groundwater invertebrates, some of which are state-listed. Great Falls swamp in Great Falls Park, Virginia, is the largest seepage swamp in the Potomac Gorge consisting of approximately 20 ac (0.3 sq. mi). The swamp formed as fine sediment accumulated, resulting in poorly drained clay soils. The swamp is fed by many groundwater seeps that feed three small streams draining to the wetland (Erdman et al. 2004).

Along the shores of the Potomac River, near the southern end of the parkway, lies Dyke Marsh Wildlife Preserve, one of the largest tidal marshes in the jurisdiction of the National Park Service and one of the largest remaining freshwater tidal wetlands in the Washington Metropolitan Area. It is composed of 154 ha (380 acres) of tidal freshwater marsh, swamp forest, and river floodplain. The vegetation here is dominated by narrow-leaved cattails (*Typha angustifolia*), but also contains some large stands of arrow arum (*Peltandra virginica*), sweet flag (*Acorus calamus*), pickerelweed (*Pontederia cordata*), yellow bullhead lily (*Nuphar luteum*), jewelweed (*Impatiens capensis*), river bullrush (*Scirpus fluviatilis*), and wild rice (*Zizania aquatica*) (**Figure 2-15**).

Dyke Marsh is composed of three major vegetation communities, the tidal freshwater marsh, the floodplain forest, and the swamp forest (Hopfensperger et al. 2004). The original marsh consisted of approximately 650 ac (1.02 sq. mi). In the early 1800s, walls (dikes) were built around the perimeter of the marsh to create land that was then used to graze livestock or grow crops. Dredging during the 1950’s and 60’s resulted in the removal of approximately one-third of the emergent marsh, which has been replaced with deep water, reaching 30 feet (9 m) below mean tide level. The United States government gained control of the management of the marsh in 1976.

Figure 2-15 Narrow-leaved cattails, pickerelweed and arrow-arum in Dyke Marsh. Source: Brent Steury.

Flora

The vascular flora record of GWMP contains at least 1,314 taxa, representing 1,284 species, 11 intraspecific taxa (below species rank), and 18 hybrids from 607 genera in 153 families. Plants are comprised of 44 pteridophytes (ferns and fern allies), 138 trees (16 coniferous, 122 deciduous), 148 shrubs and low suffrutescent (semi-woody) taxa, 25 woody vines, and 959 herbaceous taxa (40 vines, 19 submerged or floating aquatic species, 119 grasses, 115 sedges, 13 rushes, and 653 forbs) (Steury 2011). Of these, 375 are non-native. Of the non-native species, 46 are common enough in some areas to be considered invasive.

The vegetation of GWMP includes a complex of upland and floodplain forest, and tidal marsh communities, as well as several rare vegetation types that occupy the bedrock terraces, exposed rocks, and frequently flooded river shores (**Figure 2-16**). These areas fall within the region broadly classified as oak-hickory-pine forest by Skeen et al. (1993), but are strongly dominated by deciduous woodland in the park (Steury 2011). Although disturbed, secondary forests are common in formerly cleared areas of the park. Much of the contemporary forest consists of maturing second-growth stands that belong to the following ecological groups (Fleming et al. 2004): basic mesic forest, mesic mixed hardwood forest, acidic oak-hickory forest, oak/heath forest, and Piedmont/Mountain floodplain forest. Older-age stands (> 100 years) occur on ridges at both the northern and southern ends of Great Falls Park. Abrams and Copenheaver (1999) documented several white oak (*Quercus alba*) individuals more than 200 years old on the northern ridge.

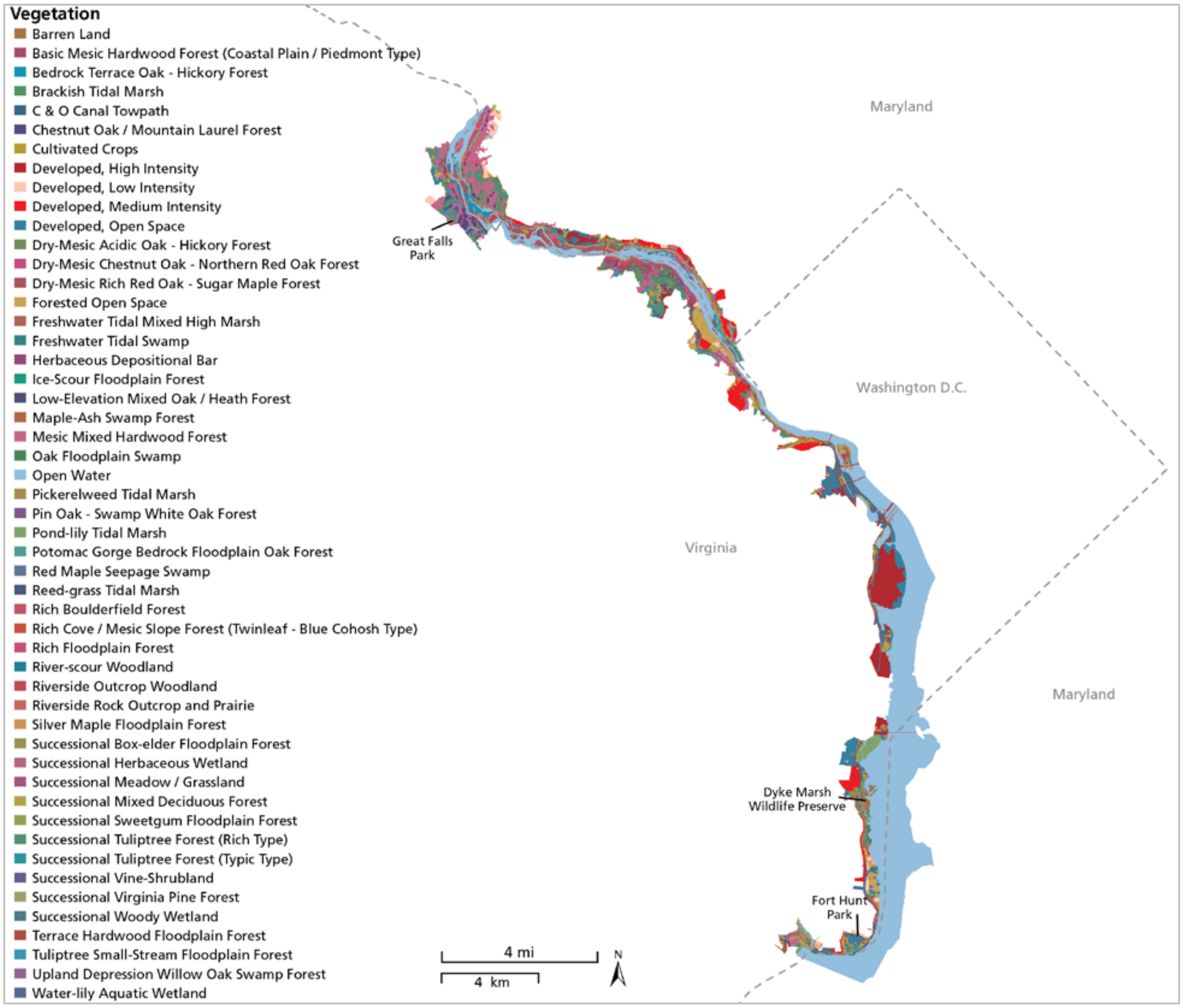

Figure 2-16 Vegetation map of GWMP.

Included in the 1,314 taxa found within GWMP are 62 woody species that have been planted in landscapes along GWMP which were not found naturally occurring elsewhere within GWMP. Of these, 14 are native to the Washington-Baltimore metro area, but not native to GWMP based on historical voucher evidence, and 48 are non-native species (Shelter and Orli 2000, 2002; Steury 2011).

<u>Ferns</u>

The woods, marshes, and swamps of GWMP provide habitat for 28 extant species of ferns and seven other vascular cryptogams such as horsetails, quillworts, and lycopoid clubmosses (**Figure 2-17**). Six additional species of ferns historically documented from GWMP are now believed to be extirpated along with spikemoss (*Selaginella rupestris*) and quillwort (*Isoetes engelmannii*).

Figure 2-17 Cinnamon fern (*Osmundastrum cinnamomeum*) fiddleheads in Great Falls Swamp with skunk cabbage (*Symplocarpus foetidus*) in background. Source: Brent Steury.

<u>Grasses, sedges and rushes</u>

A total of 116 extant species of grasses are known from within GWMP including the Virginia state rare species prairie cordgrass (*Spartina pectinata*) (Steury 2011; Steury et al. 2008). The sedges (*Cyperaceae*) make up one of the most diverse groups of vascular plants within GWMP. Currently, 106 species in 11 genera are known to be extant within GWMP and nine additional species are known from historic specimen records. These include the watch-listed species Carey's sedge (*Carex careyana*) and Short's sedge (*Carex shortiana*), and state rare species Davis' sedge (*Carex davisii*), eastern straw sedge (*Carex straminea*), and flatstem spikerush (*Eleocharis compressa*). The populations of Davis' sedge, found in Great Falls Park, Roaches Run, and Dyke Marsh, are the only populations of this species that occur within the Commonwealth of Virginia. Additionally, the rushes and wood rushes (*Juncaceae*) are represented by 13 species within GWMP (Steury 2011; Steury et al. 2008). Great Falls also supported the lowest number of introduced species, and the greatest percentage of native species, especially within the diverse areas along the Potomac Gorge. The introduced species of greatest management concern is Japanese stiltgrass (*Microstegium vimineum*), an invasive grass found to occur in all the NCR parks sampled (Englehardt et al. 2007).

<u>Lichens</u>

A baseline inventory of bark-dwelling lichens in GWMP was conducted from 2004 to 2006. In five sampling plots, 15 species of macrolichens were identified, including species of *Usnea* which are generally observed to be sensitive to air quality degradation (Lawrey 2011).

Both the algae and fungus in lichens absorb water, minerals, and pollutants from the air. Sensitive lichen species can develop structural changes in response to air pollution. Over time, sensitive species may be replaced by pollution-tolerant species. Therefore, the species of lichens present in a location and the concentration of pollutants measured within lichens can be indicative of air quality (Nortrup 2011). Five permanent lichen biomonitoring sites have been established in GWMP. At each location, abundance of tree-inhabiting macrolichens is recorded and a specimen of the common lichen *Flavoparmelia caperata* is collected for elemental analysis (George Mason 2014).

Mosses and Liverworts

An inventory of mosses and liverworts has been conducted at Great Falls Park, Virginia. Liverworts prefer marshier banks similar to those on the Virginia side of the Potomac Gorge, and vary greatly in size and habitat (Evans 2008). To date, a total of 36 species of liverworts and 115 species of mosses have been documented at the park.

Mushrooms and Fungi

The numerous species of fungi found within GWMP have not yet been fully inventoried. During the 30-hour BioBlitz of the Potomac Gorge in 2006, a total of 55 fungal species were identified within GWMP (Evans 2008) (**Figure 2-18**). To date, 192 species of fungi and slime molds have been identified from the park.

Figure 2-18 Sulphur shelf fungi (*Laetiporus sulphureus*). Source: Brent Steury.

Trees and Shrubs

A total of 138 species of trees (16 coniferous, 122 deciduous) have been documented from the GWMP (Steury, 2011). In the 20 NCRN I&M monitoring plots in GWMP, tulip poplar

(*Liriodendron tulipifera*) has the highest tree Importance Value (IV) of any species. This species, along with white ash (*Fraxinus americana*), and black cherry (*Prunus serotina*) are shade intolerant trees common early in forest succession (Schmit et al. 2012). Shrubs and other low suffrutescent taxa are represented by 148 species, 48 of which are non-native species (Steury, 2011). The most common shrub species within GWMP is northern spicebush (*Lindera benzoin*) (Schmit et al. 2010). Five of the trees or shrubs known from GWMP are listed by Virginia or Maryland as rare, threatened or endangered. During 2009 vegetation monitoring, the only exotic tree encountered was a single Malus *spp.* sapling (Schmit et al. 2010). Of the three shrub species observed in 2009, two were exotic. None of the shrubs were particularly abundant (Schmit et al. 2010). The invasive tree of heaven (*Ailanthus altissima*) is present on Theodore Roosevelt Island and elsewhere in GWMP; however further monitoring is required to see if this species is increasing (Schmit 2012).

Wildflowers

A total of 653 species of wildflowers have been documented from George Washington Memorial Parkway (Steury, 2011) (**Figure 2-19**).

Figure 2-19 White trout lily (*Erythronium albidum*). Source: Brent Steury.

Fauna

Even though it is surrounded by human development, George Washington Memorial Parkway is home to a wide variety of animals, including mammals, birds, reptiles and amphibians, fish, snails, earthworms, millipedes and centipedes, crustaceans, mollusks, arachnids, springtails, and a large diversity of insects.

Mammals

A total of 30 species of mammals have been documented within GWMP (GWMP Animals Database 2015). These include six species of bats: big brown bat (*Eptesicus fuscus*), eastern pipistrelle (*Pipistrellus subflavus*), little brown bat (*Myotis lucifugus*), northern long-eared bat (*Myotis septentrionalis*) silver-haired bat (*Lasionycteris noctivagans*), and eastern red bat (*Lasiurus borealis*).

Other mammals known to occur within GWMP are white-footed mouse (*Peromyscus leucopus*), house mouse (*Mus musculus*), eastern mole (*Scalopus aquaticus*), northern short-tailed shrew (*Blarina brevicauda*), southeastern shrew (*Sorex longirostris*), pine vole (*Microtus pinetorum*), Norway rat (*Rattus norvegicus*), muskrat (*Ondatra zibethica*), beaver (*Castor canadensis*), eastern chipmunk (*Tamias striatus*), opossum (*Didelphis marsupialis*), eastern cottontail (*Sylvilagus floridanus*), eastern gray squirrel (*Sciurus carolinensis*), raccoon (*Procyon lotor*), red fox (*Vulpes fulva*), gray fox (*Urocyon cinereoargenteus*), striped skunk (*Mephitis mephitis*), domestic cat (*Felis catus*), coyote (*Canis latrans*), Northern river otter (*Lontra canadensis*), southern flying squirrel (*Glaucomys volans*) (**Figure 2-20**), and white-tailed deer (*Odocoileus virginianus*) (McShea and O'Brien 2003, GWMP Animals Databases 2015). The Allegheny woodrat (*Neotoma magister*) was historically collected in Great Falls Park (1949), Turkey Run Park (1917), and Dyke Marsh (1897), but recent search effort (1998) did not reveal the presence of this species and it is believed to be extirpated within GWMP.

Figure 2-20 Southern Flying Squirrel (*Glaucomys volans*) at Fort Hunt Park. Source: Ed Eder.

Birds

At least 288 species of birds have been recorded within GWMP. However, 52 of these species are considered to be extirpated from the park or are rare accidental or transitory vagrants. Among the 288 species are 13 species of conservation concern and 24 species state listed for rarity (Ladin and Shriver 2013; GWMP Animals Database 2015) (**Table 2-1**). Forest birds are a primary indicator of forest health. They are selective in choosing nesting sites, preferring to build nests only in large unfragmented forest tracks with mature trees and a healthy understory. Currently, forest bird populations are threatened by loss and degradation of habitat, including over-browsing by deer, forest tree diseases, invasion of exotic plants, changes in fire regimes, development, and forest fragmentation (Nortrup 2009). Currently, there are four active bald eagle nesting sites within GWMP. At Great Falls Park, 36 species of warblers (Family *Parulidae*) have been reported during the spring or fall migrations and approximately 262 species of birds have been documented at Dyke Marsh (GWMP Animals Database 2015) (**Figure 2-21**). Dyke Marsh is important to many resident and migratory bird species (Hopfensperger et al. 2004). It supports the only known nesting population of marsh wrens (*Cistothorus palustris*) in the upper Potomac tidal zone (Hopfensperger et al. 2004), and provides habitat for a breeding population of the least bittern (*Ixobrychus exilis*), which is rare in the state of Virginia (Steury et al. 2014).

Table 2-1 Bird species of conservation concern found within GWMP (Nortrup 2011, NPSpecies).

State listed species	Partners in Flight Watch List	Stewardship Species List
American bittern (*Botaurus lentiginosus*) Bald eagle (*Haliaeetus leucocephalus*) Blue-winged teal (*Anas discors*) Caspian tern (*Sterna caspia*) Common gallinule (*Gallinula galeata*) Cooper's hawk (*Accipiter cooperii*) Forster's tern (*Sterna forsteri*) Glossy ibis (*Plegadis falcinellus*) Golden eagle (*Aquila chrysaetos*) Great egret (*Ardea alba*) King rail (*Rallus elegans*) Least bittern (*Ixobrychus exilis*) Little blue heron (*Florida caerulea*) Northern harrier (*Circus cyaneus*) Northern saw-whet owl (*Aegolius acadicus*) Peregrine falcon (*Falco peregrinus*) Piping plover (*Charadrius melodus*) Red knot (*Calidris canutus*) Short-eared owl (*Asio flammeus*) Snowy egret (*Egretta thula*) Sora rail (*Porzana carolina*)	Prothonotary warbler (*Protonotaria citrea*)	Acadian flycatcher (*Empidonax virescens*) Carolina wren (*Thryothorous ludovicianus*) Eastern towhee (*Pipilo erythrophthalmus*) Indigo bunting (*Passerina cyanea*) Lousiana 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*)

State listed species	Partners in Flight Watch List	Stewardship Species List
Swamp sparrow (*Melospiza georgiana*) Tricolored heron (*Hydranassa tricolor*) Yellow-crowned night heron (*Nyctanassa violacea*) Virginia rail (*Rallus limicola*)		

Figure 2-21 Prothonotary Warbler (*Protonotaria citrea*) at Dyke Marsh Wildlife Preserve. Source: Ed Eder.

<u>Herpetofauna</u>

The woodlands, streams, and riverbanks found within the units of George Washington Memorial Parkway (GWMP) provide habitat for a total of 45 species of reptiles and amphibians. Areas of the park that were mostly in an urban setting or maintained as fields yielded few species of amphibians or reptiles (Pauley et al. 2005). Mixed deciduous forests or aquatic habitats located within the forest had the highest number of species. Canals, creeks, rivers, and wetlands within the park support a variety of amphibian and turtle species. Ephemeral or permanent fishless pools in the floodplain of the Potomac River are used as breeding areas for several frog and salamander species. Small intermittent streams draining the park are also important habitats for several plethodontid salamander species. These shady moist habitats are inhabited by salamanders and during the dry summer, small still pools are refuges for several frog species (Pauley et al. 2005).

The fifteen species of snakes known from GWMP are northern brown snake (*Storeria dekayi*), northern copperhead (*Agkistrodon contortrix mokasen*), eastern worm snake (*Carphophis amoenus*

amoenus), northern ringneck snake (*Diadophis punctatus edwardsi*), black rat snake (*Elaphe obsoleta*), northern watersnake (*Nerodia sipedon*), queen snake (*Regina septemvittata*), rough green snake (*Opheodrys aestivus*), eastern hognose snake (*Heterodon platirhinos*), corn snake (*Elaphe guttata*), northern black racer (*Coluber constrictor*), mole kingsnake (*Lampropeltis calligaster rhombomaculata*), eastern kingsnake (*Lampropeltus getula*), eastern milk snake (*Lampropeltis triangulum*), and eastern garter snake (*Thamnophis s. sirtalis*). Only one of these, the northern copperhead, is venomous. Northern copperheads have been reported from Turkey Run and Great Falls Parks, where they are fairly common. During the 2006 Potomac Gorge BioBlitz, three adult and eight juvenile copperheads were observed (Evans 2008).

The two species of skinks known from GWMP are the broadhead skink (*Eumeces laticeps*) and the five-lined skink (*Eumeces fasciatus*). These two species can look quite similar at certain stages of their life cycles. However, the broadhead skink matures at a larger size than that of the five-lined skink (**Figure 2-22**).

A total of six species of native turtles and two non-native (introduced) species have been recorded from GWMP. The six native species are box turtle (*Terrapene carolina*), common musk turtle (*Sternotherus odoratus*), eastern painted turtle (*Chrysemys picta picta*), eastern snapping turtle (*Chelydra s. serpentina*), wood turtle (*Glyptemys insculpta*) and red-bellied turtle (*Pseudemys rubiventris*). Feral, introduced species include the red-eared slider (*Trachemys scripta elegans*) and Chinese shoftshell (*Pelodiscus sinensis*) (Mitchell et al. 2007). The wood turtle (*Glyptemys insculpta*) is known in GWMP from two unverified records from Great Falls Park in 1994 and Turkey Run Park in 2005. Both sightings of wood turtles are tentative records, as they need confirmation. The Chinese shoftshell is known only from a 2006 record from Dyke Marsh.

Of the 21 species of amphibians that have been identified within GWMP, eight species are frogs: northern cricket frog (*Acris crepitans*), spring peeper (*Pseudacris crucifer*), gray tree frog (*Hyla versicolor*), bull frog (*Rana catesbeiana*), green frog (*Rana clamitans*), pickerel frog (*Rana palustris*), green tree frog (*Hyla cinerea*) and wood frog (*Rana sylvatica*); three species of toad: American toad (*Bufo americanus*), Fowler's toad (*Bufo woodhousii fowleri*), and eastern spadefoot toad (*Scaphiopus holbrookii*); and eight species of salamander: spotted salamander (*Ambystoma maculatum*), marbled salamander (*Ambystoma opacum*), northern dusky salamander (*Desmognathus fuscus*), two-lined salamander (*Eurycea bislineata*), longtail salamander (*Eurycea longicauda*), four-toed salamander (*Hemidactylium scutatum*), slimy white-spotted salamander ((*Plethodon cylindraceus*) and red-backed salamander (*Plethodon cinereus*). One species of newt, the Eastern/red-spotted newt (*Notophthalmus viridescens*), has also been identified within the park.

The eastern spadefoot toad was discovered in Great Falls Park in 2003 and other species of amphibians are expected to be found as search efforts increase. The white-spotted slimy salamander (*Plethodon cylindraceus*) is known only from historical records near the mouth of Spout Run and Pimmit Run.

Figure 2-22 Broadhead skink (*Eumeces laticeps*). Source: Brent Steury.

Fish

The Potomac River and its tributary streams within GWMP are home to at least 62 species of fish. Mine Run in Great Falls Park has the highest species richness of any stream in GWMP with 22 species recorded (Raesly 2004). Fish species captured during qualitative and quantitative surveys in GWMP comprise three major groups: habitat generalist, pollution tolerant species and introduced species (Raesly 2004).

Within GWMP, the fallfish (*Semotilus corporalis*) and longear sunfish (*Lepomis megalotis*) are found only in Mine Run, the swallowtail shiner (*Notropis procne*), fantail darter (*Etheostoma flabellare*), Potomac sculpin (*Cottus girardi*), and the satinfin shiner (*Cyprinella analostana*) are restricted to Turkey Run, and the northern hogsucker (*Hypentelium nigricans*) and margined madtom (*Noturus insignis*) are found only in Difficult Run. While on the Maryland side of GWMP the sea lamprey (*Petromyzon marinus*), golden redhorse (*Moxostoma erythrurum*), and greenside darter (*Etheostoma blennioides*) are known to occur only in Cabin John Creek. The American eel (*Anguilla rostrata*) is found in more GWMP streams than any other species. Dyke Marsh, located along the Potomac River, is home to at least 38 fish species.

Nearly every stream in the VA portion east of Interstate 495 (Capital Beltway) has a cascade or waterfall near its confluence with the Potomac River. These falls are barriers to upstream movement of fishes, and are, at least in part, determinants of fish composition for many park streams (Raesly 2004).

Crustaceans

Subterranean macroinvertebrates were documented in the Potomac Gorge as early as 1883 with the discovery of the eyeless and unpigmented groundwater amphipod *Stygobromus tenuis potomacus* (Holsinger 1976; Evans 2008). Forty-six species of crustaceans have been documented in GWMP, 11 isopods, 9 amphipods, 5 crayfish, one shrimp, and one ostracod. One of the amphipods found within GWMP is a species new to science, *Stygobromus sextarius*. The other eight species of amphipods known from GWMP are *Crangonyx shoemakeri*, *Crangonyx stagnicolous*, *Crangonyx palustris*, *Synurella chamberlaini*, *Gammarus fasciatus*, *Gammarus minus*, *Stygobromus pizzinii* (state listed for rarity), and *Stygobromus tenuis*. A grass shrimp (*Palaemonetes* sp.) is occasionally found in Dyke Marsh. Eighteen species of copepod have been documented within GWMP, including one species new to Virginia, *Acanthocyclops einslei*. Two non-native crayfish, the red swamp crayfish (*Procambarus clarkii*) and the virile crayfish (*Orconectes virilis*), and three native species, the devil crayfish (*Cambarus diogenes*), Appalachian brook crayfish (*Cambarus bartonii*) and spiny-checked crayfish (*Orconectes limosus*) have been found in streams and wetlands of GWMP. *Orconetectes virilis*, native to the Midwest poses a serious threat to native crayfish within the Potomac Gorge by occupying preferred habits and forcing native crayfish species into more exposed microhabitats within the Gorge (Evans 2008).

Insects, Spiders, Centipedes, Millipedes, Worms, Springtails

This group represents the greatest amount of biodiversity found in the park, and it is also the least known in terms of biological inventories (NPS 2014). Currently, a total of 76 species of butterflies, 488 species of macro-moths, and 294 species of micro-moths have been documented from GWMP. The additional taxa that have been documented include 145 species of springtails (52 undescribed, 37 species new to science), 265 species of worms (1 new to North America, 2 new to Virginia), 59 species of ants, 122 species of bees (4 new to Virginia), 176 species of sawflies (1 new to Virginia), 24 species of wasps, 111 caddisflies (1 species new to science, 2 species new to Virginia, 9 species state listed for rarity), 22 species of mayflies, 33 stoneflies, 25 species of neuroptera, 271 species of diptera (7 species new to science), 69 species of dragonflies and damselflies (3 state listed species), 37 species of arachnids, 13 millipedes (1 species new to science), 214 species of true bugs (heteroptera and homoptera) (1 species new to North America, 4 new to Virginia), 524 beetles (49 species new to Virginia, 3 new to science), 11 megaloptera, and 9 mecoptera (**Figure 2-23**).

Figure 2-23 Golden tortoise beetle (*Metriona bicolor*). Source: Brent Steury.

Mollusks

A total of 85 mollusk species have been documented within GWMP, including two species new to Virginia. Fifty-five species of land snails and slugs, 21 species of aquatic snails and limpets, and nine species of bivalves (**Figure 2-24**).

Figure 2-24 Mud snails (*Fontigens bottimeri*). Source: Brent Steury.

Biodiversity

The Potomac River Gorge extends for 15 miles along the Potomac River from above Great Falls Park to near Theodore Roosevelt Island. Because of its unusual geography, geology, and hydrology, the gorge is one of the country's most biologically diverse areas. The Gorge traverses the fall line, the meeting point of the Blue Ridge and Piedmont ecoregions, and features characteristics of both (Cohn 2004). The gorge's unique habitats include upland forests, dry bedrock terraces, floodplain woodlands and prairies, and ponds and marshes (Cohn 2004).

To date, 5,289 species have been documented within GWMP, including 74 species new to science, 3 species new to North America, 84 new to Virginia, 7 new to the District of Columbia, and 104 listed as rare by the Natural Heritage Programs of Virginia or Maryland.

Rare, threatened, endangered species

George Washington Memorial Parkway is home to at least 105 plants and animals that are considered rare, threatened, or endangered in Virginia or Maryland (**Table 2-2**). These include 47 species of vascular plants, 2 mammals, 24 birds, 3 crustaceans, 6 mollusks, 3 dragonflies, 2 butterflies, 7 moths, 10 caddisflies, and 1 beetle. Twenty extant and three historical plant species found in Great Falls Park are on the state list of rare, threatened and endangered species (Steury et al. 2008). Additionally, several species found within GWMP are the first records reported from North America (Steury 2013).

Table 2-2 Rare, threatened, and endangered plant species that occur within GWMP. Key to state and global ranking identifications included below (Fleming et al. 2013, NPS 2014d, Townsend 2004).

Species name	State (Virgina, Maryland) and global rankings	Location
American ginseng (*Panax quinquefolis*)	S4 G4	Turkey Run Park
Balsam ragwort (*Packera paupercula*)	SU G5	Great Falls Park
Blue wild-indigo (*Baptisia australis*)	S3 G5T4?	Great Falls Park
Butternut (*Juglans cinerea*)	S3? G3G4	Turkey Run Park, Great Falls Park
Carey's sedge (*Carex careyana*)	S3 G5	Turkey Run, Great Falls Park
Coville's phacelia (*Phacelia coviellei*)	S1 G2 (E in MD only)	Clara Barton Parkway, Turkey Run Park
Crested sedge (*Carex cristatella*)	S2 G5	Theodore Roosevelt Island
Davis' sedge (*Carex davissi*)	S1 G4	Great Falls Park, Roaches Run, Dyke Marsh
Dwarf bulrush (*Hemicarpha micrantha*)	S1 G4	Great Falls Park
False mermaid-weed (*Floerkea proserpinacoides*)	S3 G5	Turkey Run Park, Great Falls Park
Field chickweek (*Cerastium arvense var. velutinum*)	S2? G5T4?	Turkey Run Park, Great Falls Park
Flattened spikerush (*Eleocharis compressa*)	S2 G4	Great Falls Park
Freshwater cordgrass (*Spartina pectinata*)	S2 G5	Turkey Run Park, Great Falls Park
Gray's sedge (*Carex grayi*)	S3 G4	Theodore Roosevelt Island
Harbinger-of-spring (*Eriginea bulbosa*)	S3 G5	Great Falls Park, Turkey Run Park
Lancaster's sedge (*Cyperus lancastriensis*)	SU G5	Theodore Roosevelt Island
Large bur-reed (*Sparganium eurycarpum*)	S3 G5	Dyke Marsh
Large-seed forget-me-not (*Myosotis macrosperma*)	S2S3	Theodore Roosevelt Island
Meadow sedge (*Carex graularis var. haleana*)	S3 G5T4	Theodore Roosevelt Island
Nantucket shadbush (*Amelanchier nantucketensis*)	S1 G3Q	Great Falls Park
Narrow melicgrass (*Melica mutica*)	S1 G5 T	Clara Barton Parkway
Ostrich fern (*Matteuccia struthiopteris*)	S1 G5; S2	Turkey Run Park, Theodore Roosevelt Island
Pink valerian (*Valeriana pauciflora*)	S2 G3G4	Turkey Run Park, Great Falls Park
Purple cress (*Cardamine douglassii*)	S3 G5	Turkey Run Park, Great Falls Park
Riverbank goldenrod (*Solidago rupestris*)	S1 G4	Great Falls Park
River bulrush (*Schoenoplectus fluviatilis*)	S2 G5	Roaches Run, Daingerfield Island, Jones Point, Dyke Marsh
Rorippa sessiliflora (Nutt.) Hitchc.	S1 G5	Great Falls Park
Rough avens (*Geum laciniatum*)	S1 G5T	Dyke Marsh
Sand cherry (*Prunus pumila va. cuneata*)	S1 G5T4	Great Falls Park
Short's aster (*Aster shortii*)	S1 G4G5	Windy Run area
Short's rockcress (*Arabis shortii*)	S2 G5	Turkey Run Park, Great Falls Park
Short's sedge (*Carex shortiana*)	S3 G5	Great Falls Park
Shumard's oak (*Quercus shumardii*)	S2 G5 T	Clara Barton Parkway, Theodore Roosevelt Island
Silky dogwood (*Cornus amomum var. obliqua*)	SU G5T5	Great Falls Park
Smartweed dodder (*Cuscuta polygonorum*)	S2? G5	Dyke Marsh
Smooth azalea (*Rhododendron arborescens*)	S2 G4G5	Great Falls Park
Soft fox sedge (*Carex conjucta*)	S3 G4G5; S1? E	Great Falls Park, Theodore Roosevelt Island
Spreading rockcress (*Arabis patens*)	S2 G3	Turkey Run Park

Species name	State (Virgina, Maryland) and global rankings	Location
Starry false Solomon's seal (*Maianthemum stellatum*)	S2 G5	Turkey Run Park, Great Falls Park
Sticky goldenrod (*Solidago racemosa*)	S1 G5T4?	Great Falls Park, Turkey Run Park, Potomac Heritage Trail
Straw sedge (*Carex straminea*)	S1 G5	Great Falls Park
Sweet-scented indian-plaintain (*Hasteola suaveolens*)	S2 G3G4	Turkey Run Park, Great Falls Park
Toothed tick-trefoil (*Desmodium cuspidatum*)	S2 G5T5	Great Falls Park
Virginia false gromwell (*Onosmodium virginianum*)	S2 G4	Great Falls Park
Virginia sida (*Sida hermaphrodita*)	S1 G2	Potomac Heritage Trail
Western sunflower (*Western sunflower*)	S1 G5	Great Falls Park
White trout-lily (*Erythronium albidum*)	S2 G5	Turkey Run Park, Great Falls Park, Theodore Roosevelt Island

Key to S and G Ranks

Global rankings

G1=Extremely rare and critically imperiled with 5 or fewer occurrences or very few remaining individuals; a species especially vulnerable to extinction.

G2=Very rare and imperiled with 6 to 20 occurrences of few remaining individuals

G3=Either very rare and local throughout its range or found locally (even abundantly at some locations) in a restricted range. Usually fewer than 100 occurrences are documented.

G4=Common and apparently secure globally, though it may be rare in parts of its range, especially at the periphery.

G5=Very common and demonstrably secure globally, though it may be rare in parts of its range, especially at the periphery.

G?= Unranked, or, if following a ranking, rank uncertain

Q_T_= Signifies the rank of a subspecies or variety

G_Q= The taxon has questionable taxonomic assignment.

State Rankings

S1 – Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state. Typically 5 or fewer populations or occurrences; or very few remaining individuals (<1000).

S2 – Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 populations or occurrences or few remaining individuals (1000 to 3000).

S3 – Vulnerable in the state either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 populations or occurrences (1000 to 3000).

Populations of rare plant species occupy the section of the Potomac River Gorge extending 24 km (15 miles) along the Potomac River south to Theodore Roosevelt Island. The gorge is one of the National Park Service's most biologically diverse areas and serves as a confluence for many rare plant species and biological communities (Steury et al. 2008).

In 1995, scientists discovered a new species of amphipod, *Stygobromus sextarius*, in a freshwater seep within GWMP (Culver and Chestnut 2006; Holsinger 2009).

Virginia false-gromwell (*Onosmodium virginianum*) is a perennial herb found only in coastal states of the eastern US and listed as rare in all states from Virginia northward (Kartesz 1999). It is a U.S. G4 plant, a Virginia S2 plant, and a Maryland S1 plant according to Natural Heritage Programs of VA and MD. The tiny population on the Maryland side of the Potomac Gorge is now evidently extirpated, and it has one known site in Great Falls Park where it was observed from 2005-2012 (Barrows et al. 2013) (**Figure 2-25**).

Figure 2-25 Virginia false-gromwell (*Onosmodium virginianum*). Source: Brent Steury.

<u>Integrated cultural and natural landscapes</u>

Recognition of cultural landscapes as an important part of the National Capital Region's natural heritage is rooted in 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 aesthetic values" (Cultural Resource Management Guidelines NPS-28). The National Park Service recognizes four descriptive types of cultural landscapes that are not mutually exclusive and are relevant to properties nationwide in both public and private ownership. These four types are historic sites, historic designed landscapes, historic vernacular landscapes, and ethnographic landscapes (Slaiby and Mitchell, 2003).

GWMP is comprised of a number of documented cultural landscapes within the park's Historic District boundaries and contribute to the significance of the parkway and other historic sites it manages. As part of the management of these cultural landscapes, GWMP preserves the original design of the parkway that focused on capturing certain viewsheds, alignments, and existing natural settings. By characterizing the parkway as a cultural landscape, GWMP acknowledges that exotic species are part of the landscape plan (Robinsons and Associates, 2011). At least 13 of the exotic species recently planted at GWMP have been documented as escaping into natural areas (Steury 2011), and two of these, Japanese pagoda tree (*Styphnolobium japonicum)* and linden virburnum (*Viburnum dilatatum),* are now widespread exotic nuisances and thousands of dollars have been spent on their control. Other exotic species such as English ivy (*Hedera helix),* Japanese Honeysuckle (*Lonicera japonica),* and Amur honeysuckle (*Lonicera maackii),* historically planted along the GWMP are now so pernicious that they are beyond control and occupy vast areas of GWMP land.

The treatment of cultural landscapes as a cultural resource has been an evolution within the NPS. Cultural landscapes were not formally identified until 1988, when the NPS characterized landscapes as a type of cultural resource in NPS Management Policies. Although the GWMP's first Cultural Landscape Report was written in 1986 (for the Mount Vernon Memorial Highway), the program was not fully integrated into the GWMP's practices until 1999. At present, GWMP has identified seventeen cultural landscapes; of those identified, the following have initiated or completed the Cultural Landscape Reports (CLR) and Cultural Landscape Inventories (CLI): Mount Vernon Memorial Highway CLR, Fort Hunt Park CLI; Arlington House CLR, Memorial Avenue CLI, Lady Bird Johnson CLI; North Parkway CLI, George Washington Memorial Parkway Central Section Vegetation CLR, Arlington Ridge Park CLI, Arlington House CLI, and Theodore Roosevelt Island CLI (Robinsons and Associates, 2011).

<u>Soundscapes</u>

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).

GWMP units are located within the Washington Metropolitan Area and in great proximity to major cities and thus are greatly affected by residential developments and major highways. It also experiences high volume of land traffic as well as air traffic due to its proximity to Reagan National Airport and Dulles International Airport.

Studies have found that anthropogenic noise can impact avian species composition in highly urbanized areas (Goodwin and Shriver 2010). Physiological and behavioral responses to noise have been documented in a variety of animals, including frogs and toads (Sun and Narins 2005), and bats

(Schaub et al. 2008), and for an increasing variety of birds (Brumm and Todt 2002; Slabbekoorn and Peet 2003; Fuller et al. 2007; Goodwin and Shriver 2007).

Lightscapes

The natural darkness associated with the night sky is an important natural, scientific, and cultural resource valued by the National Park Service (NPS 2012b). The clarity of night skies is important to the visitor experience as well as being ecologically important (NPS 2013c).

Artificial light sources both within and outside the national park have diminished the clarity of night skies by creating a 'haze' of light that obscures views of stars. The primary culprit is any type of outdoor lighting that allows light to shine up into the sky. Outdoor lighting is common throughout the region, including inside the national park boundaries. While such lighting is necessary for safety and security reasons, there are outdoor lighting fixtures available that direct light downward and do not allow stray light to scatter into the sky.

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 (NPS 2013c).

Artificial lighting within GWMP has contributed to the knowledge of park fauna due to the propensity of insect species to be attracted to lights. The only evidence of some species occurrence in the park is due to their attraction to the lights on the Resource Management building in Turkey Run Park. These include species state listed in Virginia such as Franck's Sphinx Moth (*Sphinx franckii*), species new to Virginia such as Speckled nettle moth (*Abrostola urentis*), and species new to science such as the recently described caddisfly, *Neophylax virginica*.

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, including resource partitioning and predation, and ultimately favoring species that are most light tolerant (Longcore and Rich 2004).

Viewsheds

The George Washington Memorial Parkway was designed to offer selected views of the Potomac River Gorge, monuments in Washington, D.C., and historic and commemorative features that line the parkway from Mount Vernon to the Great Falls of the Potomac. Many of these vistas and viewsheds are among the most iconic in the country and contribute to the parkway's role as a gateway into our nation's capital. Numerous sites and overlooks provide access to these vistas and views, which encourage visitors to stop and appreciate the scenery provided from the parkway (NPS 2014a).

The view of Great Falls is one of the most important resources in Great Falls Park (**Figure 2-26**). A large number of visitors come to the park to see this view. Three overlooks provide a formal area for viewing. Additionally, Great Falls Park, Virginia contributes to the visual quality of the C&O Canal National Historical Park (NHP). Visitors within the C&O Canal NHP, along the Billy Goat Trail, adjacent to the Potomac, along the outlooks and observation decks, or along Mary's Wall, are offered a view of Great Falls Park's natural character on the opposite banks of the river (NPS 2007). Any changes within Great Falls Park have the potential to impact the viewsheds from the C&O Canal NHP.

Great Falls Park shares a major portion of its southwestern border with Georgetown Pike. Designated a Virginia Byway by the Virginia Department of Transportation, this title applies to road corridors that contain aesthetic or cultural values near areas of historical, natural, or recreational significance. Any changes within the park bordering the Georgetown Pike would have the potential to effect views from the road (NPS 2007).

Figure 2-26 Great Falls. Source: Brent Steury.

Resource issues overview

Internal park threats

Adverse Recreational Use

George Washington Memorial Parkway is among the ten most visited units of the National Park System. With the growth of Washington, D.C. and surrounding areas, associated development pressures have consistently posed a significant problem for the parkway. The effects of this intense visitation to the parkway and heavy demands for park services, from commuters on the parkway to bikers on the Mount Vernon Trail, place increasing demands on its protected areas. The landscape response to potential visitor overuse is a resource management concern and includes overall visitor safety, especially at the bottom of steep, rocky slopes (Thornberry-Ehrlich 2009).

Trails wind through biological, historical, and geological environments at the park. Several of the trails are especially fragile, and off-trail hiking promotes their degradation. The cliffs and non-cliff rocky areas of Great Falls Park and Mather Gorge provide important habitat for numerous sensitive rare plants and plant communities (Marion et al. 2011). Recreational activity can pose a threat to the rare plants growing within cliff and rocky areas. Within Great Falls Park, off trail traffic by visitors accessing areas not reached by the formal trail system has led to the development of extensive informal trail networks and fragmentation of the landscape (Wimpey and Marion 2011). Trampling and loss of vegetation, alteration in vegetation composition, possible introduction and spread of non-native plants, compaction and loss of soil, and disturbance or displacement of wildlife are threats within GWMP (Marion et al. 2011; Wimpey and Marion 2011).

The park attempts to concentrate the impacts of recreation using designated trails and picnic areas. Recreational use outside designated areas places delicate ecosystems at risk for contamination from waste (Thornberry-Ehrlich 2009). Visitor safety is a primary resource management concern. Despite posted warning signs, drowning occurrences in the Potomac River at Great Falls Park are frequent.

Exotic species

Exotic species can outcompete and displace native species. Many invasive plants thrive on disturbances created within an ecosystem, such as fragmentation, wildfires, or flooding. When native species are displaced by these disturbances, invasive species can more rapidly colonize the area, further facilitating competition for resources (Nortrup 2010). Changes in habitat structure and composition of vegetation communities can affect nutrient cycling, water resources, and habitat quality for wildlife. Invasive wildlife creates similar community and ecosystem-level changes detrimental to native organisms.

Some of the most prolific non-native species within GWMP were included on historical planting plans for the parkway developed by Wilbur Simonson in 1932. These include porcelainberry (*Ampelopsis brevipedunculata*), English ivy (*Hedera helix L.*), Japanese honeysuckle (*Lonicera japonica*), amur honeysuckle (*Lonicera maackii*), and linden viburnum (*Viburnum dilatatum*) (Steury 2011) (**Figure 2-27**).

Figure 2-27 English ivy (*Hedera helix L.*) dominates ground cover. Source: Greg Zell.

Japanese stiltgrass (*Microstegium vimineum*) is a common invasive throughout the Potomac Gorge, and has become established in areas where soils are compacted due to recreational use (Erdman et al. 2004).

Exotic species in GWMP were evaluated by the National Capital Region Network (Schmit, 2012) (Table). Three species of exotic trees, tree of heaven (*Ailanthus altissima*), southern magnolia (*Magnolia grandiflora*) and white mulberry (*Morus alba*) were found but none of them is particularly widespread. Exotic trees are most problematic on Daingerfield Island, just south of Reagan National Airport. The southern magnolia trees there were remnants of a former tree nursery. Other non-native trees such as Higan cherry (*Prunus subhirtella*), Japanese pagoda tree (*Styphnolobium japonicum*), and various species of crabapple (*Malus* sps.) are also common naturalized species within GWMP (Steury 2011). Four species of exotic shrubs were found, with Amur honeysuckle (*Lonicera maackii*) as the most abundant. Linden viburnum (*Viburnum dilatatum*) is an abundant exotic shrub in natural areas of Turkey Run Park.

Exotic species were recorded on the forest floor in sixteen of the twenty monitoring plots. These species grow throughout the park. Japanese honeysuckle (*Lonicera japonica*) was found in 60% of all plots, scattered throughout the park. English ivy *(Hedera helix*) is less widespread but it has the highest cover in the plots where it is located. English ivy also has the highest total cover in the park at over 6%. Nonnative plant species comprise 28.6% (375 species) of the vascular flora of GWMP (Steury 2011). Of these non-native species at least 46 are common enough in some areas to be considered invasive (**Table 2-3**).

Table 2-3 Exotic Species at George Washington Memorial Parkway excluding insects (NPSpecies).

Category	Scientific name (Common name)
Birds	Mute swan (*Cygnus olor*) Rock dove (*Columba livia*) House finch (*Carpodacus mexicanus*) House sparrow (*Passer domesticus*) European starling *(Sturnus vulgaris*)
Flora	Amur honeysuckle (*Lonicera maackii*) Autumn olive (*Elaeagnus umbellate*) Bamboo (various species) Beefsteak plant (*Perilla frutescens*) Black locust (*Robina pseudoacacia*) Border privet (*Ligustrum obtusifolium*) Canada thistle (*Cirsium arvense*) Chinese wisteria (*Wisteria sinensis*) Chocolate vine (*Akebia quinata*) Common daylily (*Hemerocallis fulva*) Common periwinkle *(Vinca minor)* Common reed (*Phragmites australis*) English ivy (*Hedera helix)* Fig buttercup (*Ficaria verna)* Garlic mustard (*Alliaria petiolata*) Ground ivy (*Glechoma hederacea*) Himalayan blackberry *(Rubus discolor)* Hydrilla (*Hydrilla verticillata*) Ivy-leaved speedwell (*Veronica hederifolia*) Japanese flowering crabapple (*Malus floribunda)* Japanese honeysuckle (*Lonicera japonica)* Japanese hop (*Humulus japonicas*) Japanese knotweed (*Fallopia japonica*) Japanese pagoda tree (*Styphnolobium japonicum*) Japanese stiltgrass (*Microstegium vimineum*) Japanese wisteria (*Wisteria floribunda*) Johnson grass (*Sorghum halepense*) Kudzu (*Pueraria montana var. lobata*) Linden arrowwood (*Viburnum dilatatum*) Marsh dewflower (*Murdannia keisak*) Mile-a-minute weed (*Persicaria perfoliata*) Multiflora rose (*Rosa multiflora*) Musk thistle (*Cardus nutans*) Nepalese browntop (*Microstegium vimineum*) Oriental bittersweet (*Celastrus orbiculatus*) Pagoda tree (*Styphnolobium japonicum*) Poison hemlock (Conium maculatum) Porcelainberry (Ampelopsis brevipedunculata) Princess tree (Paulownia tomentosa) Purple loosestrife (*Lythrum salicaria)* Reed canarygrass (Phalaris arundinacea) Sky pencil (Ilex crenata)

Category	Scientific name (Common name)
	Sweet autumn clematis (*Clematis terniflora)* Sweet vernalgrass (Anthoxanthum odoratum) Tall fescue (Festuca (Lolium) arundinaceae) Tree of heaven (Ailanthus altissima) Wavyleaf basketgrass (Oplismenus hirtellus ssp. Undulatifolius) White mulberry (Morus alba) Wineberry (Rubus phoenicolasius) Yellow flag iris (Iris pseudacorus)
Fish	Blue catfish (Ictalurus furcatus) Bluegill (Lepomis macrochirus) Bluntnose minnow (Pimephales notatus) Channel catfish (Ictalurus punctatus) European carp (Cyprinus carpio) Flathead catfish (Pylodictis olivaris) Goldfish (Carassius auratus) Greenside darter (Etheostoma blennioides) Largemouth bass (Micropterus salmoides) Longear sunfish (Lepomis megalotis) Northern snakehead *(Channa argus*) Smallmouth bass (Micropterus dolomieu)
Gastropods	*Ambigolimax valentiana* *Arion hortensis* *Arion intermedius* *Arion subfuscus* *Bellamya japonica* *Bithynia tentaculata* *Deroceras reticulatum* *Limax maximus* *Milax gagates* *Oxychilus draparnaudi* *Paralaoma servilis*
Herptofauna	Chinese softshell turtle *(Pelodiscus sinensis*) Red-eared slider (Trachemys scripta elegans)
Mammals	Domestic cat *(Felis catus*) Norway rat (Rattus norvegicus)

The units of the park differ in which forest floor exotic is the most abundant. Japanese stiltgrass (*Microstegium vimineum*) is most common in Great Falls, Virginia. One plot in the middle of Great Falls is the most impacted with over 80% cover of stiltgrass. Exotic vines grow on trees in 30% of the plots. The three most common exotic vines were English ivy, Japanese honeysuckle, and Japanese wisteria. Oriental bittersweet and porcelain berry vine are also extremely damaging.

<u>Deer Overbrowse</u>

White-tailed deer (*Odocoileus virginianus*) densities have risen rapidly in the past few decades due to a lack of natural predators, increased forage area due to land fragmentation for suburban growth, and declines in hunting (Bates 2009) (**Figure 2-28**). Over-browsing by deer alters the structure and composition of the vegetation by extirpating native plants, and facilitating the spread of invasive species (Allen and Flack 2001). Deer populations affect other forest species that depend on vegetation structure. Opening or removing the forest understory potentially alters the soil moisture content that amphibians depend on; deer can also trample ephemeral ponds used for amphibian breeding (Pauley et al. 2005). Alteration of the shrub layer can eliminate nesting habitat for some bird species. Declines in regeneration of oaks and other mast-producing trees affect small mammal populations that depend on mast as a food source (Bates 2009). Deer have been linked to high numbers of ticks that may lead to increases in diseases such as Lyme disease (Wilson et al. 1990; Deblinger et al. 1993). They can also carry and spread chronic wasting disease to other animals (Williams et al. 2002).

Figure 2-28 White-tailed deer (*Odocoileus virginianus*) on Theodore Roosevelt Island. Source: Harvey Barrison.

Within GWMP, deer population densities are measured in Great Falls Park. The deer density at Great Falls in 2014 was 20.83 deer per square kilometer. Densities above 8 deer per square kilometer exert a negative effect on vegetation (Bates 2009; Horsley et al. 2003). Densities above 16 deer per square kilometer (40 per square mile) indicate negative effects on other wildlife species (Bates, 2009; deCalesta 1999). Local deer populations are an ongoing threat within the Potomac Gorge, as browse lines and damage to vegetation are apparent in many areas (MEG 2004). The ten-year average deer density in Great Falls is 35.83 deer per square kilometer.

<u>Water Quality</u>

Major threats to water quality in the Potomac River and its tributaries include: (1) acid drainage from coal mines in western Maryland and West Virginia; (2) sediment, nutrients, heavy metals, and organic chemicals in urban/ agricultural runoff; (3) bacteria, nutrients, and heavy metals from sewage effluent discharges; and (4) organic chemicals, heavy metals, and high biochemical oxygen demand from industries and developed areas (Thornberry-Ehrlich 2009).

Four sites in GWMP were monitored for water quality by NCRN I&M (Pieper 2012). Sites were located in Turkey Run, Pimmit Run, Mine Run, and Minnehaha Creek along George Washington Memorial Parkway. They were monitored on a monthly basis for dissolved oxygen, pH, specific conductance, temperature, acid neutralizing capacity, total nitrate, total phosphorus, depth, wetted width, flow, and discharge. Both pH and acid neutralizing capacity met threshold expectations. Specific conductance exceeded ecological thresholds for aquatic life stress at all sites except Mine Run. Salinity was consistently within the acceptable range for fresh water except for a few instances on Minnehaha Creek during the winter. Total nitrate levels are nearly equally split between meeting or exceeding threshold limits, with no discernible pattern. Phosphorus levels regularly exceeded the threshold and eutrophication values. Water temperatures always fell within the acceptable range, and followed air temperatures, suggesting that the streams are primarily surface-fed. Dissolved oxygen was consistently acceptable, and displayed a typical seasonal pattern.

Vehicle Collisions

Collisions between wildlife and vehicles on the George Washington Memorial Parkway, now a high speed commuter route in and out of the District of Columbia, are the major threat to top level predators and other large mammals in GWMP. Three of four documented occurrences of coyote and two of three documented occurrences of northern river otter in GWMP have been roadkills. Large raptors such as barred owls, red-tailed hawks, red-shouldered hawks, and sharp-shinned hawks have also been killed or injured by cars on GWMP. During a five and a half year interval between September 2004 and March 2010, 1,170 roadkills were documented on the GWMP. The actual number of roadkills is much higher than the reported tally since the full length of the GWMP was not surveyed and surveys were not conducted on weekends or during times when staff were away from the office. The Clara Barton Parkway in Maryland was also not surveyed. Roadkills documented during this five and a half year period included 355 raccoons, 312 eastern grey squirrels, 180 birds (various species), 87 whitetail deer, 65 opossums, 54 red foxes, 37 unidentifiable mammals, 19 woodchucks, 18 snakes (various species), 16 turtles (various species), 15 beavers, 5 eastern cottontail rabbits, 3 muskrats, 2 eastern chipmunks, a northern river otter and a frog (**Figure 2-29**).

Figure 2-29 Road kill northern river otter hit on George Washington Memorial Parkway while crossing road at Hog Island Gut, Dyke Marsh Wildlife Preserve, March 7, 2015. Source: Ian Steury

Regional threats

Development/encroachment

The growth of metropolitan Washington, D.C., and associated development pressures has consistently posed a significant problem for the parkway. In 2010, the Washington Metropolitan area gained approximately 1.5 million residents and many businesses set up locations in the inner suburbs such as Crystal City and Rosslyn (Robinson and Associates 2011). This influx of people placed heavy demands on park services, from commuters on the parkway to bikers on the Mount Vernon Trail. The growth also led to important administrative issues such as policing the park, safety on the trails, river, and parkway, managing maintenance, and maintaining the parkway setting. Development opportunities and new amenities for the region's expanding population not only increased pressure on the GWMP, but also compelled park officials to be active partners in local planning (Robinson and Associates 2011).

Erosion and increased sediment load

Large topographic differences occur along George Washington Memorial Parkway. The likelihood of landslides increases with precipitation and undercutting of slopes by roads, trails, and other development (Thornberry-Ehrlich 2009). The walls of many of the river and tributary valleys along the parkway are high slopes, which makes them hazardous because of the potential for rock falls, landslides, slumps, and slope creep (Thornberry-Ehrlich 2009). In 2004, a landslide closed the Windy Run access trail, a portion of the Potomac Heritage Trail at the intersection of Windy Run and the Potomac River in the Parkway (**Figure 2-30**). The cause of the landslide was a combination of a natural rainfall event that saturated weathered rock and soil near an area previously quarried, which left slopes in an unnaturally steep and unstable configuration (Steensen 2004). Historic quarrying for building stone, along the right bank of the Potomac Gorge, has altered natural slopes and left many areas of steep cliff faces capped by oversteepened soil, and in some places, deeply weathered bedrock. Similar landslides (shallow debris avalanches) occur up and down the Potomac Heritage Trail (Steensen 2004).

Erosion of the landscape and increasing impervious surface area within the Potomac River tributary watersheds leads to increases in sediment carried by the park's rivers (Thornberry-Ehrlich 2009; M. Pavich, USGS, written communication, December 2008). Sediment loads and distribution affect aquatic and riparian ecosystems. Sediment loading may result in changes to channel morphology and increase the frequency of overbank flooding (Thornberry-Ehrlich 2009).

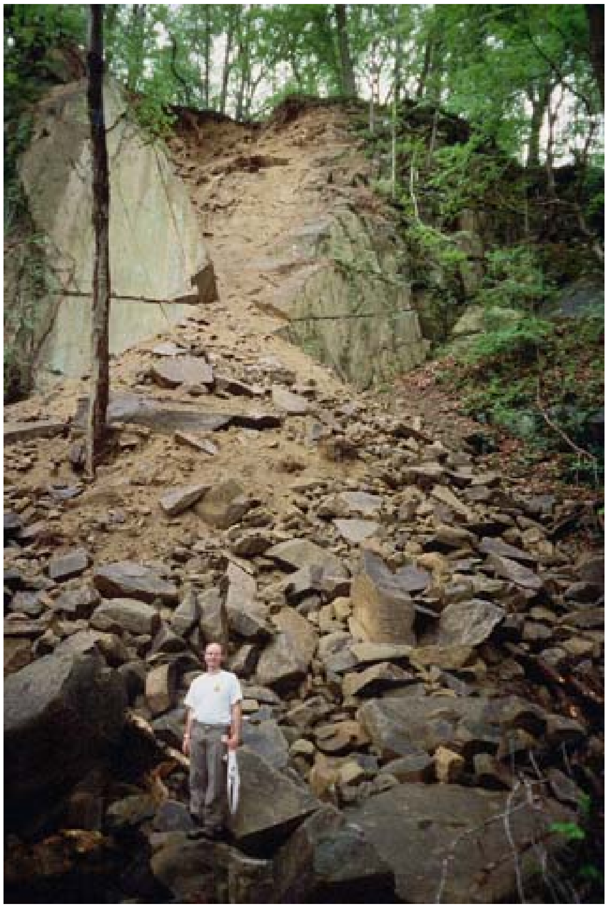

Figure 2-30 Windy Run Rock Slide, March, 2004. Source: David Steenson.

<u>Air quality</u>

Air pollution originates from several different types of sources - stationary sources, such as factories, power plants, and smelters; mobile sources, such as cars, trains, and airplanes; and naturally occurring sources, such as windblown dust (U.S. EPA 2013). The most commonly found air pollutants are particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead, the former two of which are the most widespread human health threats (U.S. EPA

2013). The 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 while high levels of nitrogen deposition acidify and fertilize soils and waters, thereby affecting nutrient cycling, vegetation composition, biodiversity, and eutrophication. Air pollution can be transported over long distances, making management difficult at the local scale.

Sea level rise and storm surge

The Potomac River experiences daily 1 meter (3 feet) tidal fluctuations at Washington, D.C., which strongly influence the flow regime of the river and its subsequent channel morphology. Relative sea level rise and surges of water associated with hurricanes and storms affect the estuarine Potomac River, and thus the shoreline of George Washington Memorial Parkway (Thornberry-Ehrlich 2009). The local rate of sea level rise is 27.4 cm (10.8 in) per century (Froomer 1980). Several meters of shoreline can be eroded in a single storm event as evidenced further south along the Potomac River at George Washington Birthplace National Monument in Virginia (Thornberry-Ehrlich 2009) and at Dyke Marsh Wildlife Preserve (Steury et al. 2014).

Much of George Washington Memorial Parkway is composed of floodplain areas along the Potomac River. Potomac River floods have exceeded the rim of the Potomac Gorge within Great Falls Park in 1936, 1937, 1942, 1972, 1985, and 1996 (Steury et al. 2008). Floods have damaged foundations of bridges, walkways, buildings, and other facilities. As global sea levels continue to rise, these inundation issues will only become more prevalent at the parkway (Thornberry-Ehrlich 2009).

Resource Stewardship

Management directives and planning guidance

Park mission

Based on enabling legislation, the mission of George Washington Memorial Parkway is to (NPS 2005): Develop, manage and preserve the park, parkway, and playground system of the National Capital area; Protect and preserve a wide variety of individual cultural, natural, recreational, and scenic resources throughout the parkway; Promote opportunities for the public to learn about and experience parkway resources.

Park purpose

The purpose statement for the George Washington Memorial Parkway was drafted through a careful analysis of its enabling legislative history that influenced its development. The unit was established when the enabling legislation adopted by Congress was signed into law on May 29, 1930. The George Washington Memorial Parkway is a scenic roadway honoring the nation’s first president, and its purpose is to protect and preserve cultural and natural resources along the Potomac River below Great Falls to Mount Vernon. The George Washington Memorial Parkway is part of a comprehensive system of parks, parkways, and recreational areas surrounding the nation’s capital (NPS 2014a).

Park significance

Significance statements express why George Washington Memorial Parkway resources and values are important enough to merit national park unit designation (NPS 2013a). Significance statements describe the distinctive nature of the park and inform management decisions, focusing efforts on preserving and protecting the most important resources and values of the park unit.

The following significance statements have been identified for GWMP:

- The Mount Vernon Memorial Highway was the first comprehensively designed modern motorway built by the federal government. It is based on the idea of a landscaped, park-like roadway corridor that protected riverfront lands and today includes an extension north to the capital beltway, as well as Spout Run Parkway and Clara Barton Parkway.

- At the time of its construction between 1929 and 1932, Mount Vernon Memorial Highway pioneered many principles of roadway design that influenced federal roadway projects throughout the nation, such as limited access construction, grade-separated intersections, cloverleaf interchanges, and landscape design, many of which are still in use today.

- The 15-mile-long Potomac Gorge, a large portion of which is managed by the George Washington Memorial Parkway, is one of the most biologically diverse natural areas in the national park system.

- By protecting the natural shoreline of the Potomac River, the George Washington Memorial Parkway protects a defining feature of the nation's capital and provides opportunities to experience iconic scenic vistas of and from Washington, D.C., and the Potomac Gorge.

- Stretching more than 25 miles, the George Washington Memorial Parkway contains many discrete natural areas, historic sites, and memorials that are significant in their own right. Some of these places were part of the originally designated parkway while others have been added by Congress over the years or acquired under the authority of the Capper-Cramton Act of 1932. These significance statements reflect why these sites are important within the national park system and warrant inclusion within the parkway.

- Jones Point Lighthouse, located in Jones Point Park, is one of the last riverine lighthouses in the United States and is the only remaining inland lighthouse in the Chesapeake Bay watershed.

- Jones Point Park contains the south cornerstone of the District of Columbia, which was the first stone set for the 1791 survey that carved the original boundary of the nation's capital from the states of Maryland and Virginia.

- Great Falls Park protects the views and access to the Great Falls of the Potomac, the largest waterfall on the Potomac River.

- Inspired by George Washington's vision for Western expansion and interstate commerce, the Patowmack Canal was one of the first canal systems in the country and used innovative engineering to meet the challenges of navigating the Great Falls of the Potomac.

- The Arlington Memorial Bridge and Memorial Avenue provide a ceremonial gateway to Arlington National Cemetery and symbolically and physically link the once-divided North and South in their alignment between the Lincoln Memorial and Arlington House, The Robert E. Lee Memorial.

- Sitting on the primary east-west axis of the L'Enfant plan for Washington, D.C., Arlington Ridge Park offers stunning views of the nation's capital. It contains the U.S. Marine Corps War Memorial, an iconic national monument dedicated to all U.S. Marines who have sacrificed their lives for the United States since 1775, and the Netherlands Carillon, a symbolic gift of friendship from the citizens of the Netherlands to the United States in thanks for the American aid received during and after World War II.

- Dyke Marsh is one of the largest freshwater tidal marshes near Washington, D.C., and has been recognized by Congress as a "unique and precious ecosystem" that provides habitat for many species of state-listed rare plants and animals.

- With its strategic location on the south side of the Potomac River, Fort Marcy once guarded the Georgetown to Leesburg Turnpike and the Chain Bridge entrance to Washington, D.C., and is one of the most completely preserved sites of the Civil War Defenses of Washington.

- Fort Hunt Park, along with Fort Washington Park, preserves the only set of Endicott Period coastal defense gun batteries built to protect Washington, D.C., during the Spanish-American War era and is the site of P.O. Box 1142, one of the most important military intelligence operations centers during World War II.

- Glen Echo Park preserves the only Chautauqua assembly site and the only early 20th century trolley amusement park in the national park system.

Status of supporting science

<u>Inventory and Monitoring program</u>

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

- Inventory the natural resources under National Park Service stewardship to determine their nature and status.

- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments.

- Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.

- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision-making.

- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

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

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

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

Research at the park

NCRN I&M has performed its own research and collaborated with a variety of outside researchers to fill gaps in knowledge and have a better understanding of park resources (**Table 2-4**). Collaborators have included various state and federal government agencies, Georgetown University, Old Dominion University, Towson University, the University of Maryland, and non-government organizations. A partial bibliography of research that has been completed at GWMP by NCRN I&M and others can be seen in **Table 2-5**.

Table 2-4 Table Status of NRCN I&M Inventories at George Washington Memorial Parkway.

Inventory	Description	Status
Air Quality Data	One of the 12 core natural resource inventories, the Air Quality Inventory provides actual measured or estimated concentrations of indicator air pollutants such as ozone, wet deposition species (NO_3, SO_4, NH_4, etc.), dry deposition species (NO_3, SO_4, HNO_3, NH_4, SO_2), and visibility (extinction for 20% cleanest days and 20% worst days for visibility).	Completed 2010
Air Quality Related Values	Air quality related values are resources sensitive to air quality, including vegetation, wildlife, water quality, and soils. This inventory identifies whether categories of these values are sensitive for a given park.	Completed 2011
Base Cartography Data	The Base Cartography inventory is one of 12 core inventories identified by the National Park Service as essential to effectively manage park natural resources. Base cartographic information from this inventory provides geographic information systems (GIS) data layers to National Park resource management staff, researchers, and research partners.	Completed 2010
Baseline Water Quality Inventory	This inventory documents and summarizes existing, readily available digital water quality data collected in the vicinity of national parks.	Completed 1996
Climate Inventory	One of the 12 natural resource inventories, the primary objective of the Climate Inventory is to obtain park-relevant baseline climate data useful to NPS biologists, hydrologists, and resource managers.	Completed 2006
Geologic Resources Inventory	The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers	Completed 2008

Inventory	Description	Status
	and staff, park planners, interpreters, and researchers with information that can help them make informed management decisions.	
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 2009
Species Occurrence & Distribution Inventories	Bats, fish, graminoids, herptiles, paleontological resources, and small mammals.	Completed (various years)
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 2-5 A partial bibliography of recent peer reviewed publications concerning the natural history of GWMP. Full references are included in the Literature Cited.

Study topic	Reference
Birds	Carter and Haramis 1980
Arthropods	Donnelly 1961; Kjar and Barrows 2004; Barrows *et al.* 2005; Culver *et al.* 2006; Mathis and Foster 2007; Steiner and Erwin 2007; Steury *et al.* 2007; Barrows *et al.* 2008; Holsinger 2009; Mathis *et al.* 2009; Barrows and Flint 2009; Kjar 2009; Kolleng 2009; Smith 2009; Steiner 2009; Steury *et al.* 2009; Mathis and Zatwarnicki, 2010; Flint 2011; Flint and Kjer 2011; Evans and Steury 2012; Steury *et al.* 2012; Mathis and Zatwarnicki 2012; Barrows 2013; Cavey *et al.* 2013; Steury *et al.* 2013a; Barrows and Smith 2014; Steury and MacRae 2014; Steury and Messer 2014; Steury et al. 2014
Climate	Davey *et al.* 2006;
Ecology	Myrick and Leopold 1963; Cohen 2004; Hopfensperger *et al.* 2007; Evans *et al.* 2008; Barrows *et al.* 2011; Wimpey and Marion 2011; Barrows *et al.* 2012; Barrows *et al.* 2013; Steury 2014b
Flora	Spooner *et al.* 1985; Abrams and Copenheaver 1999; Lea and Frye 2002; Steury 2004; Steury *et al.* 2008; Steury 2010; Steury 2011; Lea 2012; Steury 2012; Steury *et al.* 2013b; Steury *et al.* 2013c
Gastropoda	Sinclair 2010; Steury 2014a; Steury and Pearce 2014
Geology & Soils	Thornberry-Ehrlich 2009
Herptofauna	Mitchell *et al.* 2007; Steury *et al.* 2007
Hydrology	Myrick and Leopold, 1963; Harper and Heliotis, 1992; Norris *et al.* 2011
Invasive species	Adamski et al. 2009
Mammals	Johnson et al. 2008
Water Quality	Pieper *et al.* 2012
Wetlands	Hartwell 1970; Foster and Huff 1995; Engelhardt *et al.* 2005; Culver *et al.* 2006; Hopfensperger *et al.* 2006; Hopfensperger and Engelhardt 2008; Hutchins and Culver, 2008; Hopfensperger and Baldwin, 2009; Hopfensperger *et al.* 2009a; Hopfensperger *et al.* 2009b; Culver *et al.* 2012; Litwin *et al.* 2013; Palinkas *et al.* 2013; Cadol *et al.* 2014; Steury *et al.* 2014

Legislation and Acts

- Rivers and Harbors Appropriation Act, section 10 – 1899
- National Park Service Organic Act – 1916
- National Environmental Policy Act – 1969
- Clean Water Act, sections 401, 402, and 404 – 1972, as amended
- Endangered Species Act – 1973
- Redwood Act, Amending the NPS Organic Act – 1978
- Comprehensive Environmental Response and Compensation and Liability Act (CERCLA) – 1984, as amended
- Code of Federal Regulations
- Title 36, Chapter 1, Part 1, General Provisions
- Title 36, Chapter 1, Part 2, Resource Protection, Public Use and Recreation
- Title 36, Chapter 1, Part 4, Vehicles and Traffic Safety
- Title 36, Chapter 1, Part 5, Commercial and Private Operations
- Executive Orders
- Executive Order 11514, "Protection and Enhancement of Environmental Quality"
- Executive Order 11593, "Protection and Enhancement of the Cultural Environment"
- Executive Order 11988, "Floodplain Management"
- Executive Order 11990, "Protection of Wetlands"
- Executive Order 12003, "Energy Policy and Conservation"
- Executive Order 12088, "Federal Compliance with Pollution Control Standards"
- Executive Order 12372, "Intergovernmental Review of Federal Programs"
- Executive Order 13112, "Invasive Species"
- Executive Order 13186, "Responsibilities of Federal Agencies to Protect Migratory Birds"
- Executive Order 13352, "Facilitation of Cooperative Conservation"
- Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management"
- Executive Order 13508, "Chesapeake Bay Protection and Restoration"

Study Scoping and Design

Preliminary scoping and park involvement

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

Figure 3-1 Participants at the preliminary scoping workshop for George Washington Memorial Parkway. Participants from left to right: Alexcy Romero, Brent Steury, Mikaila Milton, Simon Costanzo, Stephen Syphax, Megan Nortrup, Erik Oberg, Patrick Campbell, Brianne Walsh, Jim Pieper, and Mark Lehman.

Several follow-up meetings with staff from GWMP, 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 GWMP legislative boundary that is owned by the NPS. An area 5x 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: Natural Resource Condition Assessment is 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 George Washington Memorial Parkway.

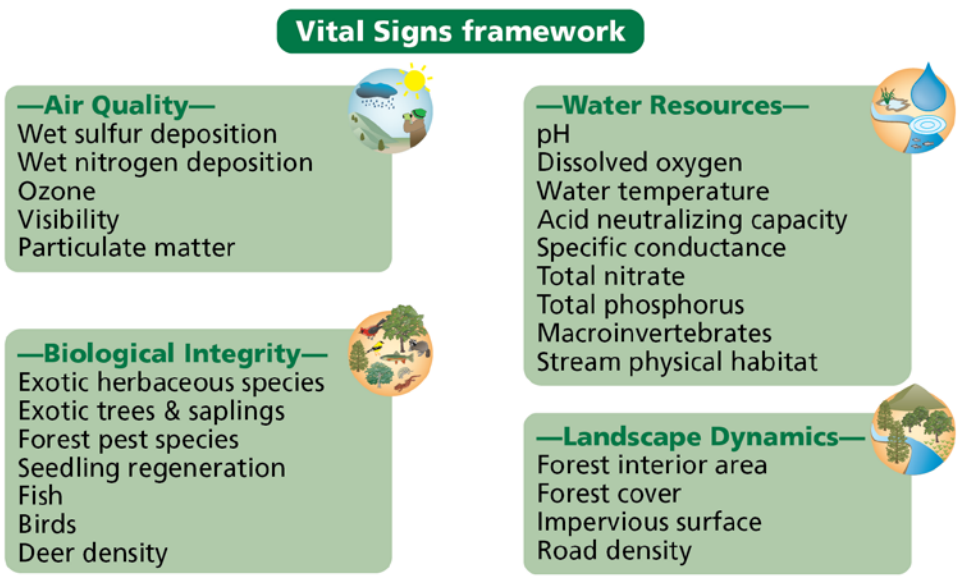

Figure 3-2 Vital signs framework used in this assessment.

General approach and methods

The general approach taken to assess natural resource condition was to determine indicators appropriate to inform current status of each vital sign, 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 in Chapter 4: Natural Resource Condition Assessment. Once attainment was calculated for each indicator, an unweighted mean was calculated to determine the condition for each vital sign category and then similarly to combine vital sign categories to calculate an overall park assessment.

Thresholds

A natural resource condition assessment requires the establishment of criteria for defining desired, as well as current ecological conditions. The current assessment was based upon explicitly defined 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 though increasing scientific research has focused upon defining ecological thresholds, uncertainty in definition as well as spatial and temporal variability has often led to disagreement on specific values (Huggett 2005; Groffman et al. 2006). 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 the light of new research or management goals and can therefore provide an important focus for the discussion and implementation of ecosystem management (Jensen et al. 2000; Pantus and Dennison 2005).

Data synthesis

It is increasingly recognized that monitoring data collected for specific purposes, such as assessing the implementation of environmental regulations, does not necessarily allow for regional assessments of ecosystem condition (U.S. EPA 2000, 2002). As a result, one of the key challenges of large-scale monitoring programs is to develop integrated and synthetic data products that can translate a multitude of diverse data into a format that can be readily communicated to decision makers, policy developers, and the public (Fancy et al. 2008). These timely syntheses of ecosystem condition can provide feedback to managers and stakeholders, so that the effectiveness of management actions as well as future management goals can be determined at multiple scales (Dennison et al. 2007). One approach to synthesizing data is to develop multiple-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), just 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 GWMP. The approach for assessing resource condition within GWMP required establishment of a reference condition (i.e., threshold) for each indicator. Thresholds ideally were ecologically based and derived from the scientific literature. However, when data were not available to support peer-reviewed ecological thresholds, regulatory and management thresholds were used.

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

Threshold attainment of indicators was calculated based on the percentage of sites or samples that met or exceeded threshold values set for each indicator. An indicator attainment score of 100% reflected that the indicator at all sites and at all times met the threshold identified to maintain natural resources. Conversely, a score of 0% indicated that no sites at any sampling time met the threshold 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 in Chapter 4: Natural Resource Condition Assessment.

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 Condition Assessment

This chapter outlines the natural resource conditions for GWMP based on a subset of important natural resources across all national park units. GWMP is somewhat unique in the national park system, being a metropolitan motorway park with extensive landscape manipulation. Hence, findings reported in this section need to be considered in this context.

Water resources

Nine indicators were used to assess water resources in GWMP: 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**). Data were collected by NCRN I&M staff and collaborators. Water quality, BIBI and PHI monitoring sites monitoring sites are shown in **Figure 4-1** and **Figure 4-2**.

Reference conditions were established for each of the nine indicators and the data were compared to these reference conditions to obtain the percent attainment, which was then converted to the condition assessment for that indicator (**Table 4-2**). George Washington Memorial Parkway scored high on attainment (good to very good) for pH (98.6%), water temperature (100%), ANC (100%), and DO (94.8%). Specific conductance and nitrate had moderate to degraded attainment (24.5% and 59.8% respectively), PHI was partially degraded, and total phosphorus, and BIBI were in very degraded condition (**Table 4-3**).

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

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

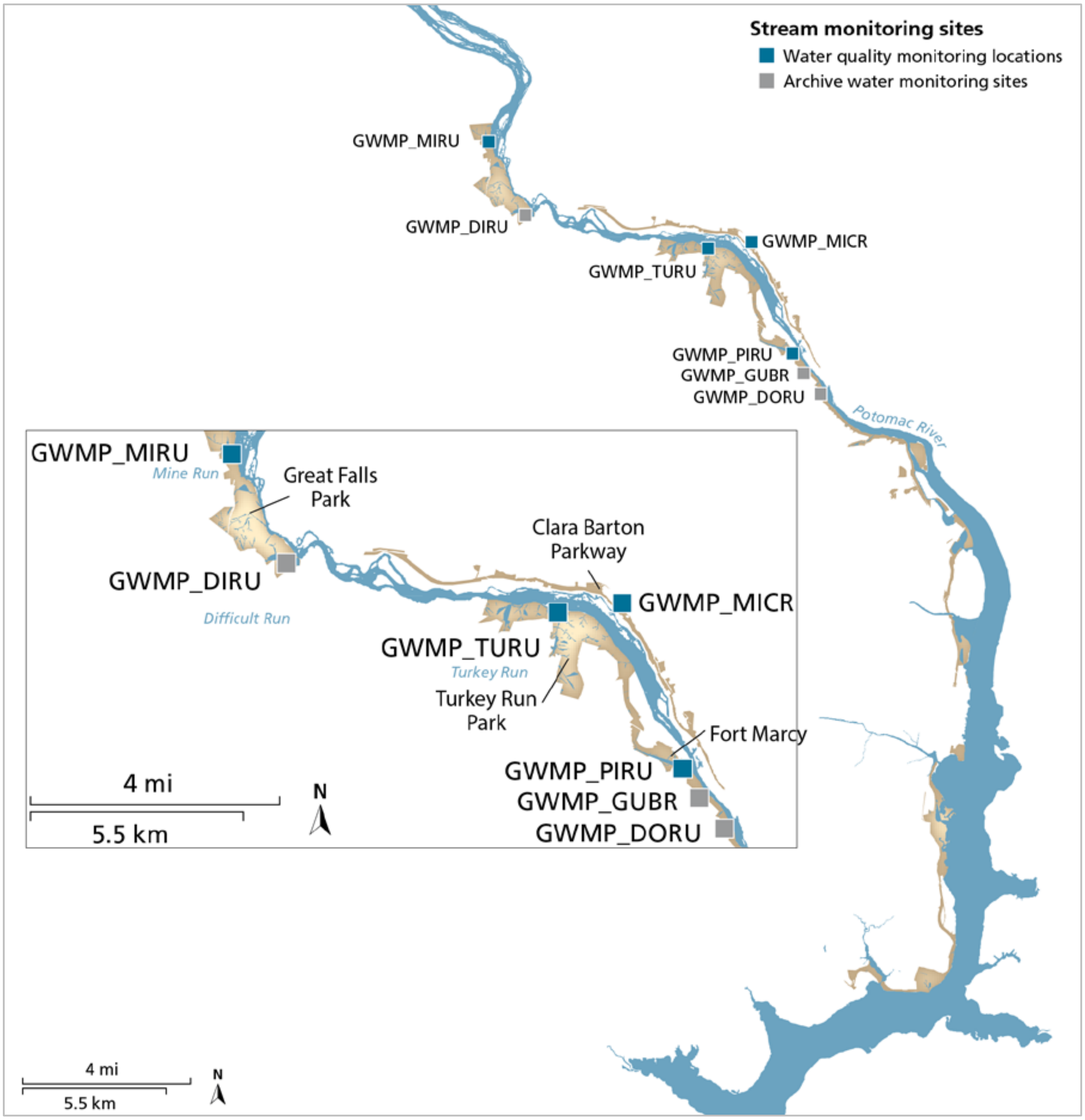

Figure 4-1 Stream sampling locations in GWMP used for long-term water quality monitoring (Norris *et al.* 2007). Sites in grey are archived NCRN I&M sample sites that were not included in the analysis.

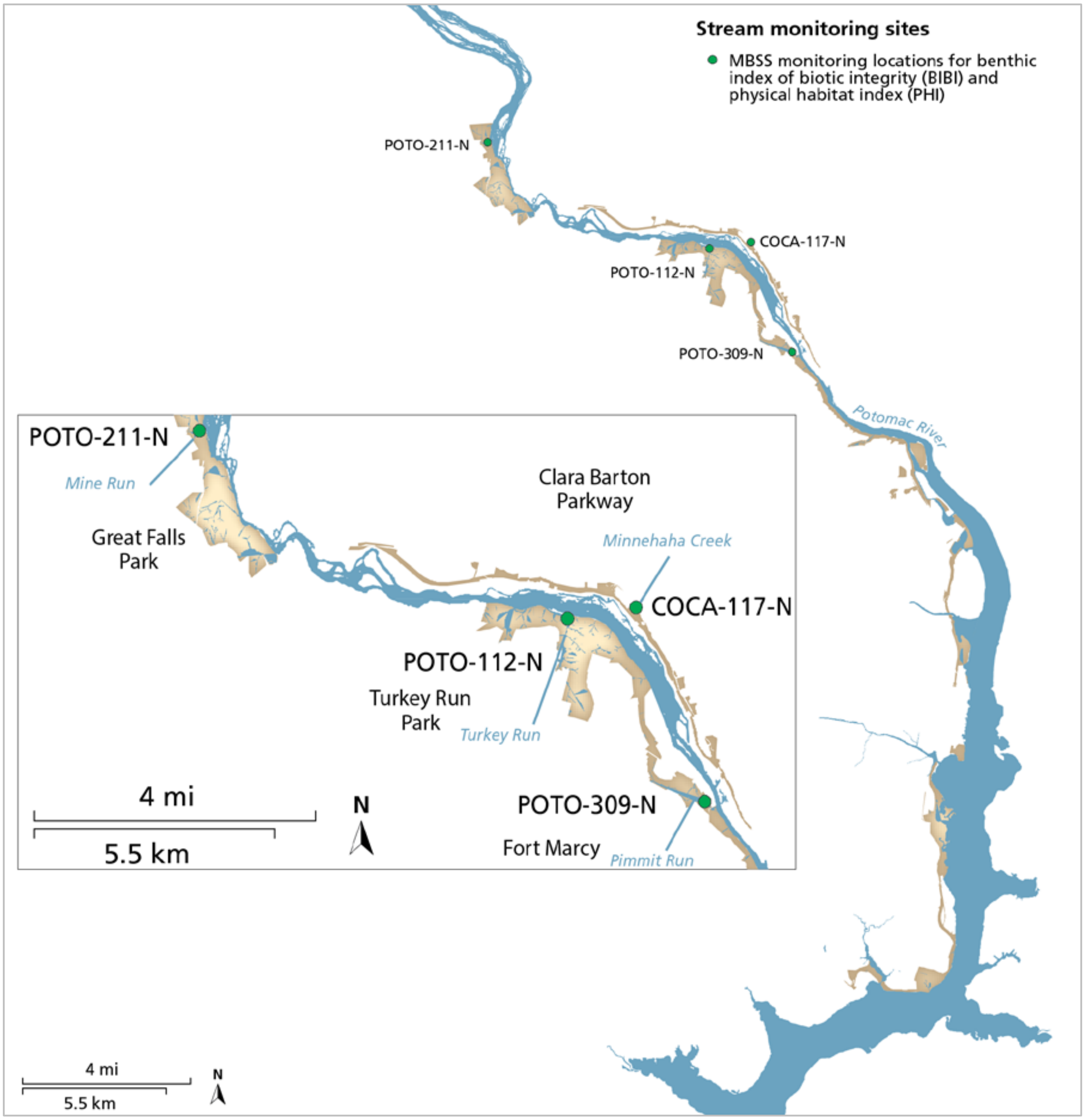

Figure 4-2 Stream sampling locations in GWMP used for MBSS benthic index of biotic integrity (BIBI) and physical habitat index (PHI) sampling.

Table 4-2 Resource indicators, data availability, reference conditions, and condition assessment categories used in the natural resource condition assessment of George Washington Memorial Parkway.

Water resource indicator	**Number of sites**	**Number of samples**	**Period**	**Reference condition/s**	**Percent attainment applied**
pH	4	327	2005-2013	6.0 ≤ pH ≤ 9.0 (VA); 6.5-8.5 (MD)	0-100% Scaled linearly
Dissolved oxygen (mg/L)	4	328	2005-2013	≥ 5.0	
Water temperature (°C)	4	330	2005-2013	≤ 32	
Acid neutralizing capacity (µeq/L)	4	332	2005-2013	≥ 200	
Specific conductance (µS/cm)	4	346	2005-2013	≤ 171	
Total Nitrate (mg/L)	4	321	2005-2013	≤ 2	
Total phosphorus (mg/L)	4	260	2005-2013	≤ 0.037	
Benthic Index of Biotic Integrity	4	7	2004-2012	1.0-1.9; 2.0-2.9; 3.0-3.9; 4.0-5.0	
Physical Habitat Index	4	7	2004-2012	0-50; 51-65; 66-80; 81-100	0-25% (scaled); 25-50% (scaled); 50-75% (scaled); 75-100% (scaled)

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

Water resource indicator	GWMP result	Percent attainment of reference condition	Condition assessment	Overall water quality condition
pH	7.7	96%	Very good	60.24% Good
Dissolved oxygen (mg/L)	8.9	95%	Very good	
Water temperature (°C)	14.4	100%	Very good	
Acid neutralizing capacity (µeq/L)	1152	100%	Very good	
Specific conductance (µS/cm)	338	25%	Degraded	
Total nitrate (mg/L)	1.9	57%	Moderate	
Total phosphorus (mg/L)	0.39	2%	Very degraded	
Benthic Index of Biotic Integrity	1.7	17%	Very degraded	
Physical Habitat Index	65.7	49.5%	Degraded	

Water pH

Description

The streams in and adjacent to GWMP are an important and unique habitat for plants, invertebrates, fish, and amphibians, as well as an important water source for mammals and birds. Freshwaters can vary widely in acidity and alkalinity due to natural causes as well as anthropogenic inputs (Pieper et al. 2012). Deposition of sulfate and nitrogen are a significant regional concern, and freshwater habitats may be impacted by acidification (Sadinski and Dunson 1992; NPS ARD 2010). 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). 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

The data analysed were collected monthly between 2005 and 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010; Pieper et al. 2012) (**Figure 4-1**). NCRN followed the sampling protocol specified in Norris et al. 2011.

Measurements were taken monthly as instantaneous records. Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results were used as the percent attainment.

Two reference conditions were used for this assessment. A reference condition pH range of 6.0 - 9.0 was used for stream locations in Virginia, which is the Virginia criteria for Class III warm waters—non-tidal coastal and piedmont zones (Virginia Water Control Board 2011). A reference condition pH range of 6.5-8.5 was used for site GWMP_MICR (Minnehaha Creek), located in Maryland, which is consistent with the state's criteria for this indicator (COMAR 2007a, 2007b, 2007c) (**Table 4-2**). All creeks sampled within GWMP are designated warm water streams.

Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (**Table 4-2**).

Condition and trend

Condition of pH in GWMP was very good, with a median pH of 7.7 and 96.3% of data points attaining the reference condition between 2005 and 2013 (**Table 4-3**, **Figure 4-3**, **Figure 4-4**). Over the data range available, no significant trend was present (p-value > 0.01) (**Figure 4-4**).

Sources of expertise

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

Figure 4-3 Attainment of pH reference condition by site from 2005 to 2013 for four stream sampling locations near GWMP. Site medians were used for this analysis.

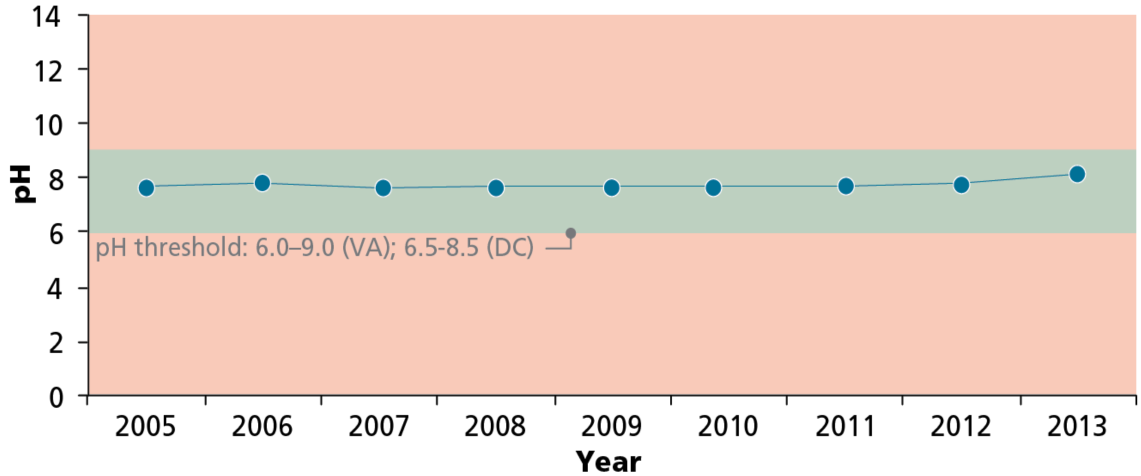

Figure 4-4 Annual median pH values for 2005 to 2013 for four stream sampling locations in GWMP.

Dissolved oxygen

Description

Dissolved oxygen (DO) concentration in water is often used as an indicator to gauge the overall health of the aquatic environment. It is needed to maintain suitable habitat for the survival and growth of fish and many other aquatic organisms. Low DO is of great concern due to detrimental effects on aquatic life. Conditions that generally contribute to low DO levels include warm temperatures, low flows, water stagnation and shallow gradients (streams), organic matter inputs, and high respiration rates. The potential loss of canopy and runoff from warm, impervious surfaces upstream can increase water temperature, decreasing available dissolved oxygen (NPS 2008). Decay of excessive organic debris in the water column from aquatic plants, municipal or industrial discharges, or storm runoff can also cause DO concentrations to be undersaturated or depleted. Insufficient DO can lead to unsuitable conditions for aquatic life and its absence can result in the unpleasant odors associated with anaerobic decomposition. Minimum required DO concentration to support fish varies because the oxygen requirements of fish vary with a number of factors, including the species and age of the fish, prior acclimatization, temperature, and concentration of other substances in the water.

Data and methods

Data was collected monthly between 2005 to 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010; Pieper et al. 2012) (**Table 4-2**). 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.

Figure 4-5 Attainment of dissolved oxygen reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

A reference condition of ≥ 5.0 mg/L was used for this assessment for all sampling locations, which is the Maryland state criteria (COMAR 2007a, 2007b, 2007c) and 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 and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (**Table 4-2**).

<u>Condition and trend</u>

Condition of dissolved oxygen in GWMP was very good, with a median DO of 8.9 mg/L and 95.1% of data points attaining reference condition of ≥ 5.0 mg/L (**Table 4-3**, **Figure 4-5**). Over the data range available, no significant trend was present (p-value > 0.01) (**Figure 4-6**).

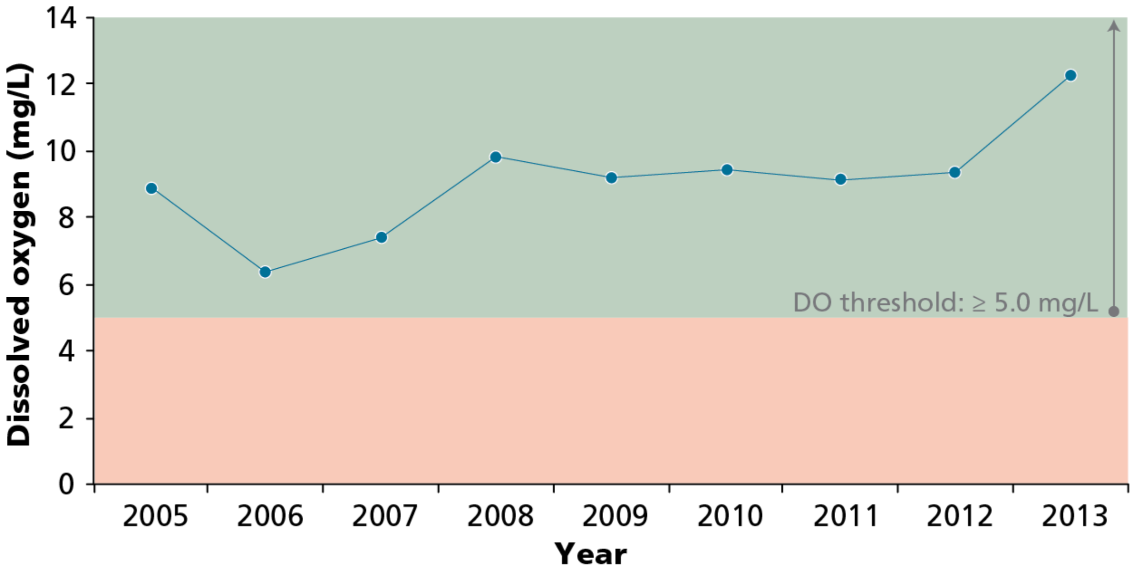

Figure 4-6 Annual median dissolved oxygen concentrations (mg/L) from 2005 to 2013 for four stream sampling locations in GWMP.

Sources of expertise

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

Water temperature

Description

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

Data and methods

Data was collected monthly between 2005 to 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010; Pieper et al. 2012) (**Figure 4-1**). NCRN followed the sampling protocol specified in Norris et al. 2011.

Measurements were taken monthly as instantaneous records. Each measurement was assessed against the reference condition and 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 State Water Control Board 2011) (**Table 4-2**).

Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (**Table 4-2**).

Condition and trend

Current condition on water temperature in GWMP was very good, with a median temperature of 14.4°C and 100% of data points attaining reference condition between 2005 and 2013 (**Table 4-3**, **Figure 4-7**, **Figure 4-8**). When the seasonal median water temperatures were calculated, temperatures were highest in the summer months (median of 21.15°C), and lower in the spring, fall and winter months (16.20°C, 11.45°C, and 5.20°C respectively).

Sources of expertise

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

Figure 4-7 Attainment of water temperature reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

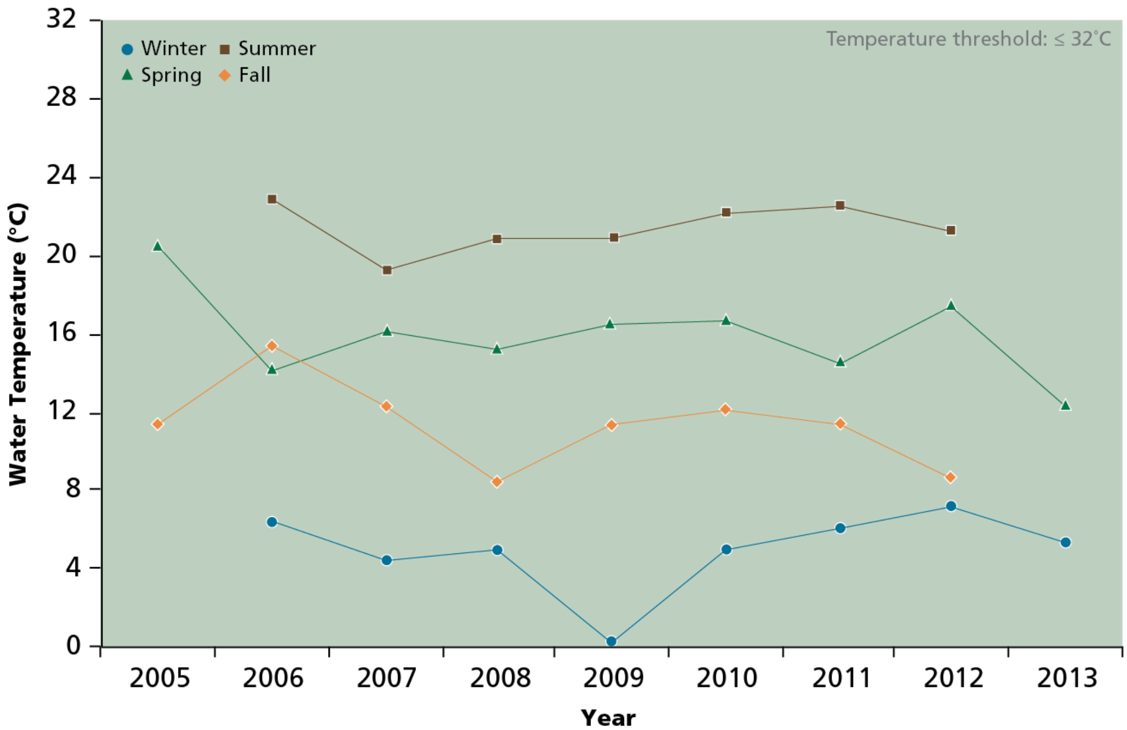

Figure 4-8 Seasonal median water temperature values (°C) from 2005 to 2013 for four stream sampling locations in GWMP.

Acid neutralizing capacity

Description

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

Data and methods

The data analysed were collected monthly at four sites between 2005 and 2013 by NCRN I&M staff (Norris and Pieper 2010; Pieper et al.2012) (**Table 4-2**). NCRN followed the sampling protocol specified in Norris et al. 2011.

The acid neutralizing capacity (ANC) threshold 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 threshold value linked to degraded streams was less than 200 µeq/L, which was used as the threshold in this assessment (Table 4-6) (Southerland et al. 2007, Norris and Sanders

2009) where 1 mg/L [1 ppm] $CaCO_3$ = 20 µeq/L. A less conservative threshold 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 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 fail result because the detection limit for ANC is higher than the reference condition.

Condition and trend

Current condition of ANC in GWMP was very good, with a mean ANC of 1152 µeq/L and 100% of data points attaining reference condition of ≥ 200 µeq/L between 2005 and 2013 (**Table 4-3**, **Figure 4-9**, **Figure 4-10**). There was an increasing trend in ANC values over the time period evaluated (**Figure 4-10**).

Figure 4-9 Attainment of acid neutralizing condition reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

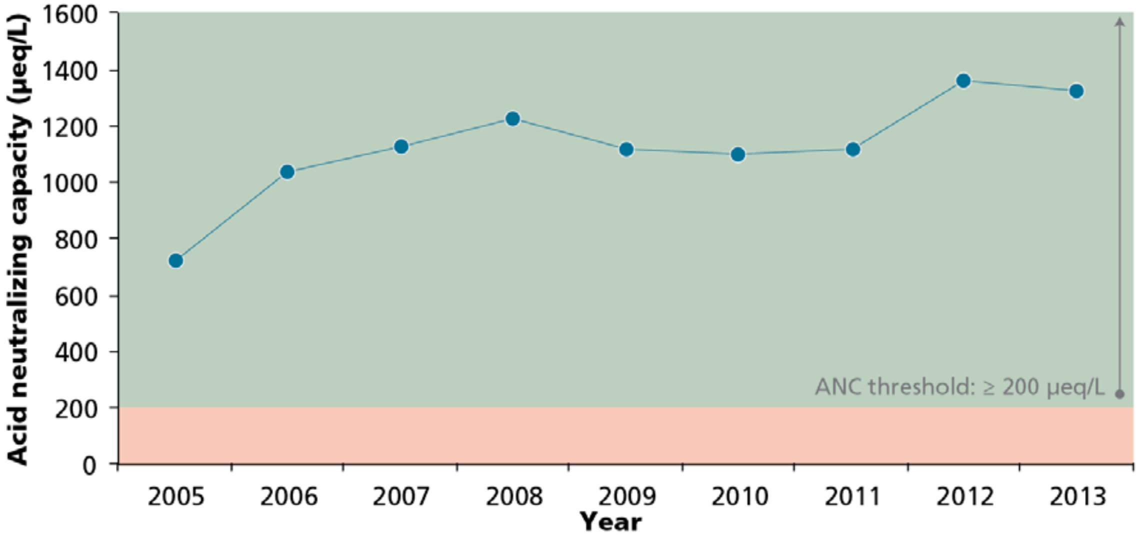

Figure 4-10 Annual median water ANC values from 2005 to 2013 for four stream sampling locations in GWMP.

Sources of expertise

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

Specific conductance

Description

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

Common sources of pollution that can affect specific conductance are deicing 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).

Data and methods

Data was collected monthly between 2005 and 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010, Pieper et al. 2012) (**Table 4-2**). NCRN followed the sampling protocol specified in Norris et al. 2011.

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

Condition and trends

Condition of specific conductance in GWMP between 2005 and 2013 was degraded, with a median conductance of 338 µS/cm and 24.4% of data points attaining the reference condition of ≤ 171 µS/cm (**Table 4-3**, **Figure 4-11**). Over the data range available, no significant trend was present (*p*-value > 0.01) (**Figure 4-12**).

Sources of expertise

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

Figure 4-11 Attainment of specific conductance reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

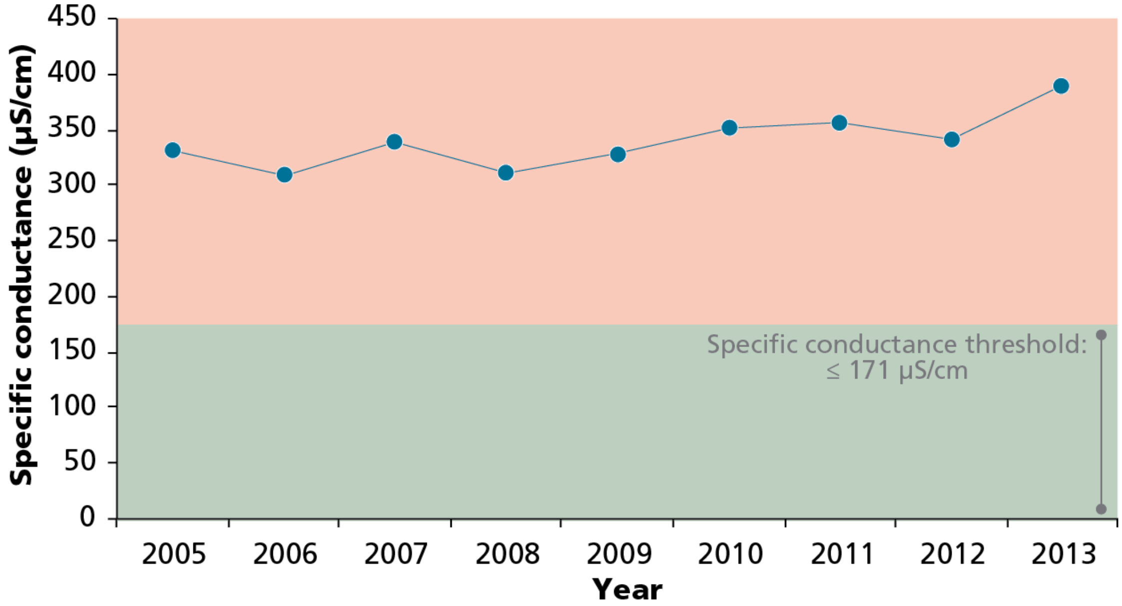

Figure 4-12 Annual median specific conductance values (µS/cm) from 2005 to 2013 for four stream sampling locations in GWMP.

Total nitrate

Description

Nitrate (NO_3) is an oxidized form of nitrogen, and is an important nutrient in healthy environments. Aquatic plants can absorb and incorporate nitrate into proteins, amino acids, nucleic acids, and other essential molecules. The presence of nitrates can occur naturally in streams from eroding rocks, soils, and animal and plant wastes (NPS 2008). 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 NO_3 can enhance the growth of algae and aquatic plants in a manner similar to enrichment in phosphorus and thus cause eutrophication of a water body. In most natural waters, inorganic nitrogen as ammonium or NO_3 is not the growth-limiting nutrient unless phosphorus is unusually high. Nitrate is typically indicative of agricultural pollution. Nitrate in surface water from inorganic sources may occur in dissolved or particulate form. 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 and 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010; Pieper et al. 2012) (**Table 4-2**). 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 nitrate concentration threshold was developed by the Maryland Biological Stream Survey (MBSS) program after their first round of sampling as described for the ANC threshold. The MBSS determined that a nitrate concentration of 2.0 mg /L (2 ppm) and above 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 4-2**).

Condition and trend

Condition of nitrate in GWMP was moderate, with a mean nitrate concentration of 1.9 mg/L and 57.6% of data points attaining reference condition of < 2.0 mg/L between 2005 and 2013 (**Table 4-3**, **Figure 4-13**). Over the data range available, no significant trend was present (p-value > 0.01) (**Figure 4-14**). Within GWMP, median nitrate concentrations (2005-2013) are highest in Minnehaha Creek (MICR), in the Clara Barton Parkway section of the park on the Maryland side of the Potomac River.

Sources of expertise

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

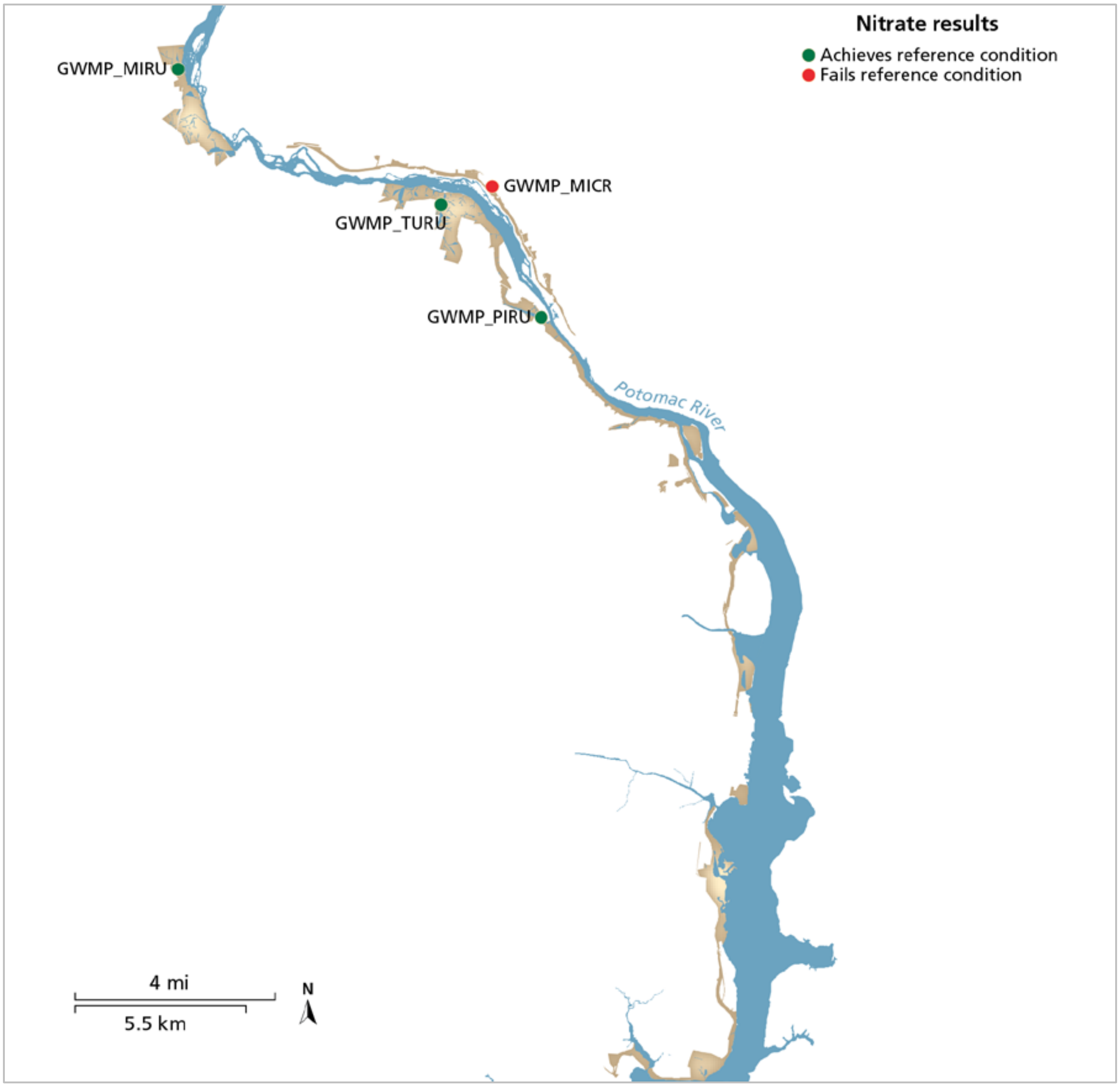

Figure 4-13 Attainment of nitrate reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

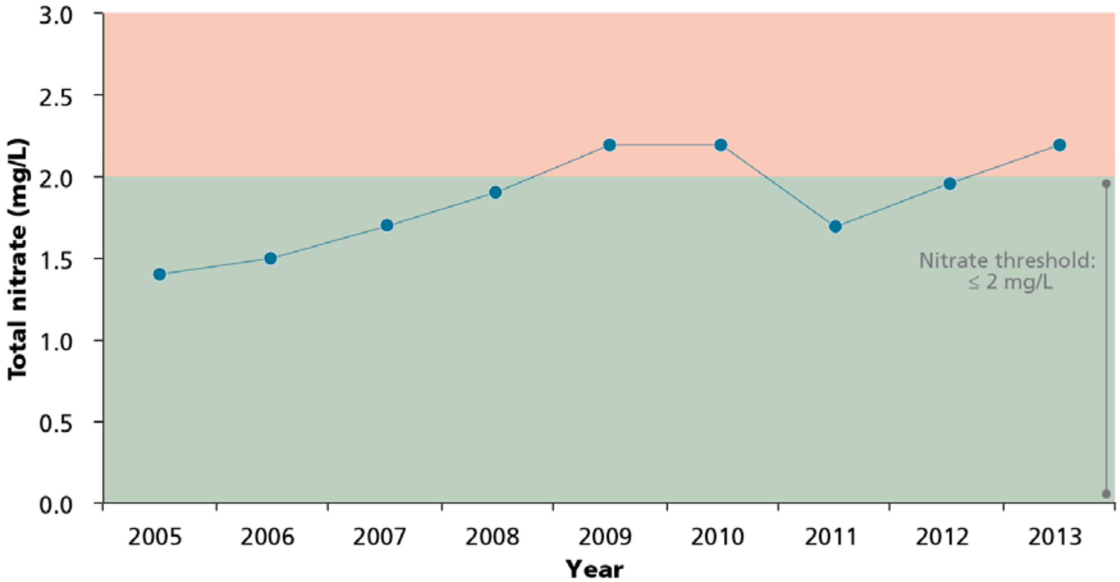

Figure 4-14 Annual median nitrate concentrations (mg/L) from 2005 to 2013 for four stream sampling locations in GWMP.

Total Phosphorus

<u>Description</u>

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

<u>Data and methods</u>

Data was collected monthly between 2005 and 2013 at four sites by NCRN I&M staff (Norris and Pieper 2010; Pieper et al. 2012) (**Table 4-2**). 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 threshold 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 phosphate is lower than the assessment threshold (J. Pieper, *pers. comm.)*

The phosphate threshold 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. George Washington Memorial Parkway is located in Ecoregion IX or the Southeastern Temperate Forested Plains and Hills (Pieper et al. 2012). The ecoregional reference condition value for total phosphorus is 0.037 mg/L (37 ppb) (U.S. EPA 2000) (**Table 4-2**). Each data point was compared against the reference condition to determine the percent attainment and condition.

<u>Condition and trend</u>

Current condition of total phosphorus at GWMP was very degraded, with a median total phosphate concentration of 0.38 mg/L and only 1.54% of data points attaining reference condition of 0.01 mg/L between 2005 and 2013 (**Table 4-3**, **Figure 4-15**). Over the data range available, no significant trend was present (*p*-value > 0.01) (**Figure 4-16**).

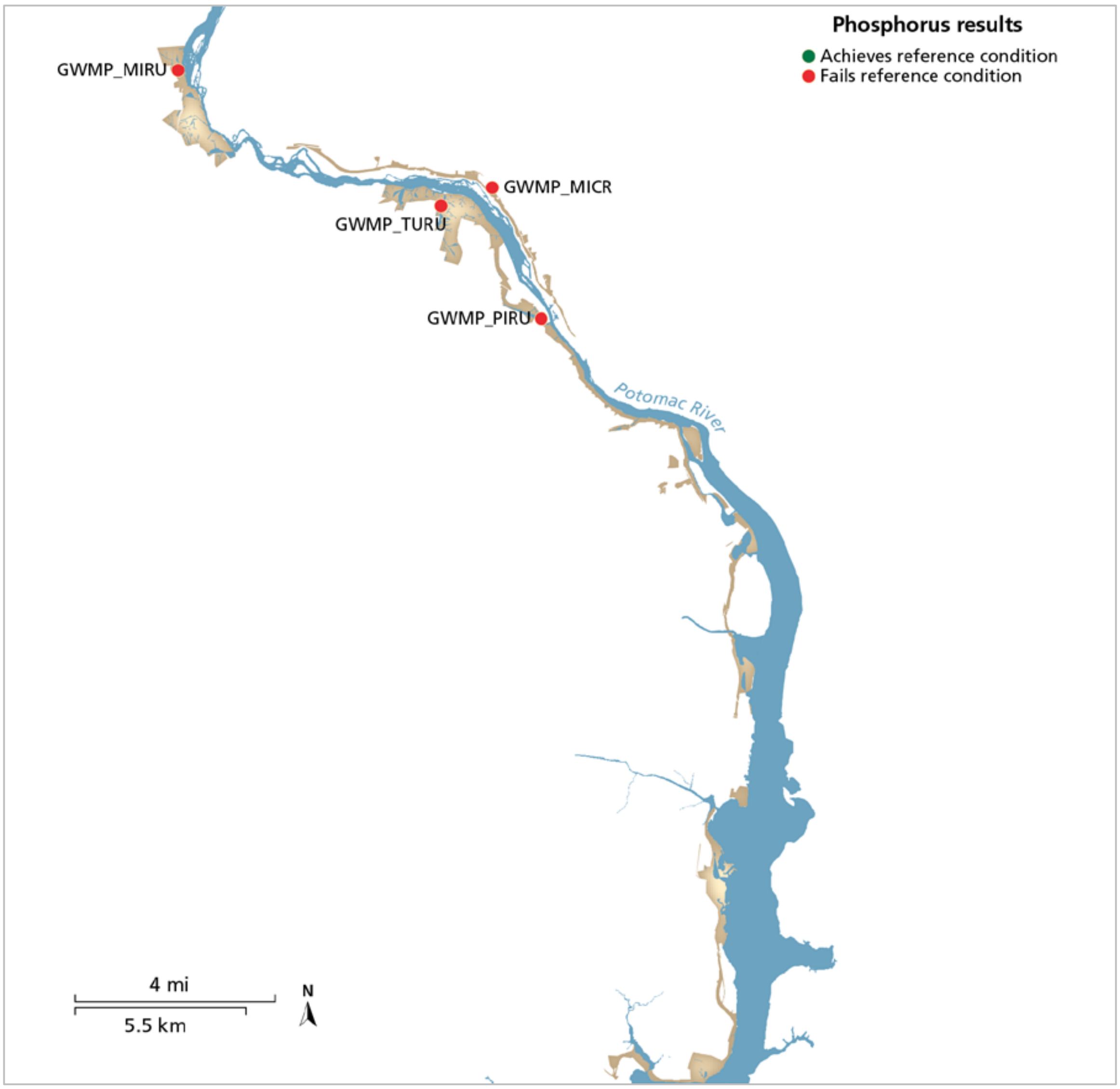

Figure 4-15 Attainment of phosphorus reference condition by site from 2005 to 2013 for four stream sampling locations in GWMP. Site medians were used for this analysis.

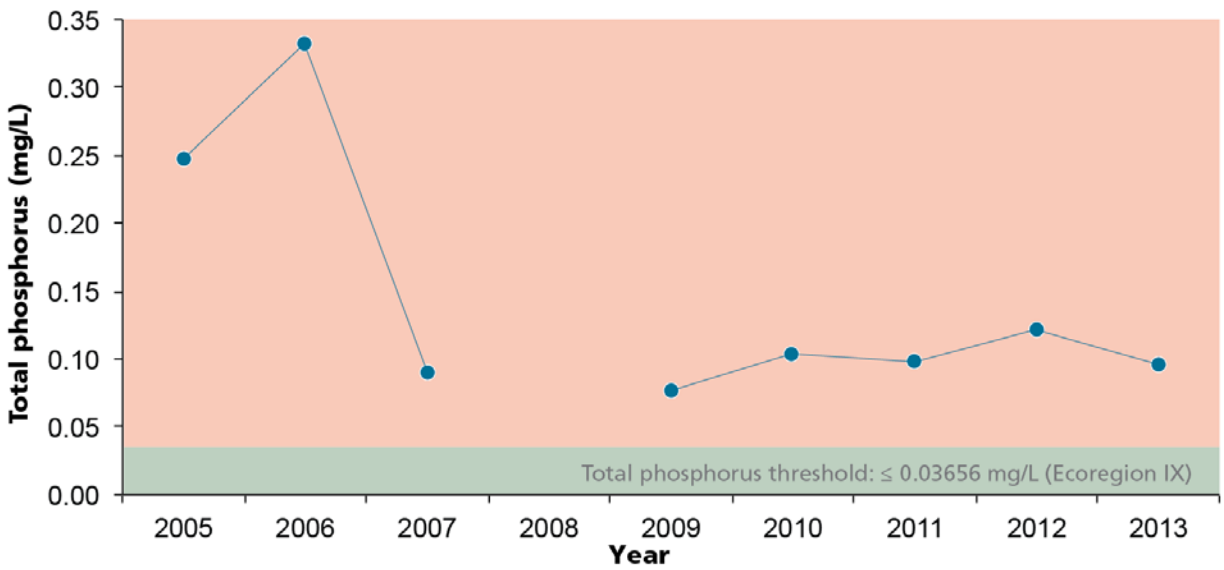

Figure 4-16 Annual median total phosphorus concentrations (mg/L) from 2005 to 2013 for four stream sampling locations in GWMP. Data was unavailable for 2008.

<u>Sources of expertise</u>

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

Benthic index of biotic integrity

Description

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

Data and Methods

Data were collected at four sites between 2004 and 2012 by NCRN I&M staff (**Table 4-2**; 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 (**Table 4-2**, **Table 4-4**). 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 4-4 Benthic Index of Biological Integrity (BIBI) categories, percent attainment, and condition assessment.

BIBI range	Percent attainment	Condition
4.0-5.0	100%	Good
3.0-3.9	Scaled linearly	Fair
2.0-2.9	Scaled linearly	Poor
1.0-1.9	0%	Very poor

Condition and trend

Current condition of benthic macroinvertebrates in GWMP was very degraded, with a median BIBI of 1.67 and 16.7% attainment of reference condition (**Table 4-3**, **Table 4-5**, **Figure 4-17**). Mine Run in Great Falls Park had the highest BIBI result (2012) with an index of 3.33 (**Figure 4-18**). With the exception of Mine Run, stream sampling points within GWMP are at the end of very long stretches of stream with high development. Upstream of Mine Run is mainly protected park lands, therefore Mine Run scores higher than the other sampling sites for BIBI.

No trend analysis was possible with the current data set.

Table 4-5 Benthic Index of Biotic Integrity (BIBI) in GWMP.

Year	Site ID	NRCN Site	Location	BIBI
2012	POTO-112-N-2012	GWMP_TURU	Turkey Run	1.67
2012	POTO-211-N-2012	GWMP_MIRU	Mine Run	3.33
2012	POTO-309-N-2012	GWMP_PIRU	Pimmit Run	2.33
2009	COCA-117-N-2009	GWMP_MICR	Minnehaha Creek	*
2006	POTO-309-N-2006	GWMP_PIRU	Pimmit Run	1.33
2004	POTO-211-N-2004	GWMP_MIRU	Mine Run	1.33
2004	POTO-112-N-2004	GWMP_TURU	Turkey Run	1.67

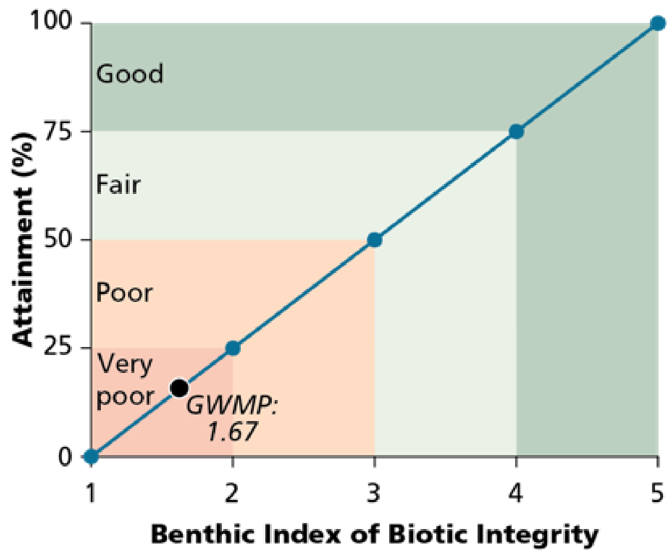

Figure 4-17 Application of percent attainment categories to the Benthic Index of Biotic Integrity (BIBI) categories. BIBI at GWMP was very degraded, with a mean of 1.67, which equated to 16.7% of the reference condition.

Sources of expertise

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

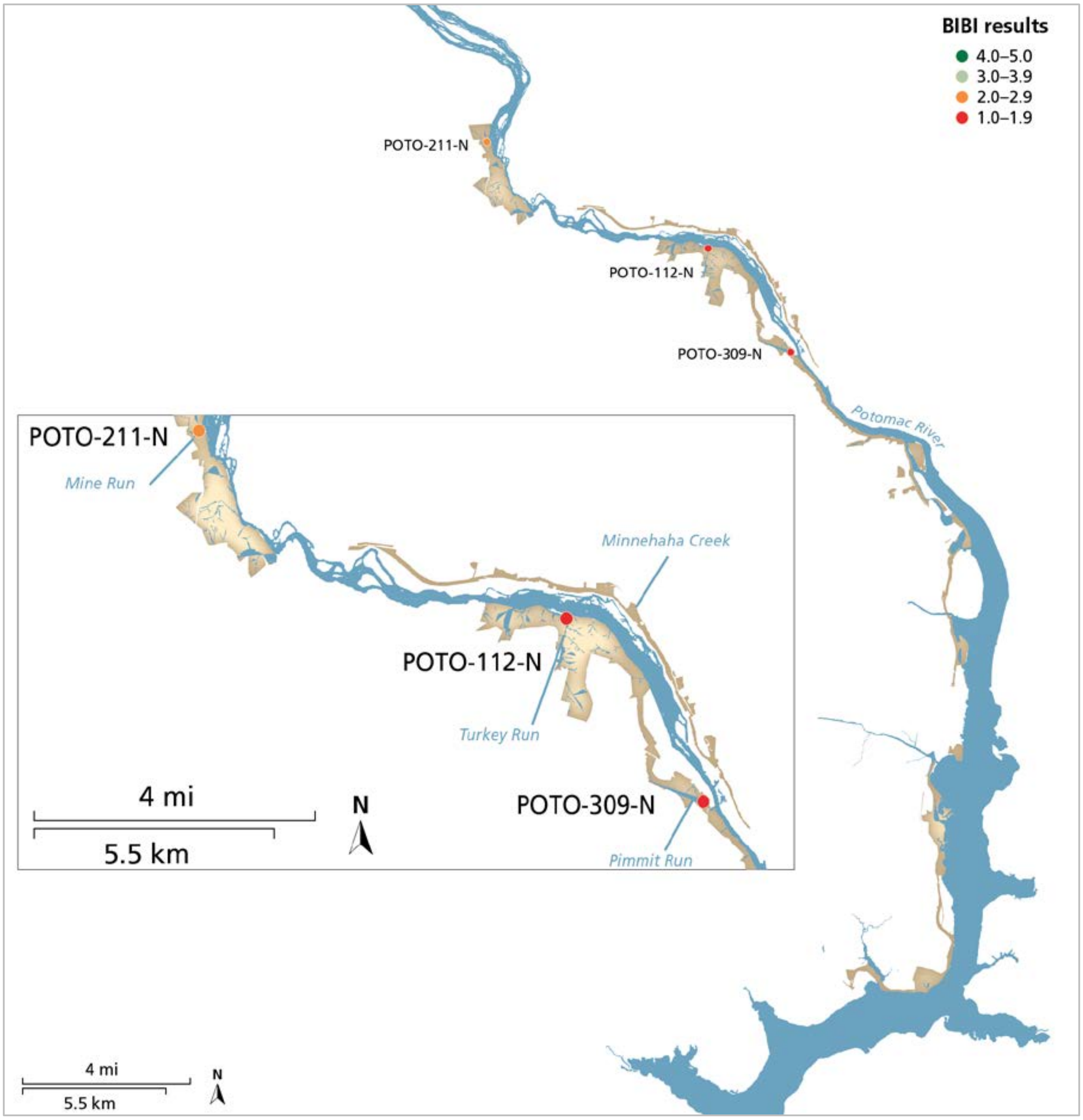

Figure 4-18 Attainment of Benthic Index of Biotic Integrity (BIBI) reference condition by site for three stream sampling locations in GWMP.

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 aquatic communities of fish and macroinvertebrates must live (Paul et al. 2012; Nortrup 2013).

Data and methods

Data for the Physical Habitat Index (PHI) were collected at 4 sites between 2004 and 2012. NCRN followed the National Capital Region Biological Stream Survey protocol (**Table 4-2**) (Norris and Sanders 2009). To calculate a stream's Physical Habitat Index (PHI) score, streams are sorted by physiographic province and then compared against high quality reference streams in the same physiographic class. All of the streams monitored in GWMP fall into the Eastern Piedmont stream class. As a result, the following eight characteristics are evaluated: riffle quality, stream bank stability, woody debris, in-stream habitat available for fish, epifaunal substrate, shading, remoteness, and embededness of substrates (Nortrup 2013).

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 threshold was developed by the Maryland Biological Stream Survey (MBSS) program after initial sampling as described for the ANC threshold (see Section 0). 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 (**Table 4-2**).

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

Condition and Trend

Current condition of PHI in GWMP was partially degraded, with a median PHI of 65.7, which equated to a 49.5% attainment of the reference condition (Table 4-3, Table 4-6, Figure 4-19, Figure 4-20). No trend analysis was possible with the current data set.

Table 4-6 Stream physical Habitat Index (PHI) in GWMP.

Year	Site ID	NRCN Site	Location	PHI
2012	POTO-112-N-2012	GWMP_TURU	Turkey Run	65.70
2012	POTO-211-N-2012	GWMP_MIRU	Mine Run	67.83
2012	POTO-309-N-2012	GWMP_PIRU	Pimmit Run	62.47
2009	COCA-117-N-2009	GWMP_MICR	Minnehaha Creek	72.98
2006	POTO-309-N-2006	GWMP_PIRU	Pimmit Run	59.86
2004	POTO-211-N-2004	GWMP_MIRU	Mine Run	65.91
2004	POTO-112-N-2004	GWMP_TURU	Turkey Run	64.64

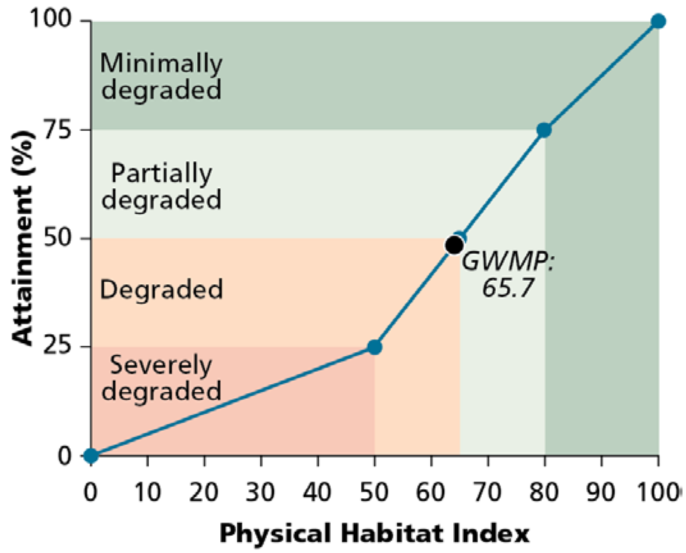

Figure 4-19 Application of the percent attainment categories to the Physical Habitat Index (PHI) value categories. PHI at GWMP was 65.7 which equated to 49.5% attainment of the reference condition.

<u>Sources of expertise</u>

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

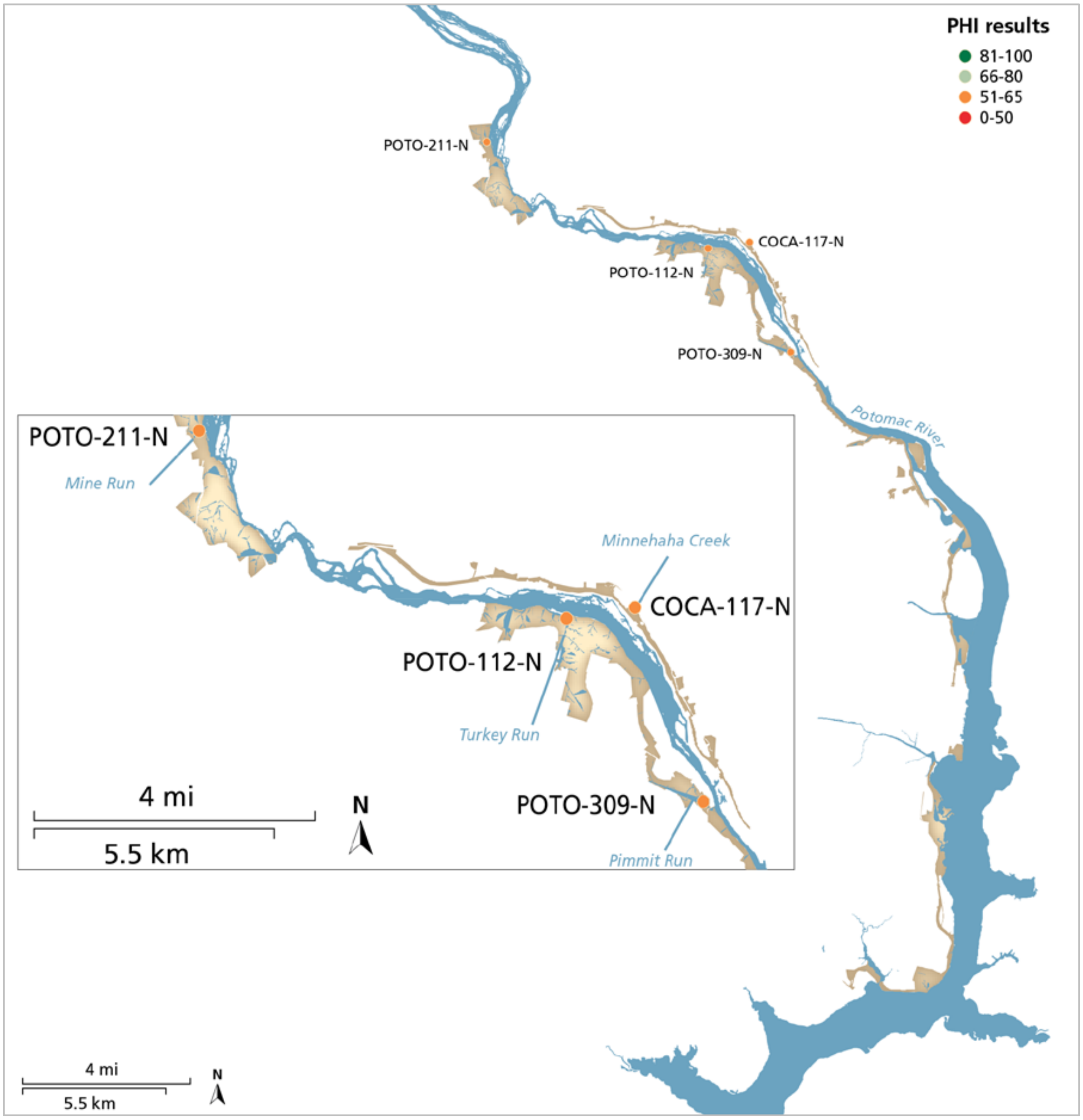

Figure 4-20 Attainment of Physical Habitat Index (PHI) reference condition by site for four stream sampling locations in GWMP.

Biological integrity

Biological integrity summary

Seven indicators were used to assess biological integrity in George Washington Memorial Parkway—cover of exotic herbaceous species, area of exotic trees and saplings, presence of forest pest species, stocking index, stream fish index of biotic integrity (FIBI), bird community index (BCI), and deer density. An eighth metric, biodiversity, was included for informational purposes but was excluded from the overall assessment. All data were collected by NCRN I&M staff and collaborators except for deer data, which was gathered by the NCR Regional Wildlife Biologist. Forest monitoring sites and deer counting routes are shown in **Figure 4-21**, FIBI monitoring sites are shown in **Figure 4-22** and bird community index sites are shown **Figure 4-23**.

Table 4-7 Ecological monitoring framework data for Biological Integrity provided by agencies and specific sources included in the assessment of GWMP.

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

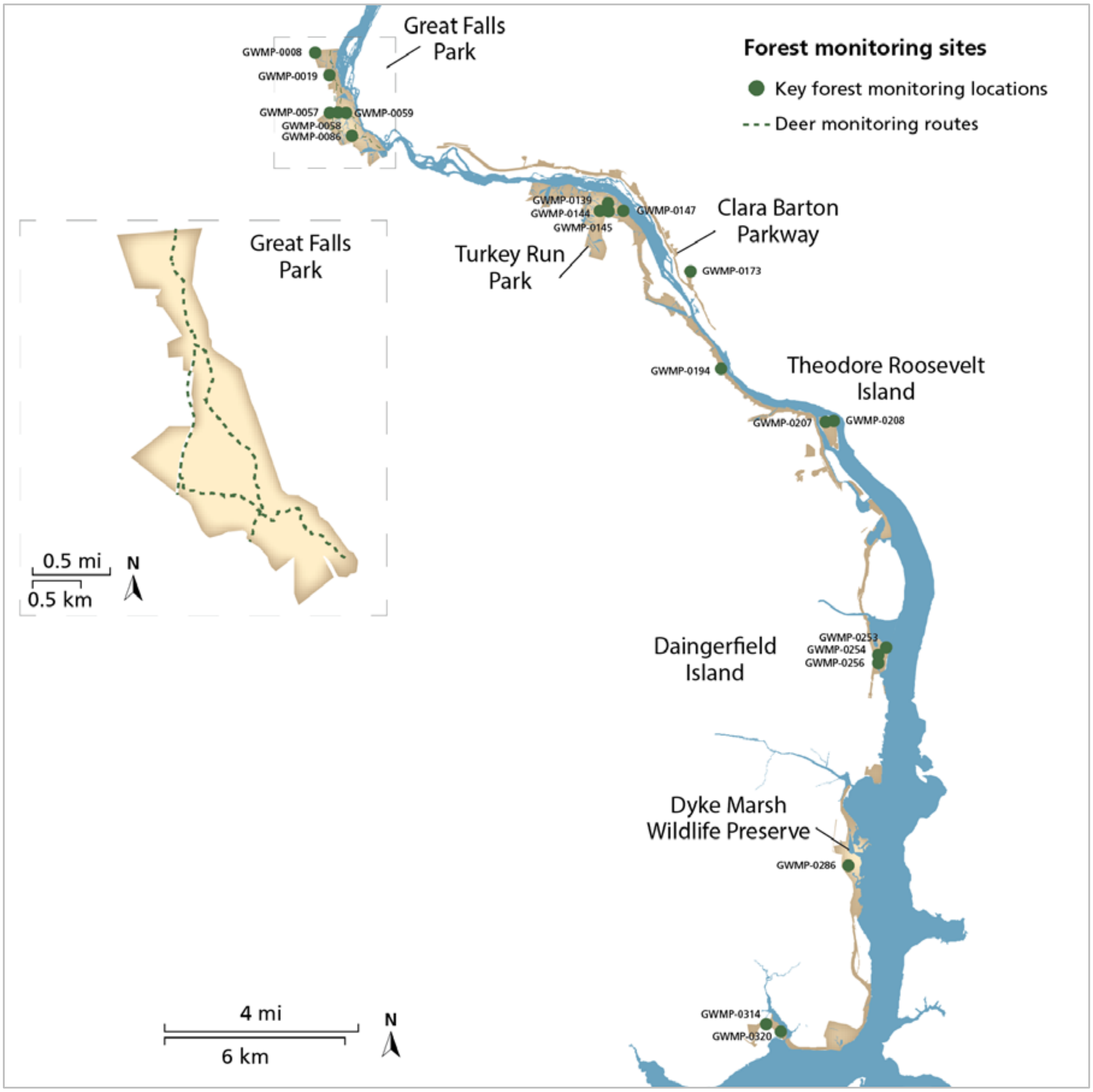

Figure 4-21 Forest monitoring sites and deer counting routes in GWMP.

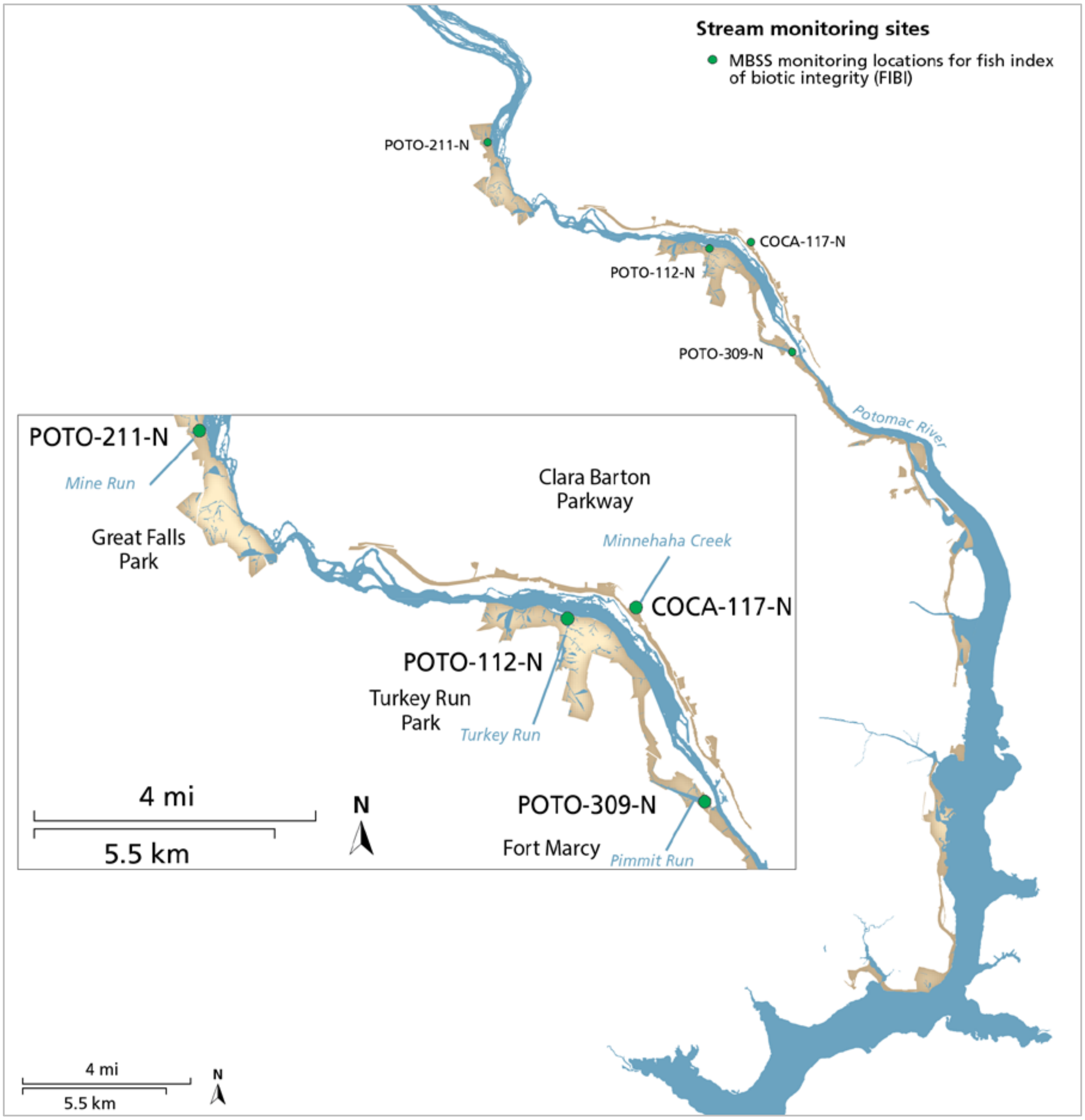

Figure 4-22 Fish index of biotic integrity (FIBI) monitoring sites in GWMP.

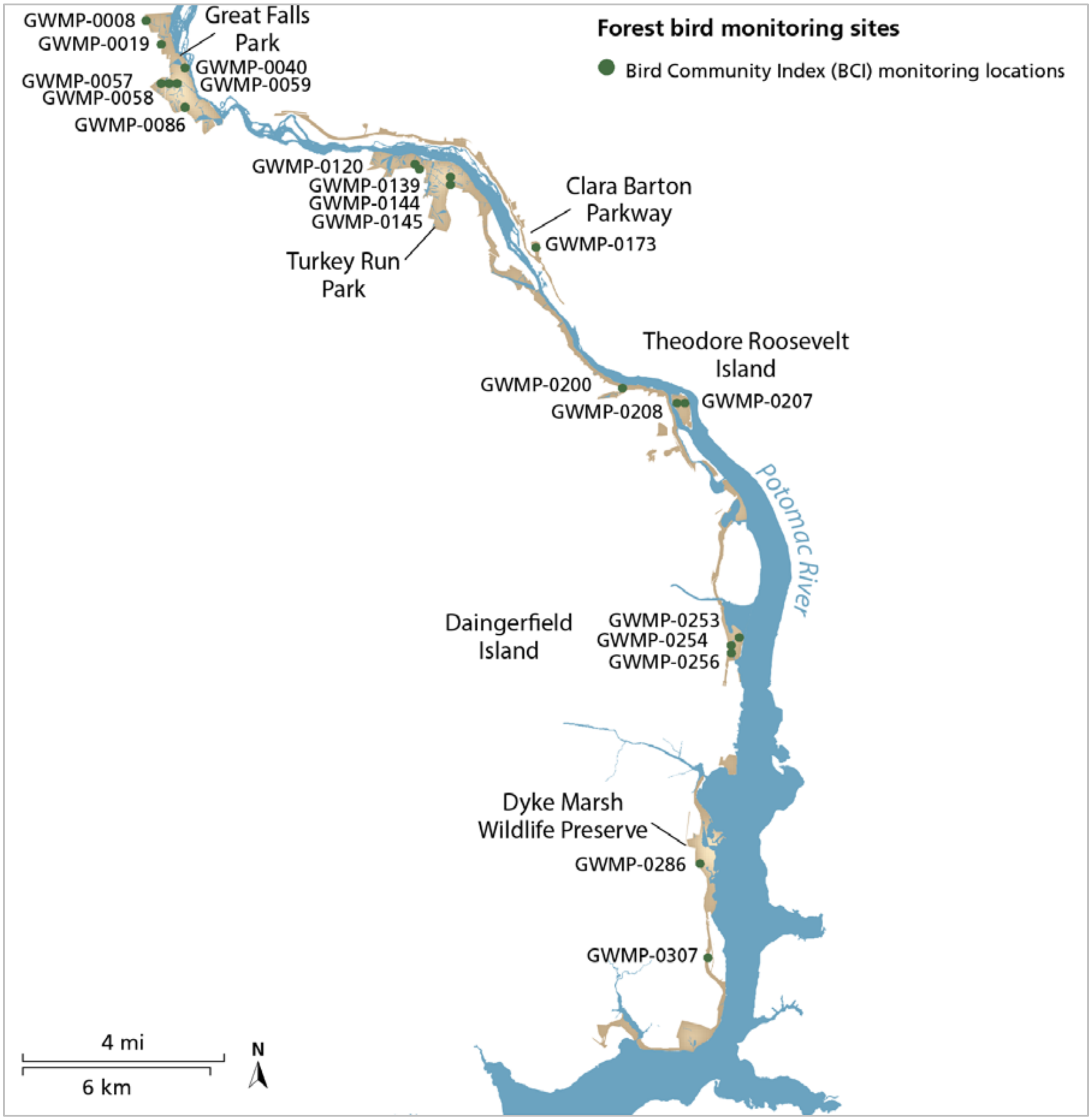

Figure 4-23 Bird monitoring sites used for BCI scoring in GWMP.

Reference conditions were established for each of the seven indicators (**Table 4-8**) and the data were compared to these reference conditions to obtain the percent attainment. Single reference conditions were used for exotic plants, forest pests, and native tree seedling regeneration, while multiple reference conditions were used for FIBI and BCI scores.

George Washington Memorial Parkway had variable results from I&M monitoring data for biological integrity. The park scored as very good condition for presence of forest pest species within the NPS Inventory & Monitoring plots (100% attainment) and basal area of exotic trees and saplings (92.5% attainment); degraded condition for stocking index (30% attainment), FIBI (16.5% attainment), and BCI (38.4% attainment); and very degraded for cover of exotic herbaceous species and deer density (20%, 0% attainment respectively) (**Table 4-9**).

Table 4-8 Biological integrity indicators, data availability, reference conditions, and condition assessment categories used in the natural resource condition assessment of George Washington Memorial Parkway.

Biological integrity indicator	Number of sites	Number of samples	Period of observation	Reference condition	Percent attainment applied
Cover of exotic herbaceous species	20	20	2010-2013	0% (absence)	0-100% scaled linearly
Area of exotic trees & saplings	20	40	2010-2013	< 5%	0-100% scaled linearly
Presence of forest pest species	20	20	2010-2013	< 1%	0-100% scaled linearly
Stocking index	20	20	2010-2013	> 115	0-100% scaled linearly
Fish index of biotic integrity	4	7	2004-2012	1.0-1.9; 2.0-2.9; 3.0-3.9; 4.0-5.0	0-100% scaled linearly
Bird community index	20	138	2007-2013	< 40; 40.1-52; 52.1-60; >60	0-25% (scaled); 25-50% (scaled); 50-75% (scaled); 75-100% (scaled)
Deer density	Park	14	2001-2012	< 8 /km^2	0-100% scaled linearly
Biodiversity	Park	32	2004-2014	N/A	N/A

Table 4-9 Summary of resource condition assessment of Biological Integrity in GWMP.

Biological integrity indicator	GWMP Result	Percent attainment of reference condition	Condition assessment	Overall biological integrity condition
Presence of exotic herbaceous species (% of plots with exotic species)	20.1%	20%	Very degraded	42.5% Moderate
Area of exotic trees & saplings (% of basal area)	4.1%	92.5%	Very good	
Presence of forest pest species (% trees infested)	0%	100%	Very good	
Stocking index	11	30%	Degraded	
Fish index of biotic integrity	1.7	17%	Poor	
Bird community index	46.5	38%	Low integrity	
Deer density	34.0 /km^2	0%	Very degraded	

Exotic herbaceous species

Description

Invasive exotic plants are species that aggressively compete with and displace native plant communities. The result can be loss and destruction of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, reduced groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Although certain plant species were 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).

Data and methods

Forest monitoring took place at 20 sites in GWMP from 2010-2013, but not all plots were measured every year (Schmit et al. 2009) (**Figure 4-21**). 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 threshold and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The Organic Act that established the National Park Service in 1916 and the U.S. Department of Interior NPS Management Policies (U.S. Department of the Interior 2006) mandate the conservation of natural resources (see Section 0). Because of the threat to the park posed by exotic herbaceous plants, the threshold used for this assessment was that exotic herbaceous plants should be completely absent (**Table 4-8**). 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 cover of exotic herbaceous species in GWMP was very degraded, with 20.1% cover and 20% of data points attaining reference condition (**Table 4-9**, **Table 4-10**, **Figure 4-24**). No trend analysis was possible with the current data set.

Table 4-10 Presence of exotic herbaceous plants. Site locations are shown in **Figure 4-21**.

Site	Year	Exotic plants
GWMP-0144	2013	Present*
GWMP-0147	2013	Present*
GWMP-0194	2013	Present*
GWMP-0139	2012	Present*
GWMP-0145	2012	Present*
GWMP-0173	2012	Present*
GWMP-0286	2012	Present*
GWMP-0320	2012	Present*
GWMP-0008	2011	Present*
GWMP-0019	2011	Absent
GWMP-0057	2011	Present*
GWMP-0058	2011	Absent
GWMP-0059	2011	Present*
GWMP-0253	2011	Present*
GWMP-0254	2011	Present*
GWMP-0256	2011	Present*
GWMP-0086	2010	Absent
GWMP-0207	2010	Present*
GWMP-0208	2010	Present*
GWMP-0314	2010	Absent

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

Sources of expertise

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

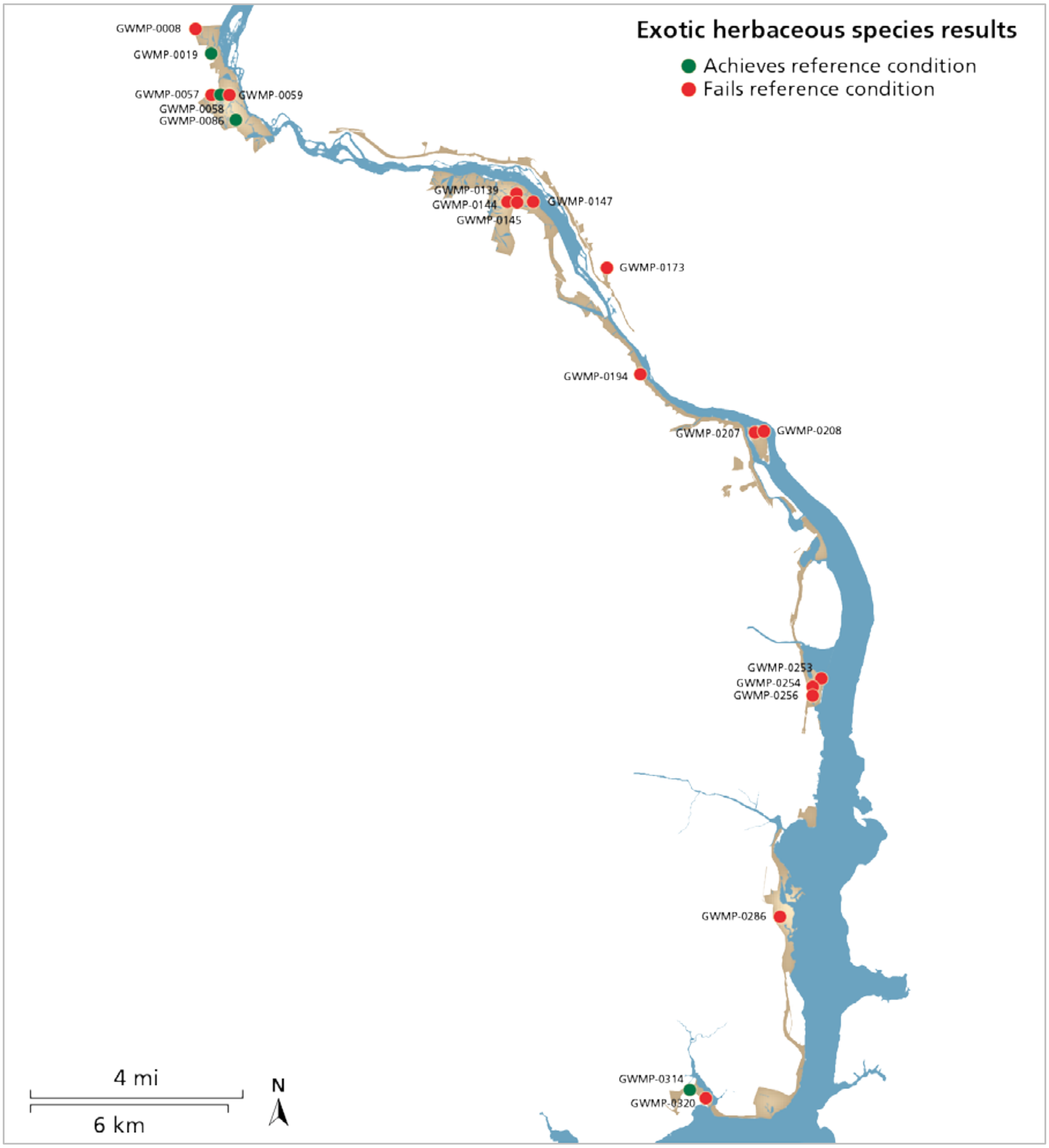

Figure 4-24 Exotic herbaceous species results by site for GWMP.

Exotic trees & saplings

Description

Invasive exotic plants are non-native species that can reduce abundance and diversity of native plant communities (Vila et al. 2011). The result can be loss and destruction of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, reduced groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Exotic plant species, especially those that are invasive, are a ubiquitous and growing threat in the National Capital Region (NCRN 2008, 2010). Exotic tree species present within GWMP include sweet cherry (*Prunus avium*), tree of heaven (*Ailanthus altissima*), princess tree (*Paulownia tomentosa*) , higan cherry (*Prunus subhirtella*), Callery pear (*Pyrus calleryana*), white mulberry (*Morus alba*), paper mulberry (*Broussonetia papyrifera*), osage orange (*Maclura pomifera*), white poplar (*Populus alba*), white willow (*Salix alba*), crack willow (*Salix fragilis*), pagoda tree (*Styphnolobium japonicum*), and various species of crabapple (*Malus sp.)*

Data and methods

Forest monitoring took place annually but not all plots were measured every year, and data was recorded for 2010-2013 (Schmit et al. 2009) (**Table 4-7**). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

The basal area of exotic trees and saplings in a plot was calculated as a percentage of total tree basal area. Results from each plot were assessed against the threshold and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The threshold used for this assessment was that the abundance of these invasive exotic plants should not exceed 5% of total basal area. Because 100% eradication is not a realistic goal, the threshold 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. This threshold 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 (**Table 4-8**). To determine the overall condition assessment for exotic trees and saplings in GWMP, and mean of all values was compared against the reference condition. One sampling quadrant in GWMP had exotic trees present, and when using the median, this value was not represented.

Condition and trend

Condition for basal cover of exotic trees and saplings in GWMP was very good, with a mean of 4.1 percent cover and 92.5% of data points attaining the reference condition of ≤ 5% of total basal area (**Table 4-9**, **Table 4-11**, **Figure 4-25**).

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 4-11 Percent basal area of exotic trees and saplings. Site locations are shown in **Figure 4-25**.

Site	Year	Exotic Trees	Exotic Saplings
GWMP-0144	2013	0	0
GWMP-0147	2013	0	0
GWMP-0194	2013	0	0
GWMP-0139	2012	0	0
GWMP-0145	2012	0	0
GWMP-0173	2012	0	0
GWMP-0286	2012	0	0
GWMP-0320	2012	0	0
GWMP-0008	2011	0	0
GWMP-0019	2011	0	0
GWMP-0057	2011	0	0
GWMP-0058	2011	0	0
GWMP-0059	2011	0	0
GWMP-0253	2011	1.2	0
GWMP-0254	2011	42.1*	0
GWMP-0256	2011	29.2*	0
GWMP-0086	2010	0	0
GWMP-0207	2010	5	85.5*
GWMP-0208	2010	0	0
GWMP-0314	2010	0	0

*Values outside the reference condition of ≤ 5% cover.

Figure 4-25 Exotic tree and sapling results by site for GWMP.

Forest pests

<u>Description</u>

Emerald ash borer (*Agrilus planipennis*) is a growing threat within GWMP. Ash trees are present in all parks of the NCRN. White ash (*Fraxinus americana*) is the most common, and the tenth most common tree of any species in NCRN forests. Other ash species in the NCRN are green ash (*F. pennsylvanica*), black ash (*F. nigra*), and pumpkin ash (*F. profunda*). All are susceptible to emerald ash borer (NCRN quarterly fall 2012). The insect feeds on and kills ash trees, an important neighborhood and landscaping tree, one to three years after infestation. Emerald ash borer adults can fly at least ½ mile from the tree where they emerge, but humans can spread EAB much faster by moving infected wood and tree material. Preliminary results (Knight and Long et al.) found that once infested, healthy ash stands can reach nearly 100% mortality of ash trees > 1 inch in diameter within six years. Initially the decline is slow and symptoms of EAB are not obvious, but later in the infestation mortality rates accelerate rapidly (NCRN quarterly fall 2012). The emerald ash borer was first detected in North America in Michigan in 2002 and was found in Maryland in August 2003 after arriving on infested nursery trees sent to Prince George's County (Maryland DNR).

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

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.

<u>Data and methods</u>

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) (**Table 4-7**). 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 threshold and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

Due to the destructive nature and potential for forest damage from these pests, the threshold used was established as any observation of these pests (i.e., > 1% of trees infested) being considered degraded (**Table 4-8**). 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 insect pests was very good, with 0% of trees infested and 100% of data points attaining reference condition of having no forest pest species present (**Table 4-9**, **Table 4-12**, **Figure**

4-26). Although not detected by I&M monitoring, emerald ash borer is widespread in GWMP and hundreds of emerald ash borer infested ash trees have been cut down to prevent hazardous tree falls near road and buildings. Hemlock is a rare tree in GWMP and all known trees are infested with hemlock woolly adelgid. Gypsy moth has killed approximately 15 large white oaks in Ft. Marcy and Great Falls Park and GWMP conducted aerial pesticide spraying for gypsy moth one year at Ft. Marcy.

No trend analysis was possible with the current data set.

Table 4-12 Percent of trees with evidence of forest pest species.

Site	Year	% trees with pests
GWMP-0144	2013	0
GWMP-0147	2013	0
GWMP-0194	2013	0
GWMP-0139	2012	0
GWMP-0145	2012	0
GWMP-0173	2012	0
GWMP-0286	2012	0
GWMP-0320	2012	0
GWMP-0008	2011	0
GWMP-0019	2011	0
GWMP-0057	2011	0
GWMP-0058	2011	0
GWMP-0059	2011	0
GWMP-0253	2011	0
GWMP-0254	2011	0
GWMP-0256	2011	0
GWMP-0086	2010	0
GWMP-0207	2010	0
GWMP-0208	2010	0
GWMP-0314	2010	0

<u>Sources of expertise</u>

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

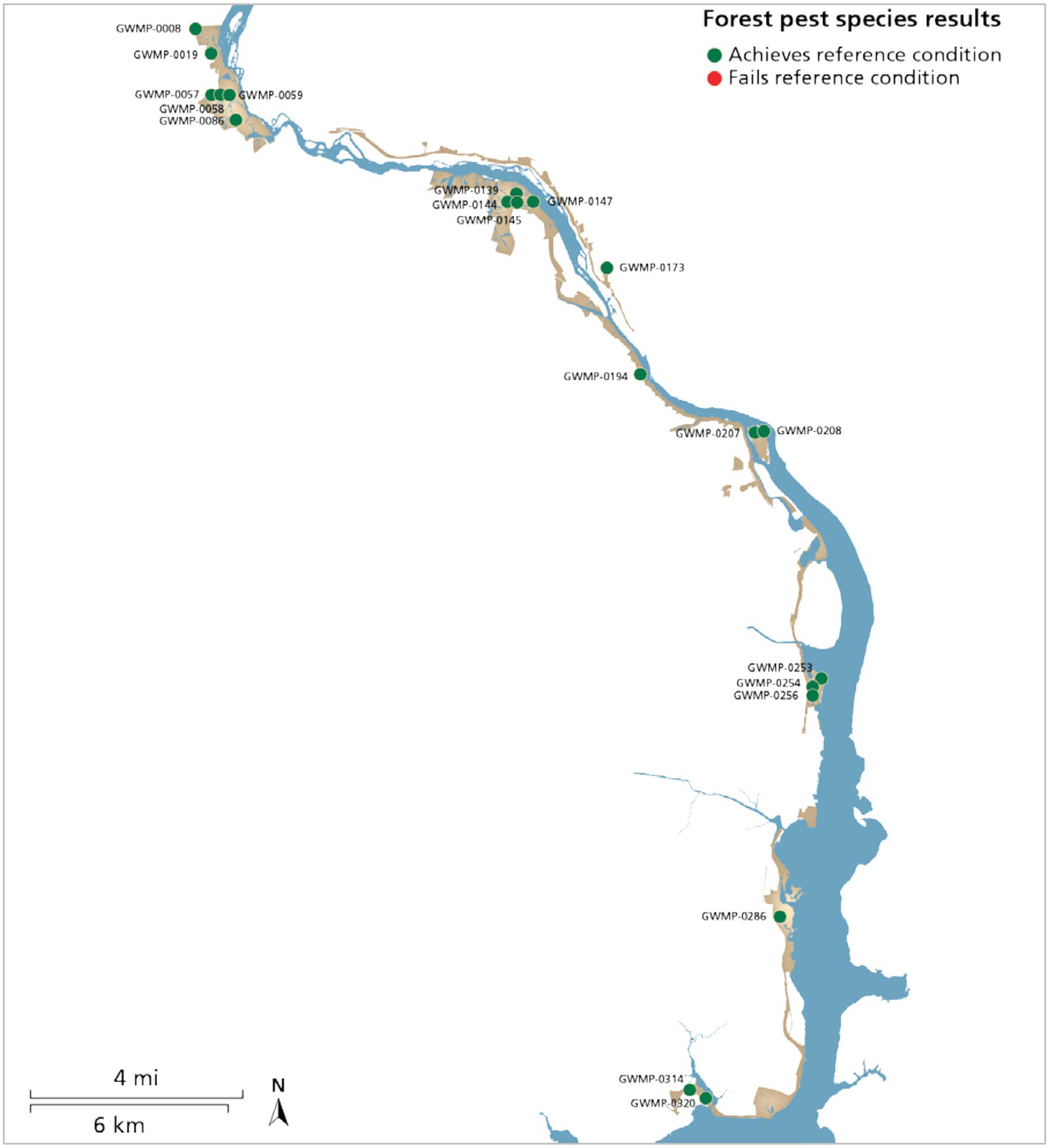

Figure 4-26 Forest pest species results by site for GWMP.

Seedlings and forest regeneration

Description

Forests are the dominant natural vegetation in the parks of the National Capital Region Network. Many factors including dense white-tailed deer populations and fire suppression in forested regions can alter forest stand development and reduce wildlife habitat by reducing or eliminating young tree seedlings, shrubs, and herbaceous plants (Tierson et al. 1996; Jordan 1967; Marquis 1981; Tilghman 1989; Horsely et al. 2003; Coté et al. 2004; Nowacki and Abrams 2008). In response to regeneration concerns, scientists at the U.S. Forest Service developed a measure, called the 'stocking index' to determine if regeneration is sufficient (Marquis and Bjorkman 1982). The index takes into account three different aspects of forest regeneration: the number of seedlings recorded, the size of the seedlings, and the geographic distribution of the seedlings. The more seedlings and small saplings present, the better. Size is important, as taller seedlings are more likely to survive than smaller seedlings. Finally, a forest is more likely to successfully regenerate if the seedlings are spread out than if they are concentrated in only a few places (Schmit and Nortrup 2013).

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit et al. 2009) (**Table 4-7**). 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 were counted and the height of each seedling 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. Seedlings were defined as trees less than 1 cm in diameter at breast height and ≤ 15 cm in height. Each measurement was assessed against the threshold and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

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 (**Table 4-8**). This threshold is used in forests with high deer density to take into account deer browse effects on seedling growth and survival (Schmit and Nortrup 2013). 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 (**Table 4-8**).

Condition and trend

Current condition for stocking index in GWMP was very degraded, with a mean stocking index value of 10.8 seedlings/ha and 30% of data points attaining reference condition of > 115 (**Table 4-9**,

Table 4-13, **Figure 4-27**).

No trend analysis was possible with the current data set.

Table 4-13 Stocking index values.

Site	Year	Stocking index
GWMP-0144	2013	9.25
GWMP-0147	2013	139
GWMP-0194	2013	7.25
GWMP-0139	2012	125.5
GWMP-0145	2012	12.25
GWMP-0173	2012	7.25
GWMP-0286	2012	77.25
GWMP-0320	2012	118
GWMP-0008	2011	66.5
GWMP-0019	2011	152.75
GWMP-0057	2011	0
GWMP-0058	2011	21
GWMP-0059	2011	4.25
GWMP-0253	2011	5.25
GWMP-0254	2011	0
GWMP-0256	2011	0
GWMP-0086	2010	17
GWMP-0207	2010	4.25
GWMP-0208	2010	19
GWMP-0314	2010	5.25

Sources of expertise

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

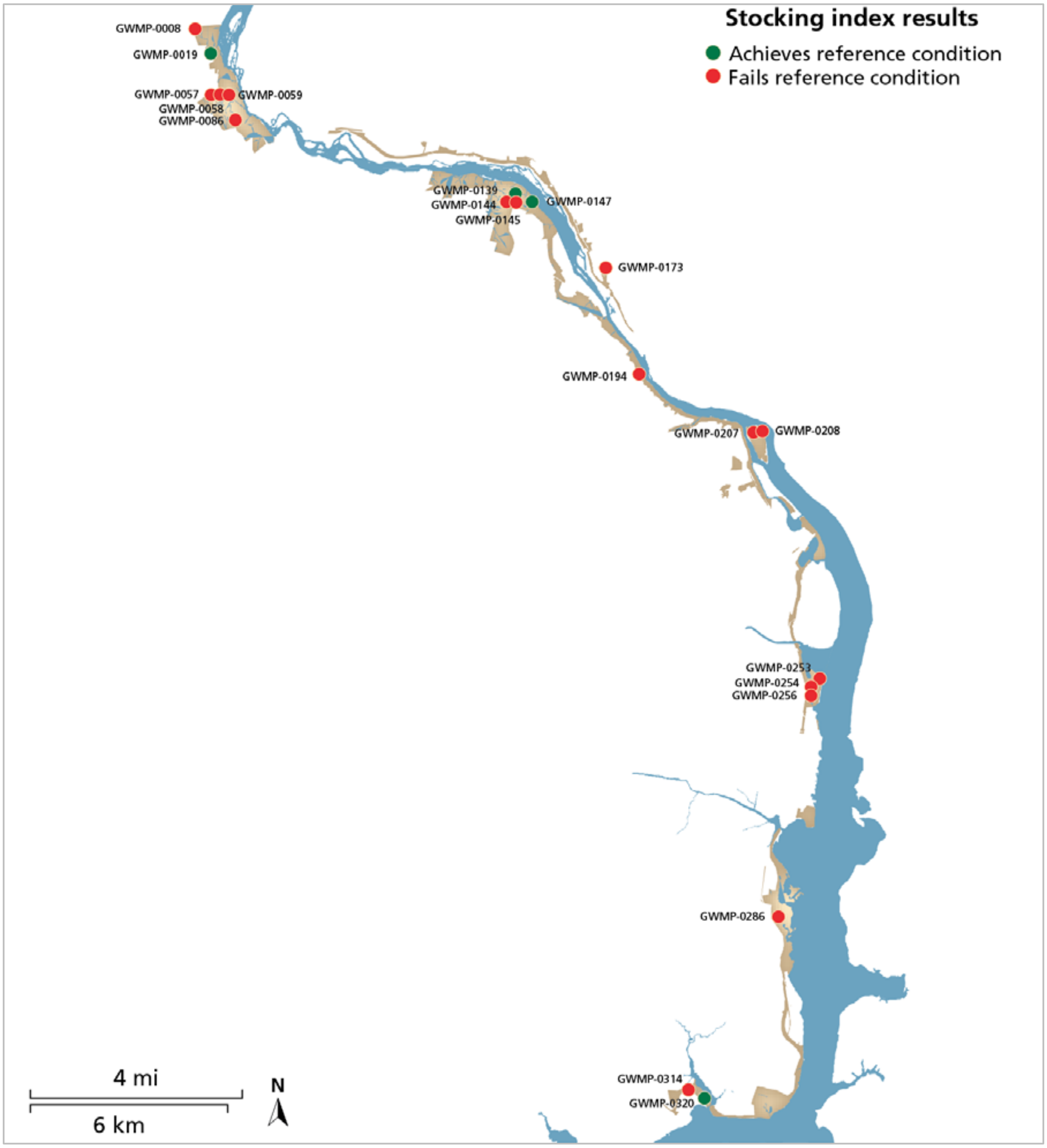

Figure 4-27 Stocking index results by site for GWMP.

Fish

Description

The Fish Index of Biotic Integrity (FIBI) was proposed as a way of providing a more informative measure on anthropogenic influence on fish communities and ecological integrity than measurements of physiochemical 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 four sites during 2004, 2006, and 2012. NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Sites were classified based on physical and chemical data and fish assemblages were compared to identified reference sites. Reported data are for one FIBI assessment per site.

FIBI values were ranked as follows: 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good), and these were the scale and categories used in this assessment (Southerland et al. 2007). The range of FIBI scores from 1 to 5 were scaled linearly from 0 to 100% attainment (**Table 4-14**). 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 4-14 Fish Index of Biotic Integrity (FIBI) categories, percent attainment, and condition assessment.

FIBI range	Percent attainment	Condition
4.0-5.0	100%	Good
3.0-3.9	Scaled linearly	Fair
2.0-2.9	Scaled linearly	Poor
1.0-1.9	0%	Very poor

Condition and trends

Current condition of FIBI in GWMP was very poor, with a median FIBI of 1.67 and 16.5% attainment of reference condition (**Table 4-9**, **Table 4-15**, **Figure 4-28**, **Figure 4-29**).

No trend analysis was possible with the current data set.

Table 4-15 Fish Index of Biotic Integrity (FIBI) in GWMP. Monitoring sites are shown in **Figure 4-22**.

Year	Site	Site Name	FIBI
2012	POTO-211	Mine Run	3.67
2012	POTO-309	Pimmit Run	1.67
2012	POTO-112	Turkey Run	2.33
2009	COCA-117	Minnehaha Creek	1.67
2006	POTO-309	Pimmit Run	1.67
2004	POTO-211	Mine Run	3
2004	POTO-112	Turkey Run	1

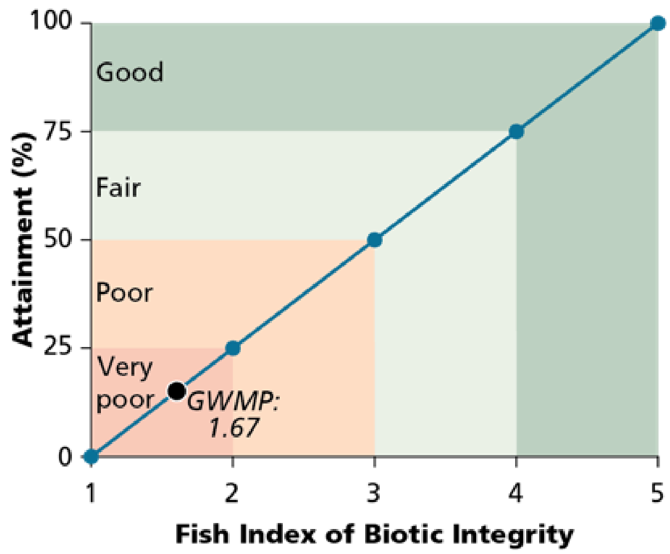

Figure 4-28 Application of the percent attainment categories to the Fish Index of Biotic Integrity (FIBI) value categories. FIBI at GWMP was 1.67, which equated to 16.67% attainment of the reference condition.

<u>Sources of expertise</u>

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

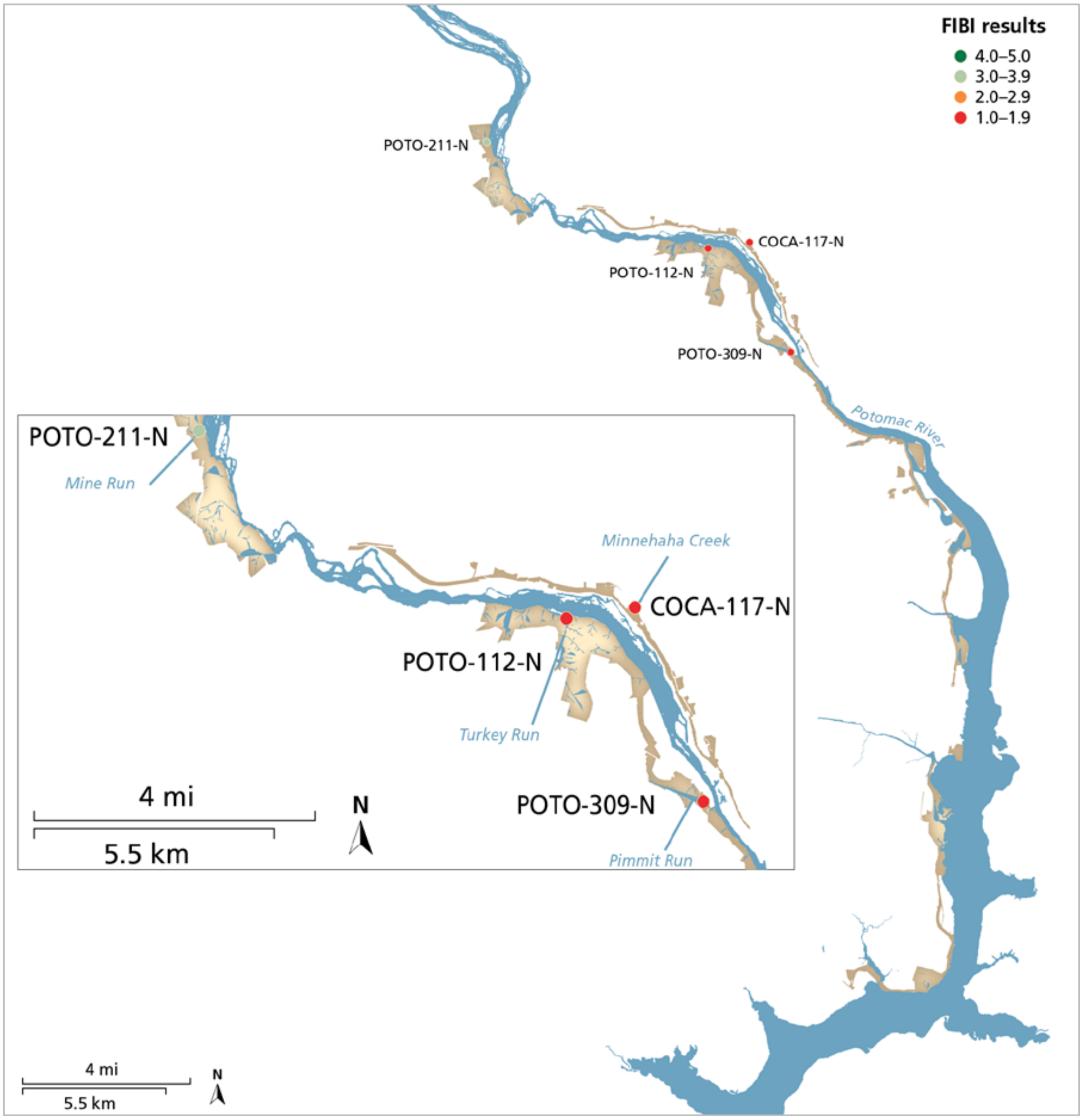

Figure 4-29 Attainment of Fish Index of Biotic Integrity (FIBI) reference condition by site for four sampling locations in GWMP.

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). There is evidence that noise alters singing behavior (Brumm and Todt 2002; Slabbekoorn and Peet 2003; Wood and Yezerinac 2006), decreases abundance near roads (Reijnen et al. 1996; Forman et al. 2002; Benitez-Lopez et al. 2010), and alters patterns of abundance of species that depend on song frequency (Rheindt 2003; Hu and Cardoso 2009; Goodwin and Shriver 2010).

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 20 sites between 2007 and 2013 (**Table 4-8**). Point count data was used to calculate 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). These were the scale and categories used in this assessment (O'Connell et al. 1998) (**Table 4-8**).

Each of the four BCI value categories was assigned a percent attainment range. Each BCI value was compared to these reference conditions and given a percent attainment and converted to a condition assessment.

Condition and trend

The 2007-2013 BCI in GWMP showed medium integrity, with a median of 46.5 and a value of 38.4% attainment of reference condition (**Table 4-9**, **Table 4-16**, **Figure 4-30**, **Figure 4-31**). Over the data range available, no significant trend was present (p-value > 0.01) (**Figure 4-32**).

Table 4-16 Bird Community Index (BCI) values at 20 sites in GWMP. Value is the median of all 20 monitoring sites. Monitoring site locations are shown in Figure 4-22

Year	Score
2013	47.3
2012	46.3
2011	43.3
2010	47.8
2009	42.0
2008	46.8
2007	46.8

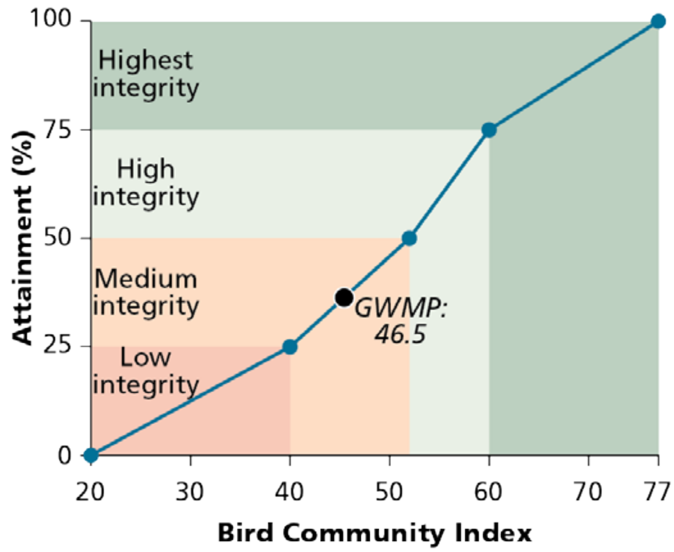

Figure 4-30 Application of the percent attainment categories to the Bird Community Index (BCI) value categories. Median BCI at 20 monitoring sites in GWMP was 46.5, which equated to 38.4% attainment of the reference condition.

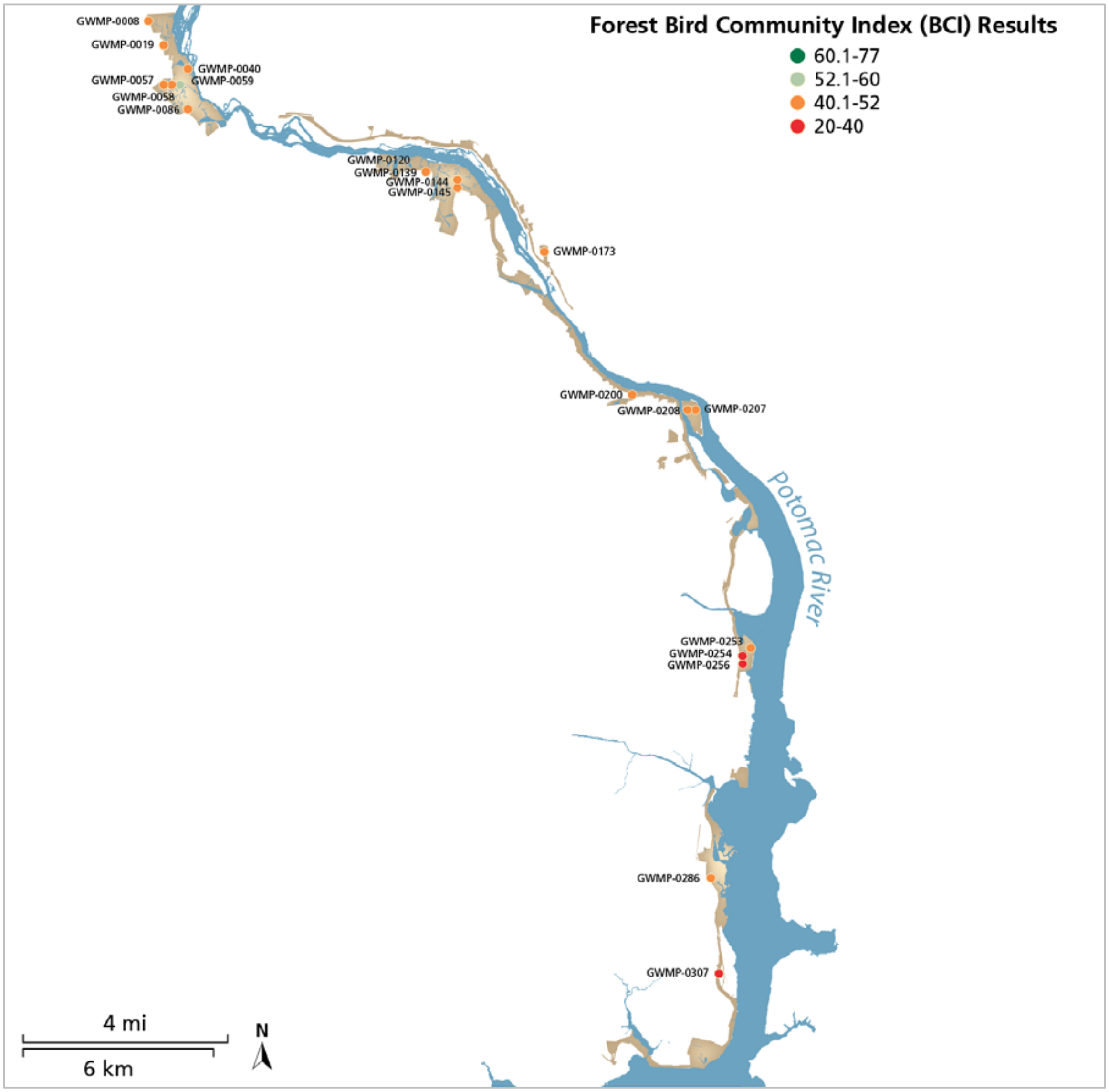

Figure 4-31 Bird Community Index (BCI) condition by site from 2007 to 2013 for 20 monitoring locations in GWMP. Median of all years was used for analysis.

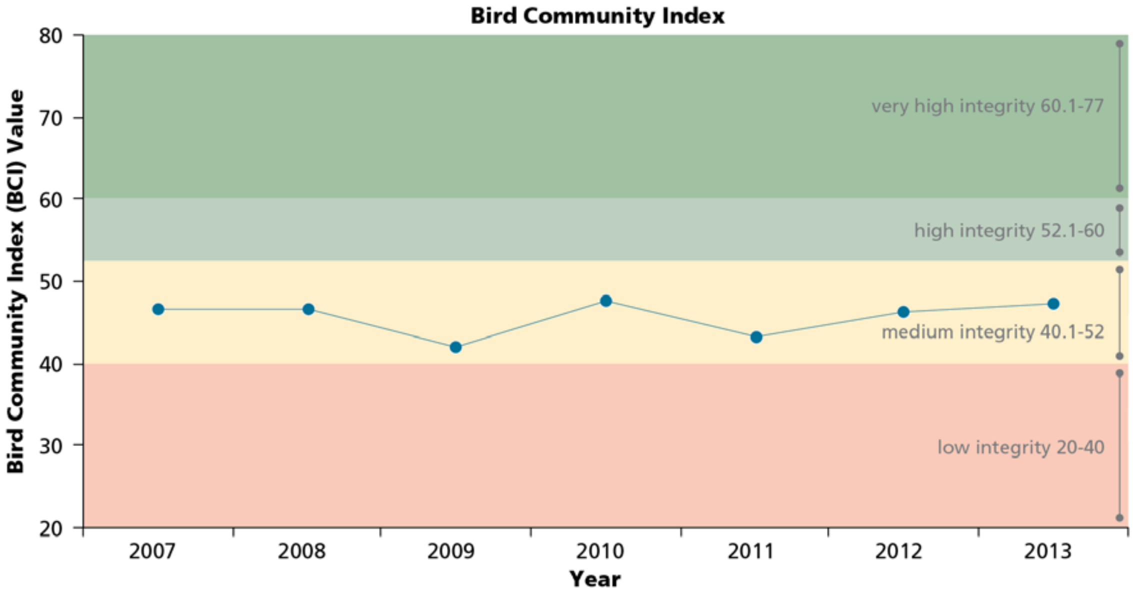

Figure 4-32 Median Bird Community Index (BCI) values at all sites in GWMP between 2007 and 2013

Sources of expertise
John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Deer density
Description
White-tailed deer (*Odocoileus virginianus*) are considered a significant stressor on forests of the National Capital Region. White-tailed deer densities throughout the eastern deciduous forest zone increased rapidly during the latter half of the 20th century and may now be at historically high levels. McCabe and McCabe (1997) estimate that pre-European deer densities in the eastern United States ranged between 3.1 and 4.2 deer/km^2 (8.0 and 10.9 deer/ mi^2) in optimal habitats. Today, examples of deer populations exceeding 20 deer/ km^2 (52 deer/ mi^2) are commonplace (e.g., Knox 1997; Russell et al. 2001; Augustine and deCalesta 2003; Rossel Jr. et al. 2005; Griggs et al. 2006; Mc-Donald 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 in Great Falls Park annually between 2001 and 2014 using the distance survey method (Bates 2006, 2009) (**Figure 4-21**). Each measurement was assessed against

the reference condition and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The forest threshold for white-tailed deer density (8.0 deer/km^2 [21 deer/mi^2]) is a well-established ecological threshold (Horsley et al. 2003) (**Table 4-8**). 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.

<u>Condition and trend</u>
Current condition of deer population density in Great Falls Park was very degraded, with 0% of years attaining the reference condition of < 8.0 deer/km^2. Population estimates for deer population for 2001–2014 exceeded the reference condition of < 8 deer/km^2, in all sampling years, with a median deer population of 33.97 deer/km^2 for all years (**Table 4-9**, **Figure 4-33**).

In 2004 and 2013 there was a decrease in deer population size. The small size of the park, and culling of deer at the adjoining county park contributes heavily to count variation within GWMP (Bates 2008).

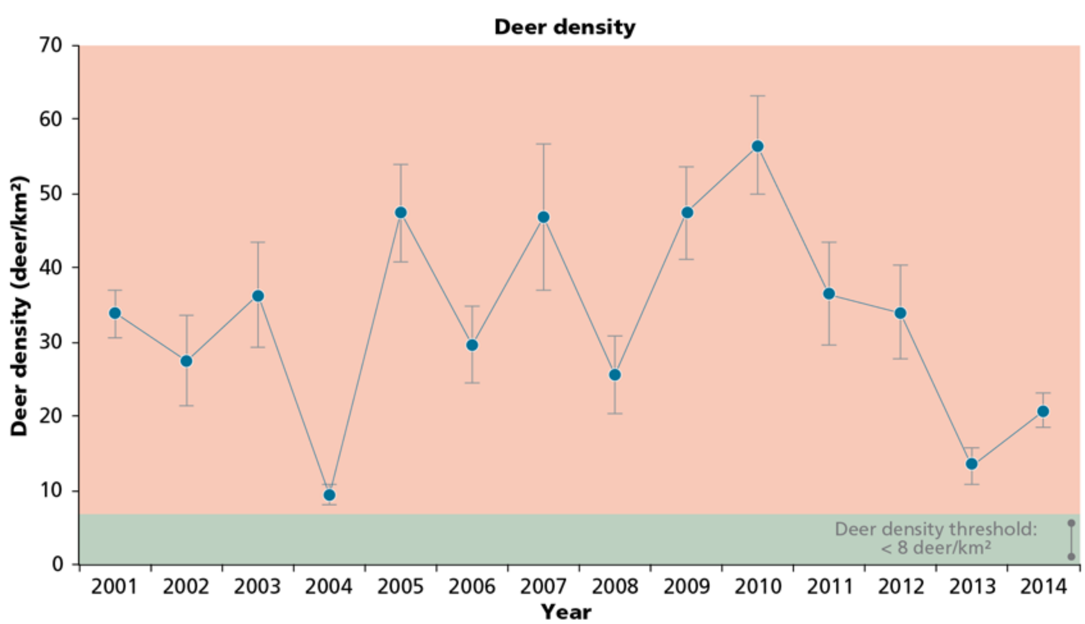

Figure 4-33 Annual mean deer density (deer/km^2) from 2001 to 2014 in GWMP. Reference condition (< 8 deer/km^2) is shown in gray. Error bars represent ± the standard error.

Sources of expertise
Scott Bates, Wildlife Biologist, National Park Service, Center for Urban Ecology.

Rare, threatened, endangered species

Description
The Potomac Gorge is one of the most biologically diverse habitats within the whole national park system, and the unique geology, geography, and hydrology of the gorge produce an array of rare species and communities. The area features plants characteristic of two ecoregions. Researchers have identified at least 30 distinct natural vegetation communities, several of which are globally rare and imperiled, some of which are found nowhere else on Earth.

George Washington Memorial Parkway has been conducting its All Taxa Biodiversity Index (ATBI) for 10 years. The ATBI is a long-term inventory process, aiming to catalog all biodiversity within the park. To date, 5,289 species have been documented within GWMP, including 74 species new to science, 3 species new to North America, 84 new to Virginia, 7 new to the District of Columbia, and 105 listed as rare by the Natural Heritage Programs of Virginia or Maryland, including three federally threatened species.

Data and Methods
To evaluate biodiversity within George Washington Memorial Parkway, the presence of state-listed rare, threatened, and endangered species was used as an indicator. The following ranks are used by the Virginia Department of Conservation and Recreation to set protection priorities for natural heritage resources (Virginia.gov) (**Table 4-17**).

Table 4-17 Virginia Department of Conservation and Recreation ranking categories for rare, threatened, and endangered species.

Rank	Description
S1	Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state. Typically 5 or fewer populations or occurrences; or very few remaining individuals (<1000).
S2	Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 populations or occurrences or few remaining individuals (1000 to 3000).
S3	Vulnerable in the state either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 populations or occurrences (1000 to 3000).

In order to assess the importance of rare, threatened, and endangered species in GWMP, the density of rare, threatened or endangered (RTE) species that occur within GWMP, in comparison to the entire commonwealth of Virginia, was used for this indicator.

Virginia has 2,045 RTE species and 42,775 square miles of land, of which GWMP has 97 RTE species in 6.2 square miles of land. Calculating the density of RTE species per square mile for the entire commonwealth of Virginia results in 0.05 RTE species per square mile. Calculating the density of RTE species per square mile for GWMP results in 16 species per square mile (Table 4-18 Comparison of the number of rare, threatened, and endangered species in Virginia and GWMP per square mile.). This highlights that on average, GWMP has 320 times the density of RTE species than the rest of the Commonwealth of Virginia (**Table 4-18**). Note that at the time this report was published, this does not take into account the 84 species new to Virginia found in GWMP that are not as yet on the Virginia RTE list or the 74 species new to science found in GWMP.

Table 4-18 Comparison of the number of rare, threatened, and endangered species in Virginia and GWMP per square mile.

	Number of RTE Species	Land Area (square miles)	RTE Species per square mile
Virginia	2045	42,775	0.5
GWMP	96	6.2	16

Sources of expertise
http://www.dcr.virginia.gov/natural_heritage/help.shtml (Roble 2013).

Landscape dynamics

Landscape Dynamics summary

Four indicators were used to assess landscape dynamics in GWMP—forest interior area, forest cover, impervious surface, and road density (measured at two different scales) (**Table 4-19**). 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 and area 5x 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 parkway.

Reference conditions were established for each indicator (**Table 4-20**) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that indicator. This resulted in an overall landscape dynamics condition attainment of 2%, or very degraded condition (**Table 4-21**).

Table 4-19 Ecological monitoring framework data for Landscape Dynamics provided by agencies and specific sources included in the assessment of GWMP.

Indicator	Agency	Reference/Source
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	NPS2010a, Jin *et al.* 2013, NPS 2014a
Forest cover (within park)	NPS NPScape, National Land Cover Database 2011	NPS2010a, Jin *et al.* 2013, NPS 2014a
Forest cover (within park + 5x buffer)	NPS NPScape, National Land Cover Database 2011	NPS2010a, Jin *et al.* 2013, NPS 2014a
Impervious surface (within park)	NPS NPScape, National Land Cover Database 2011	NPS2010a, Jin *et al.* 2013, NPS 2014a
Impervious surface (within park + 5x buffer)	NPS NPScape, National Land Cover Database 2011	NPS2010a, Jin *et al.* 2013, NPS 2014a
Road density (within park)	NPS NPScape	NPS2010b, NPS 2014b
Road density (within park + 5x buffer)	NPS NPScape	NPS2010b, NPS 2014b

Table 4-20 Landscape dynamics indicators, data availability, reference conditions, and condition assessment categories used in the natural resources condition assessment of George Washington Memorial Parkway.

Landscape dynamics indicator	Number of sites	Number of samples	Period of observation	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	0-100% scaled linearly
Forest cover (within park)	Park	1	2011	> 59%	0-100% scaled linearly
Forest cover (within park + 5x buffer)	Park	1	2011	> 59%	0-100% scaled linearly
Impervious surface (within park)	Park	1	2011	< 10%	0-100% scaled linearly
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	0-100% scaled linearly
Road density (within park + 5x buffer)	Park	1	2006	< 1.5 km/km^2	0-100% scaled linearly

Table 4-21 Summary of landscape dynamics resource condition assessment at GWMP.

Landscapes dynamics indicator	GWMP result	Percent attainment	Condition assessment	Overall landscape dynamics condition
Forest interior area (within park)	16	16	Very degraded	2% Very degraded
Forest interior area (within park + 5x buffer)	5.7	5.7	Very degraded	
Forest cover (within park)	44.6	0	Very degraded	
Forest cover (within park + 5x buffer)	30	0	Very degraded	
Impervious surface (within park)	6.6	100	Very good	
Impervious surface (within park + 5x buffer)	14.6	0	Very degraded	
Road density (within park)	8.1	0	Very degraded	
Road density (within park +5x buffer)	7.3	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, and 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 4-19**) 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 threshold 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 5x 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 (**Table 4-20**).

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 GWMP at the scale of the park and at the scale of the park plus the 5x buffer was 10% and 4%, respectively (**Table 4-21**, **Table 4-22**, **Figure 4-34**). This indicated very degraded condition at the scale of the park, as well as at the 5x area scale. Note: forest interior area at an additional scale (park boundary plus a 30 km buffer) is also shown in **Table 4-22** for reference but was not included in the current assessment.

No trend analysis was possible with the current data set.

Table 4-22 Forest interior area (%) in GWMP.

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

Sources of expertise

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

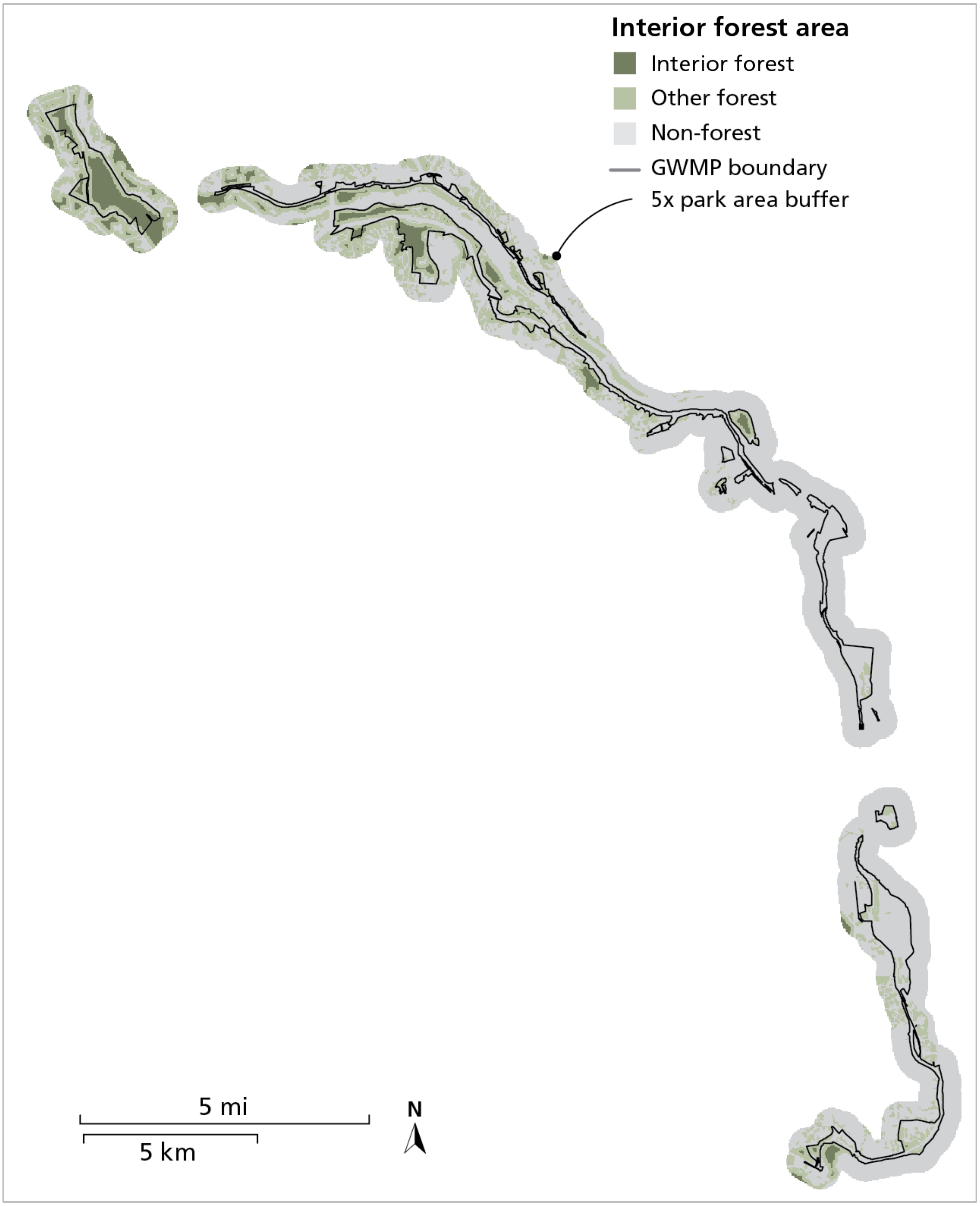

Figure 4-34 Extent of forest interior area within and around GWMP. The 5x area buffer is an area five times the total area of the park, evenly distributed as a ‘buffer’ around the entire park boundary.

Forest cover

Description

Forest is the dominant historical land use in the region surrounding GWMP and is still the dominant land use within the park itself (**Figure 2-3**). 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 NPSscape Phase 1 Landcover methods and script tools (NPS 2010) (**Table 4-19**). The source data for this analysis was the 2011 National Land Cover Database (NLCD) (Jin et al. 2013). Three of the NLCD classifications were considered to be forested areas for this analysis: Deciduous Forest, Evergreen Forest, and Mixed Forest.

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

A forest cover threshold 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 5x 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 result of the one-off calculation (**Table 4-20**).

Condition and Trend

At the scale of the park, forest cover in GWMP was 53.2%, which is below the reference condition of 59%. This resulted in 0% attainment and very degraded condition (**Table 4-21**, **Table 4-23**, **Figure 4-35**).

When a buffer of 5x the park was added, forest cover dropped to 46.9%, also below the reference condition of 59%, resulting in 0% attainment of the reference condition and indicating very degraded condition. Note: forest cover at an additional scale (park boundary plus a 30 km buffer) is also shown in **Table 4-23** for reference but was not included in the current assessment.

No trend analysis was possible with the current data set.

Table 4-23 Forest cover in GWMP.

Area	Forest cover (%)
Park	50.4
Park + 5x area	45.7
Park + 30 km	27.9

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

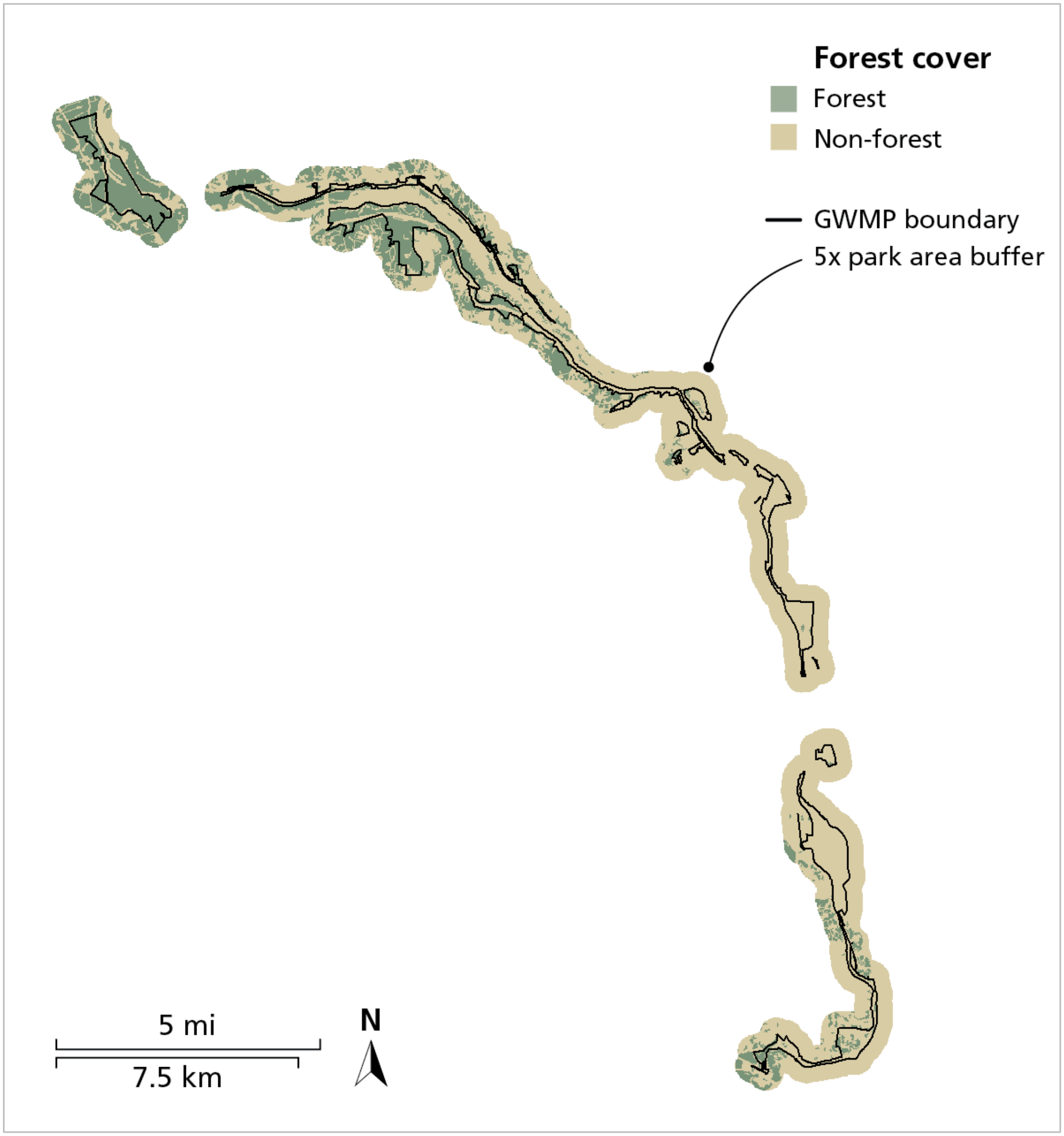

Figure 4-35 Extent of forest and non-forest landcover within and around GWMP. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

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 above 10% impervious surface (Arnold and Gibbons 1996). Recent studies on stream macroinvertebrates continue to show shifts to more tolerant species and reductions in biodiversity at around this same threshold (Lussier et al. 2008). A study of nine metropolitan areas in the United States demonstrated measurable effects of impervious surface on stream macroinvertebrate assemblages at impervious surface cover below 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 2010b, Jin *et al.* 2013, NPS 2014b) (**Table 4-19**).

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 Insert end parenthesis?% (Arnold and Gibbons 1996; Lussier et al., 2008).

An impervious surface threshold of < 10% was used in this assessment and data used in this assessment represent a one-off calculated at two scales: 1) within the park boundary and 2) within the park boundary plus an area 5x 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 GWMP at the scale of the park and the scale of the park plus the 5x buffer was 13.09% and 13.11%, respectively. These were both above the reference condition of 10% impervious surface, resulting in 0% attainment and very degraded condition at both scales (**Table 4-21**, **Table 4-24**, **Figure 4-36**) Note: impervious surface at an additional scale (park boundary plus a 30 km buffer) is also shown in **Table 4-24** for reference but was not included in the current assessment.

Areas adjacent to the park with the highest cover of impervious surface include the Washington, D.C. metropolitan area.

No trend analysis was possible with the current data set.

Table 4-24 Impervious surface (%) in GWMP.

Area	Impervious surface (%)
Park	13.09
Park + 5x area	13.11
Park + 30 km	17.92

Sources of expertise

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

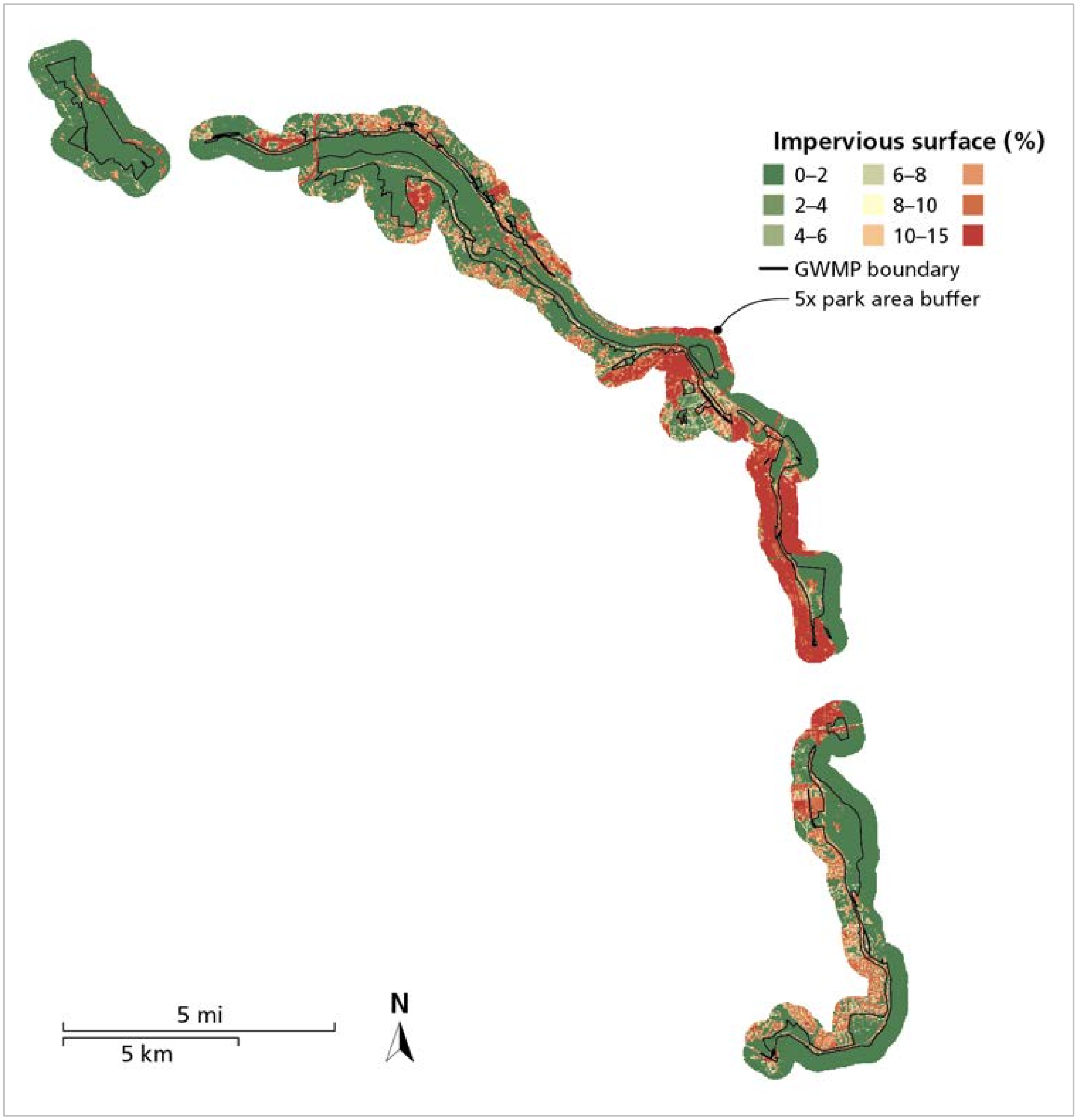

Figure 4-36 Percent impervious surface within and around GWMP. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

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 4-19**). The 2010 ESRI Streets layer (ESRI 2010) was used as the source data. All of the features in this layer were included in this analysis with the exception of ferry routes.

Road densities higher than 1.5km/km^2 have been shown to impact turtle populations, while densities higher than 0.6 km/km^2 can impact natural populations of large vertebrates (Forman et al. 1995; Gibbs and Shriver 2002; Steen and Gibbs 2004). A road density threshold of < 1.5km/km^2 was used in this assessment and data used in this assessment represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area 5x the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (**Table 4-20**). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

At the scale of the park, and at the scale of the park plus the 5x buffer road density in GWMP was 2.8 km/km^2, and 8.8 km/km^2, respectively (**Table 4-21**, **Table 4-25**, , **Figure 4-38**). These both exceeded the reference condition of 1.5 km/km^2, resulting in 0% attainment and very degraded condition at both scales.

In the years 2004-2006, GWMP staff kept an informal tally of road kill incidents along the section of the parkway that runs through Turkey Run Park. While there was no analysis completed on the data set, occurrences of vehicle strike of mammals and amphibians on the parkway do appear to increase during the summer and fall months, when visitation on the parkway is highest. Deer strikes on the GWMP increase during fall rutting season, turtle strikes occur almost exclusively during June nesting season, and bird strikes greatly increase during spring breeding season.

Table 4-25. Road density (km/km^2) in GWMP.

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

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

Sources of expertise

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

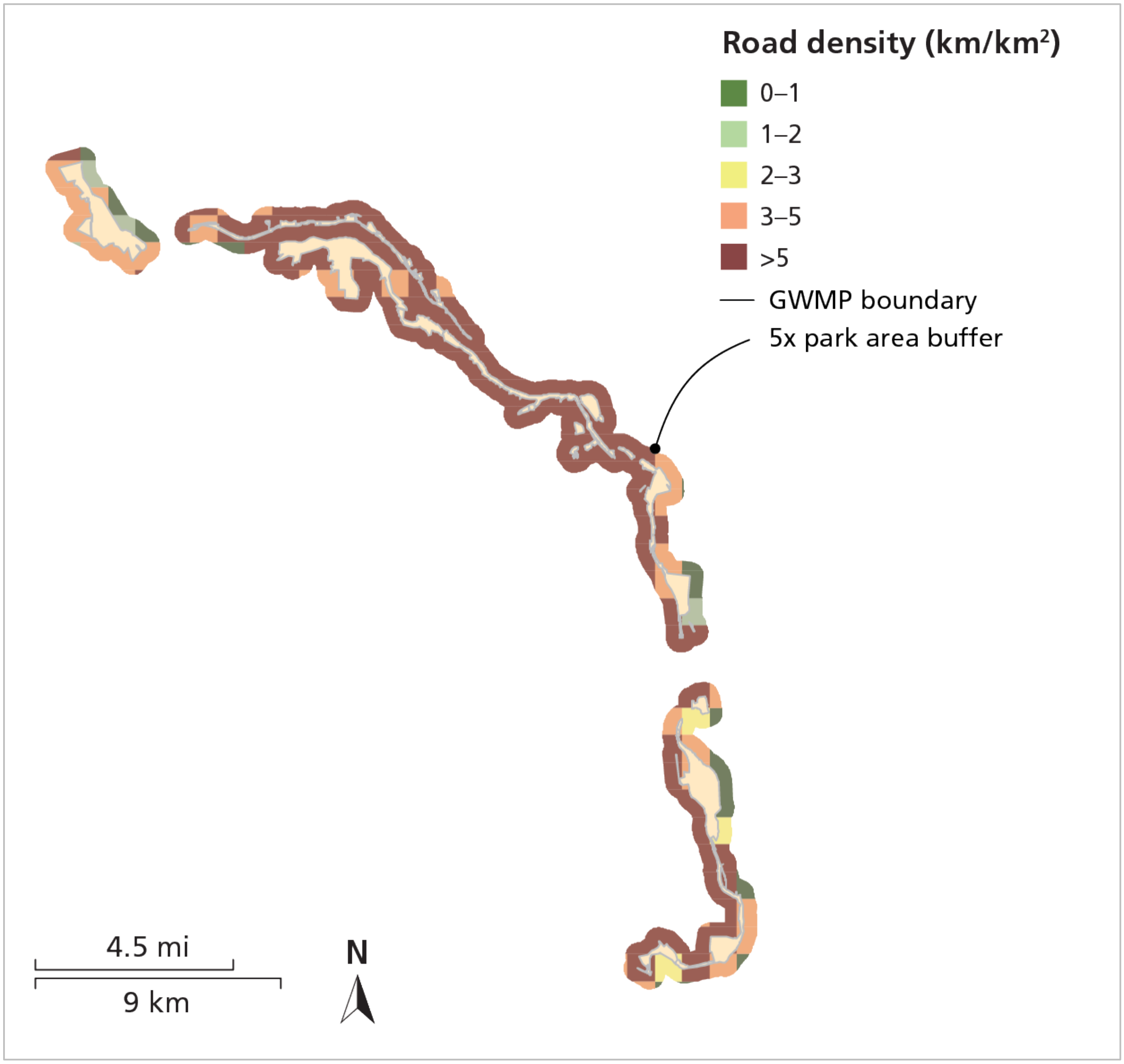

Figure 4-37 Road density within and around GWMP. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

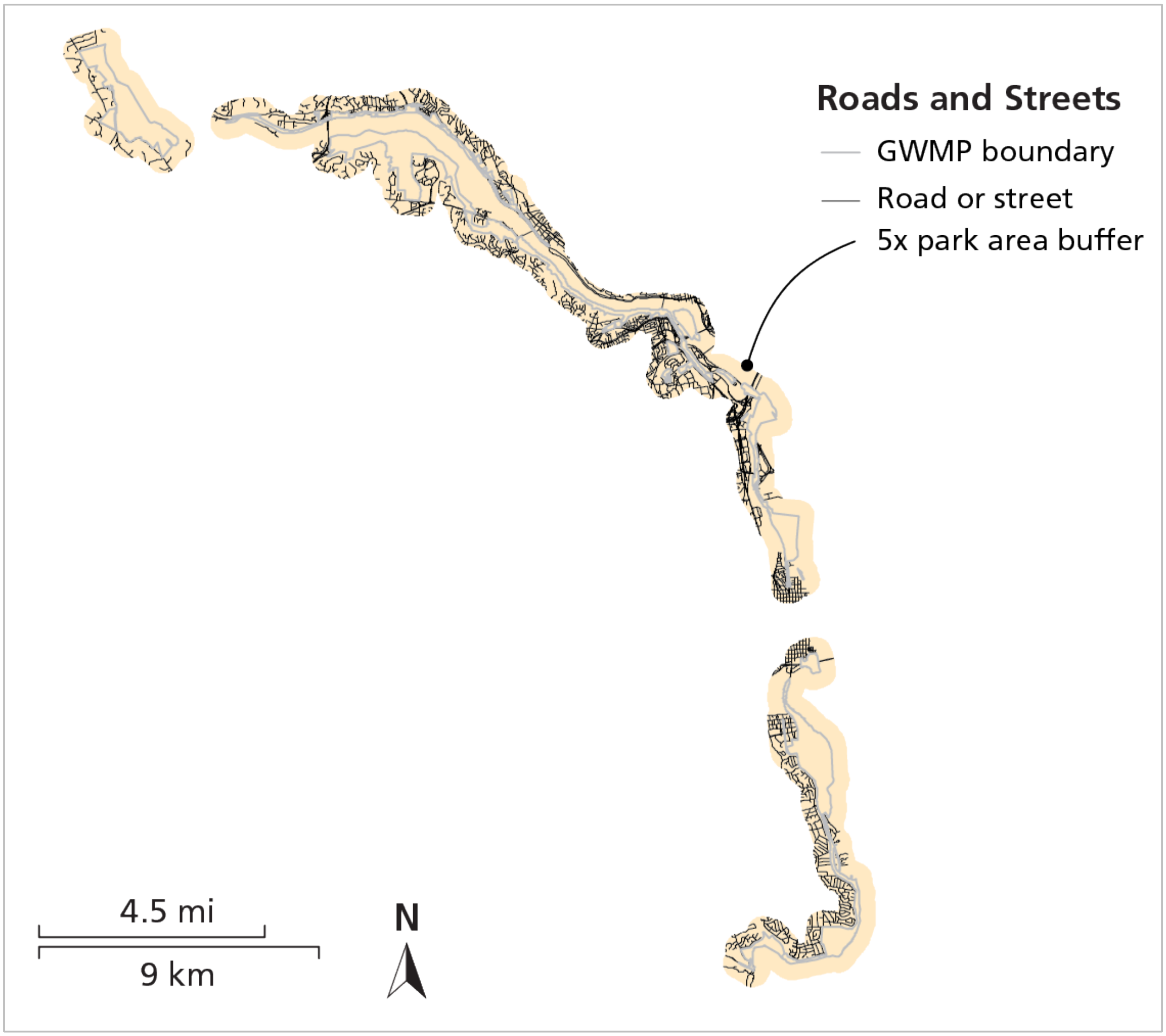

Figure 4-38 Map of the roads and streets in and around GWMP. This is the base map from which **Figure 4-37** was generated.

Air quality

Air quality summary

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).

Of the EPA criteria pollutants, the NPS Air Resources Division (ARD) provides assessments of all except lead and carbon monoxide. Five indicators were used to assess air quality in GWMP: 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 4-26**). 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 unit centroid, which is the location near the center of the park and within the park boundary (**Figure 4-39**). Data for particulate matter and mercury deposition were obtained from national monitoring sites (**Table 4-26**).

Table 4-26 Ecological monitoring framework data for Air Quality provided by agencies and specific sources included in the assessment of GWMP.

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

Reference conditions were established for each of the five indicators (**Table 4-27**) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that indicator. Multiple reference condition categories were used in accordance with the NPS ARD documentation (NPS ARD 2011) (**Table 4-27**).

To assess trends, data from the NPS ARD report were used where possible (NPS ARD 2011). Otherwise, monitoring sites closest to GWMP from the National Atmospheric Deposition Program (NADP) and Interagency Monitoring of Protected Visual Environments (IMPROVE) program were used (**Table 4-26**).

GWMP scored 0% attainment (or condition of significant concern) for all air quality indicators except particulate matter (55.17% attainment). This resulted in an overall air quality condition attainment of 9.2%, or very degraded condition (**Table 4-28**).

Table 4-27 Air quality indicators, data availability, reference conditions, and condition assessment categories used in the natural resource condition assessment of George Washington Memorial Parkway.

Air quality indicator	Number of sites	Number of samples	Period of observation	Reference conditions	Percent attainment applied
Wet sulfur deposition (kg/ha/yr)	Whole park	N/A*	2006-2010	< 1; 1-3; >3	0-100% scaled linearly
Wet nitrogen deposition (kg/ha/yr)	Whole park	N/A*	2006-2010	< 1; 1-3; >3	0-100% scaled linearly
Ozone (ppb)	Whole park	N/A*	2006-2010	≤ 60; 60.1-75; >75	0-100% scaled linearly
Ozone (W126; ppm-hrs)	Whole park	N/A*	2006-2010	< 7; 7-13; >13	0-100% scaled linearly
Visibility (dv)	Whole park	N/A*	2006-2010	<2; 2-8; >8	0-100% scaled linearly
Particulate matter (PM2.5; µg/m3)	2	1974	2002-2012	≤12; 12.1-15; >15	0-100% scaled linearly
Mercury deposition (ng/L)	2	701	2005-2011	N/A	N/A

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

Table 4-28 Summary of air quality resource condition assessment at GWMP.

Air quality indicator	GWMP result	Percent attainment of reference condition	Condition assessment	Overall air quality condition
Wet sulfur deposition (kg/ha/yr)	4.8	0%	Significant concern	9% Very degraded
Wet nitrogen deposition (kg/ha/yr)	4.3	0%	Significant concern	
Ozone (ppb)	79.4	0%	Significant concern	
Ozone (W126; ppm-h)	15.4	0%	Significant concern	
Visibility (dv)	13.0	0%	Significant concern	
Particulate matter (PM2.5; µg/m^3)	13.4	55%	Moderate	
Mercury deposition (ng/L)	7.6	N/A	N/A	

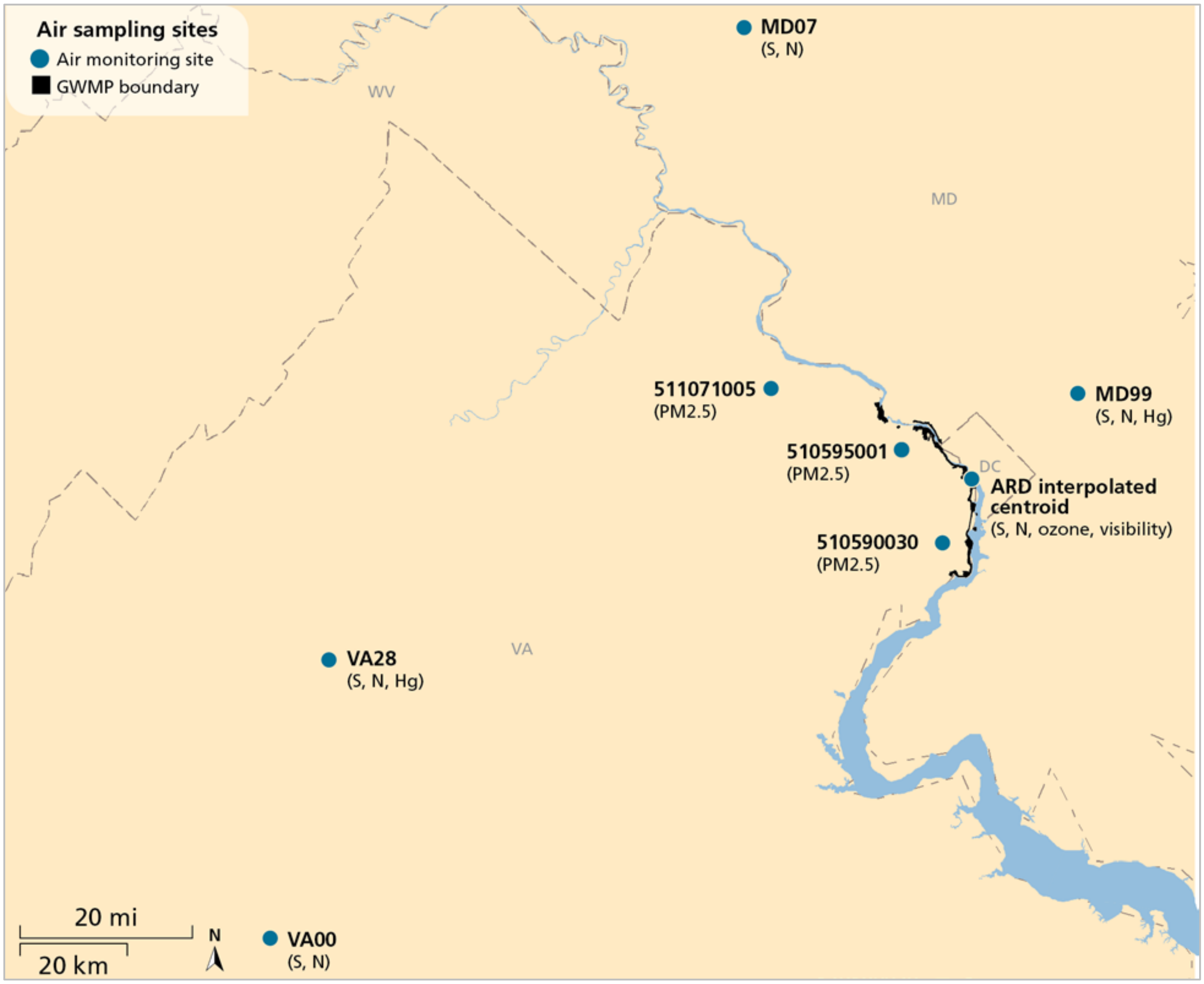

Figure 4-39 Regional air quality monitoring sites for ozone, visibility, particulate matter, mercury deposition, and wet deposition of sulfur and nitrogen. Wet deposition, ozone, and visibility data for 2006-2010 were interpolated by NPS ARD to estimate mean concentrations for GWMP.

Wet Sulfur Deposition

Description

Emissions of sulfur dioxide (SO2) 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 SO2 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, SO2 is highly mobile and can be transported distances greater than 500 km (311 miles) (Driscoll et al. 2001). Wet sulfate (SO42-) deposition is significant in the eastern parts of the United States (**Figure 4-40**).

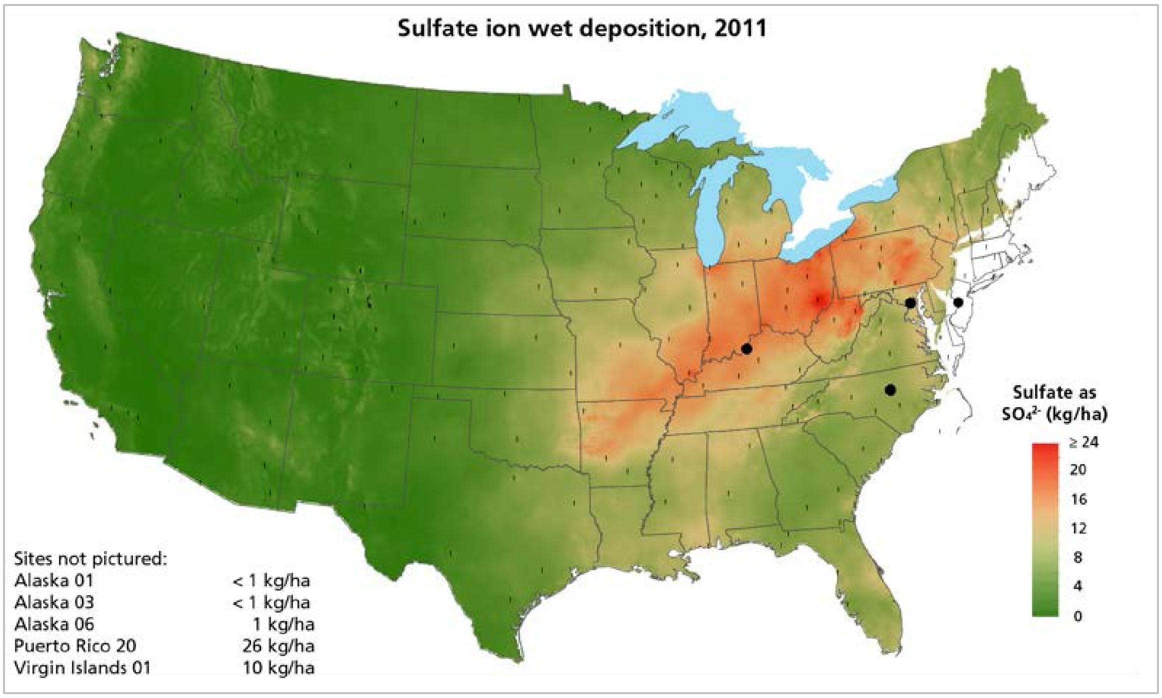

Figure 4-40 Total wet deposition of sulfate (SO_4^{2-}) for the continental United States in 2011 (NADP/NTN, 2013).

Data and Methods

The reference condition for total sulfur wet deposition is ecological (i.e. for protection of the natural environment). Natural background total 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).

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 2012b). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for GWMP was taken from the interpolation at the park centroid, which is a location near the center of the park (**Figure 4-39**).

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). 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 (NPS ARD 2011) (**Table 4-27**).

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

Additionally, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to GWMP were used. These included sites VA00 (Charlottesville) in Virginia, and sites MD99 (Beltsville, Prince George's County), MD07 (Catoctin) in Maryland (**Table 4-26**, **Figure 4-39**).

<u>Condition and trend</u>

Interpolated wet sulfur deposition between 2006 and 2010 for GWMP was 4.8 kg/ha/yr which resulted in 0% attainment of reference condition, or a condition that is of significant concern (NPS ARD 2012) (**Table 4-28**, **Figure 4-41**, **Figure 4-42**).

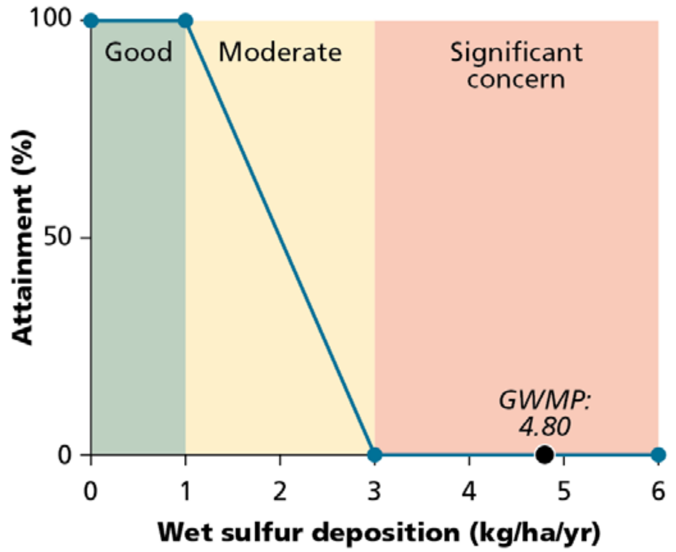

Figure 4-41 Application of the percent attainment categories to the wet sulfur deposition value categories. Wet sulfur deposition at GWMP was 4.8 kg/ha/yr, which equated to 0% attainment of the reference condition.

In an assessment that ranked National Capital Region Network parks according to relative risk from sulfur (and nitrogen) acidification effects, GWMP was ranked at moderate risk for ecosystem sensitivity, suggesting that streams and soils in the park are vulnerable to acidification (Sullivan et al. 2011a, b). The assessment included consideration of several factors that influence risk to park resources: N and S Pollutant Exposure, inherent Ecosystem Sensitivity, and Park Protection mandates. GWMP ranked very high for pollutant exposure, and moderate for ecosystem sensitivity and park protection (Sullivan et al. 2011a, b). At this time, park streams are not showing signs of acidification. Because this ranking is completed at a regional scale, GWMP falls into the moderate risk category because the NCRN experiences high pollutant inputs.

When deposition data were analyzed from the three locations closest to the park, MD07 and VA00 showed a significant improvement over the past decade (p-value < 0.01). The other site MD99 did not show such a trend (**Figure 4-42**).

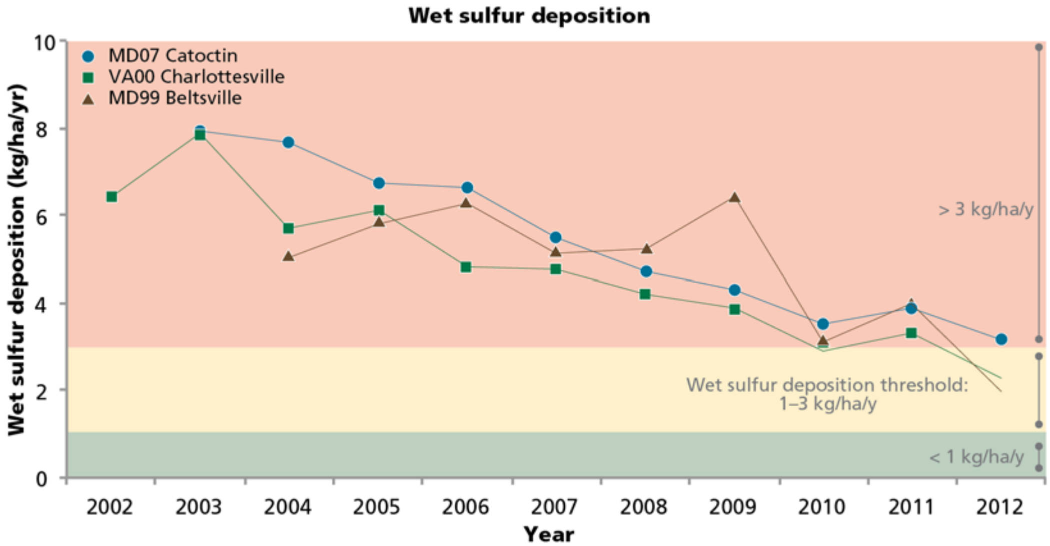

Figure 4-42 Annual wet deposition of sulfate (kg/ha/yr) at three sites closest to GWMP reported as SO_4 deposition.

Sources of expertise
Holly Salazer, NPS Air Resources Division 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/

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). Since 1970, in addition to human health effects, it was increasingly recognized that there were significant ecosystem impacts of atmospheric nitrogen deposition, including acidification and nutrient fertilization of waters and soils (Sullivan et al. 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 4-43**).

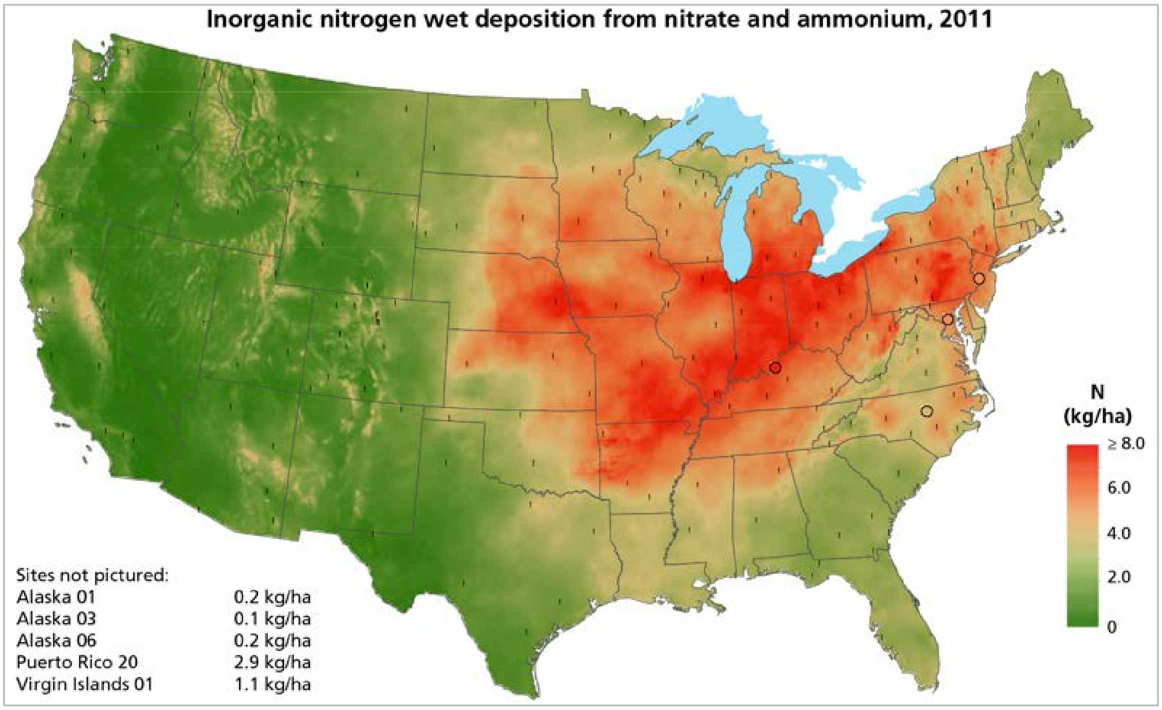

Figure 4-43 Total wet deposition of nitrate (NO_3-) and ammonium (NH_4+) (kg/ha) for the continental United States in 2011 (NADP/NTN).

<u>Data and Methods</u>

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 2011). 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 (**Table 4-27**). For the current assessment, the reported wet deposition value was assessed against these guidelines.

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), and Air Quality Estimates (NPS ARD 2011) (**Table 4-26**). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for GWMP was taken from an interpolation at the park centroid (**Figure 4-39**).

This analysis meant that there was only one value reported for wet nitrogen deposition for GWMP, so this value was assessed against the three reference condition ranges described above (**Table 4-27**).

To assess trends, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to GWMP were used. These included sites VA00 (Charlottesville) in Virginia, and sites MD99 (Beltsville), and MD07 (Catoctin) in Maryland (**Figure 4-39**).

Condition and trend

Interpolated wet nitrogen deposition between 2006 and 2010 for GWMP was 4.3 kg/ha/yr which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2012) (**Table 4-28**, **Figure 4-44**).

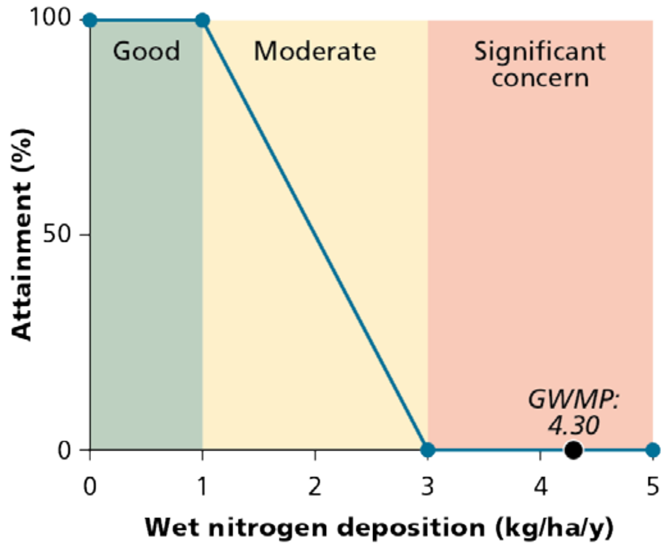

Figure 4-44 Application of the percent attainment categories to the wet nitrogen deposition value categories. Wet sulfur deposition at GWMP was 4.3 kg/ha/yr, which equated to 0% attainment of the reference condition.

In an assessment that ranked National Capital Region Network parks according to relative risk from sulfur (and nitrogen) acidification effects, GWMP was ranked at moderate risk for ecosystem sensitivity, suggesting that streams and soils in the park are vulnerable to acidification (Sullivan et al. 2011a, b). At this time however, park streams are not showing signs of acidification.

When deposition data were analyzed from the three sites closest to the park, none of the sites showed a significant improvement of wet deposition over the past decade (*p*-value >0.01) (**Figure 4-45.**).

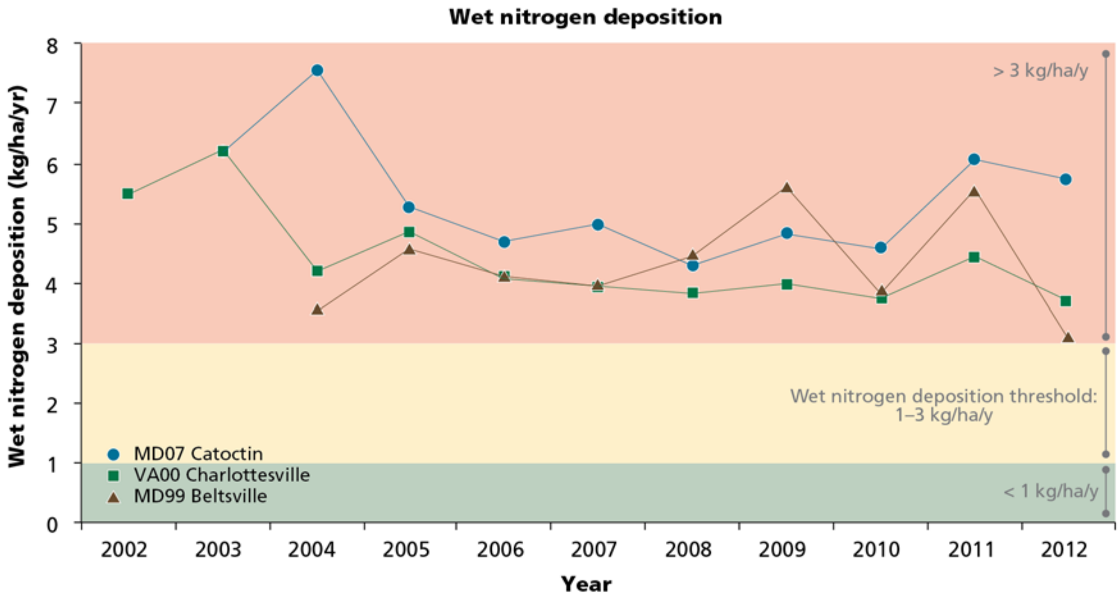

Figure 4-45 Annual wet deposition of total nitrogen (kg/ha/yr) at the three sites closest to GWMP.

Sources of expertise

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

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

Ozone

Description

Ozone is a secondary atmospheric pollutant, meaning it is not directly emitted but rather is formed by a sunlight-driven chemical reaction on nitrogen oxides and volatile organic compounds emitted largely from burning fossil fuels (Haagen-Smit and Fox 1956). In humans, ozone can cause a number of health-related issues such as lung inflammation and reduced lung function, which can result in 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. The W126 standard is a cumulative exposure index over a specific time period. The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥100 ppb (0.10 ppm) during that period (NPS 2005).

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 2008).

The ozone concentration data used for the assessment of current condition were taken from the NPS ARD Air Quality Estimates (NPS ARD 2011) (**Table 4-26**). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for GWMP was taken from the interpolation at the park centroid, which is the location near the center of the park.

The EPA's ozone standards are used as a benchmark for rating ozone condition. These standards were revised in 2008 in order to be more protective of human health and welfare. The primary and secondary standards are identical. To attain these standards, the 3-year average of the annual 4^{th} highest daily maximum 8-hour average ozone concentrations measured at each monitor must not exceed 75 parts per billion (ppb). For parks within the contiguous U.S., ozone condition is based on 5-year averages computed from on-site data when available (NPS ARD 2013).

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 ozone value was assessed against these guidelines (**Table 4-27**).

Vegetation sensitivity is also considered for ozone condition assessment. Data shows that some plant species are more sensitive to ozone than humans and the ozone standard is not protective of some vegetation. Both the three-year average annual fourth-highest daily maximum eight-hour concentration (averaged over five years) 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 2013).

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-h) are considered safe for sensitive plants (or 100% attainment of reference condition) and > 13 ppm-h is considered a significant concern for very sensitive plant species (or 0% attainment). Values of 7-13 ppm-h represent a moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (NPS ARD 2010, 2011).

Only one ozone concentration value for GWMP was available, so this value was assessed against the three reference condition ranges described above.

Condition and trend

Interpolated fourth-highest daily maximum eight-hour ozone concentration between 2006 and 2010 for GWMP was 79.4 ppb, which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2012) (**Table 4-28**, **Figure 4-46**). GWMP is located in an EPA designated 8-hour ozone non-attainment county, and therefore, the overall air quality condition is automatically placed in the Warrants Significant Concern category (NPS 2013).

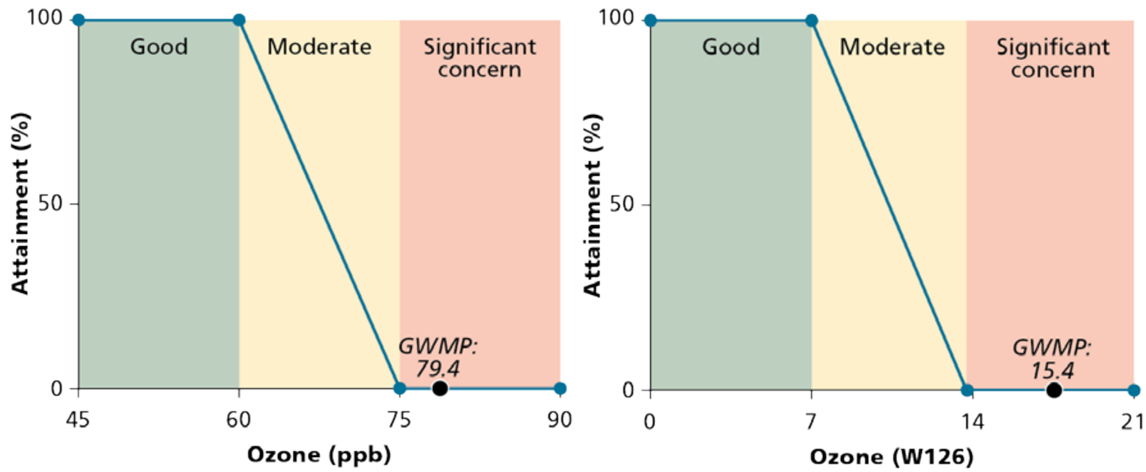

Figure 4-46 At GWMP, ozone was 79.4 ppb and ozone W126 was 14.6, which equated to 0% attainment for both reference conditions.

Interpolated W126 value between 2006 and 2010 for GWMP was 15.4 ppm-h, which resulted in 0% attainment of reference condition, or a condition of significant concern (**Table 4-28**, **Figure 4-46**).

Based on a country-wide assessment of visibility trends between 2000 and 2009 within 165 parks, there was an improving trend in ozone within GWMP, but it was not statistically significant ($0.05 \geq p \geq 0.15$) (NPS ARD 2013). In the eastern United States, ozone trends are generally improving over the past 10 years, largely influenced by the implementation of the NOx State Implementation Plan (SIP) Call rule (EPA 2010, NPS ARD 2010) (**Figure 4-47**).

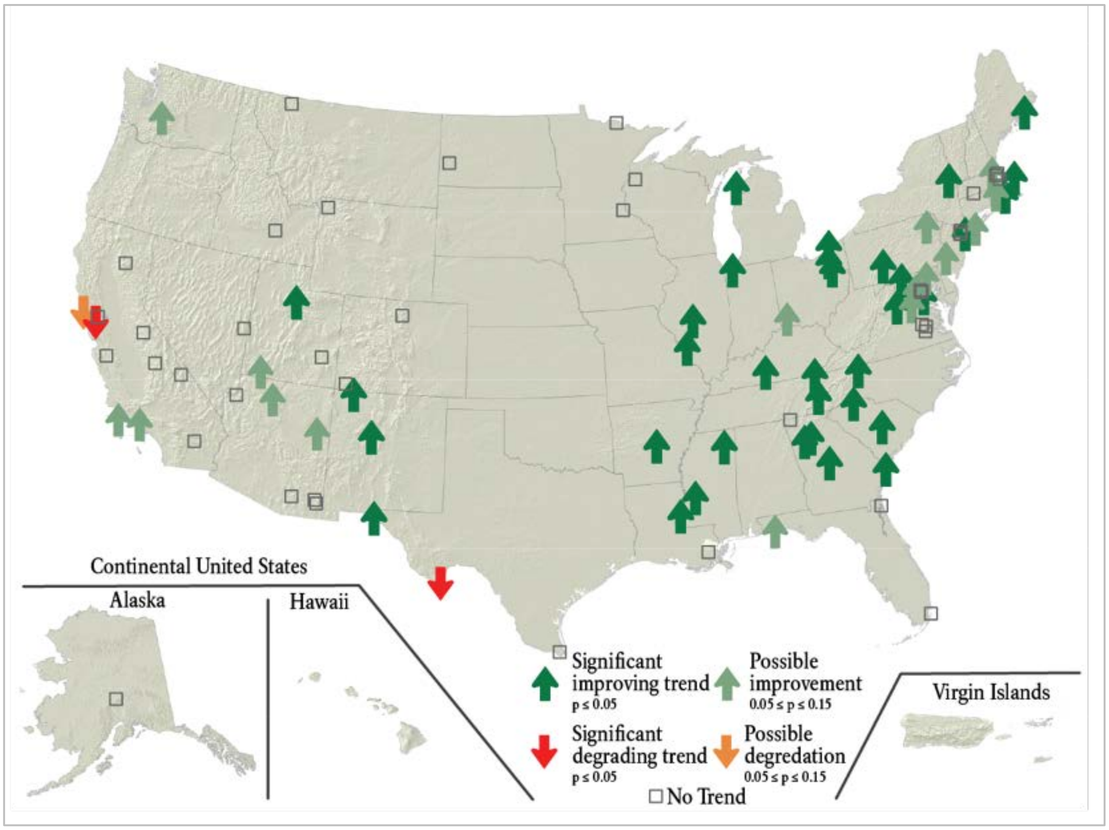

Figure 4-47 Trends in annual fourth-highest eight-hour ozone concentration (ppb/yr), 2000-2009 (NPS ARD).

<u>Sources of expertise</u>
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/

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, 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 (U.S. EPA 2003, NPS ARD 2012). 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 GWMP and all others designated as Class II under the Clean Air Act.

The haze index data used for the assessment of current condition at GWMP were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2012) (**Figure 4-26**). These estimates were calculated on a national scale between 2006 and 2010 using an interpolation model based on monitoring data. The value for GWMP was taken from the interpolation at the park centroid.

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 this assessment, the reported visibility value was assessed against these guidelines (NPS ARD 2012) (**Table 4-27**).

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

Condition and trend

Interpolated haze index between 2006 and 2010 for GWMP was 13.0 dv, which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2012) (**Table 4-28**, **Figure 4-48**).

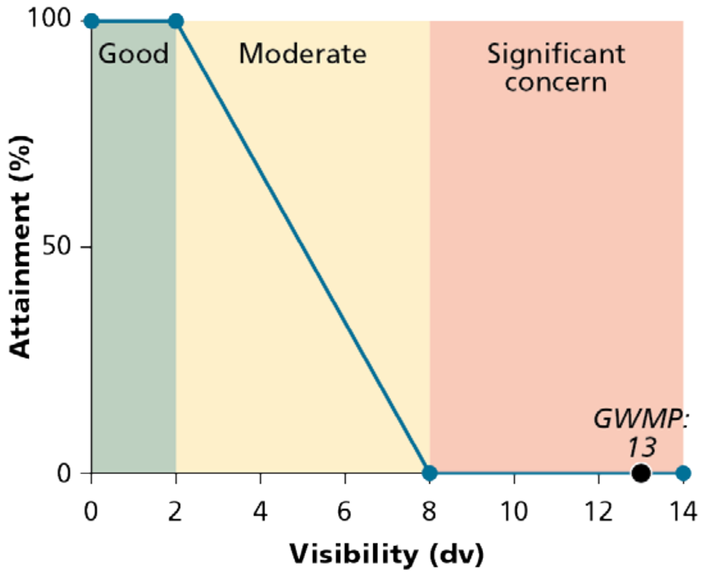

Figure 4-48 Application of the percent attainment categories to the visibility value categories. Visibility at GWMP was 13.0 dv, which resulted in 0% attainment of the reference condition.

Based on a country-wide assessment of visibility trends between 2000 and 2009 within 165 parks, there was a statistically significant improving trend in visibility within GWMP ($p \leq 0.05$) (NPS ARD 2013) (**Figure 4-49**).

Sources of expertise

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

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

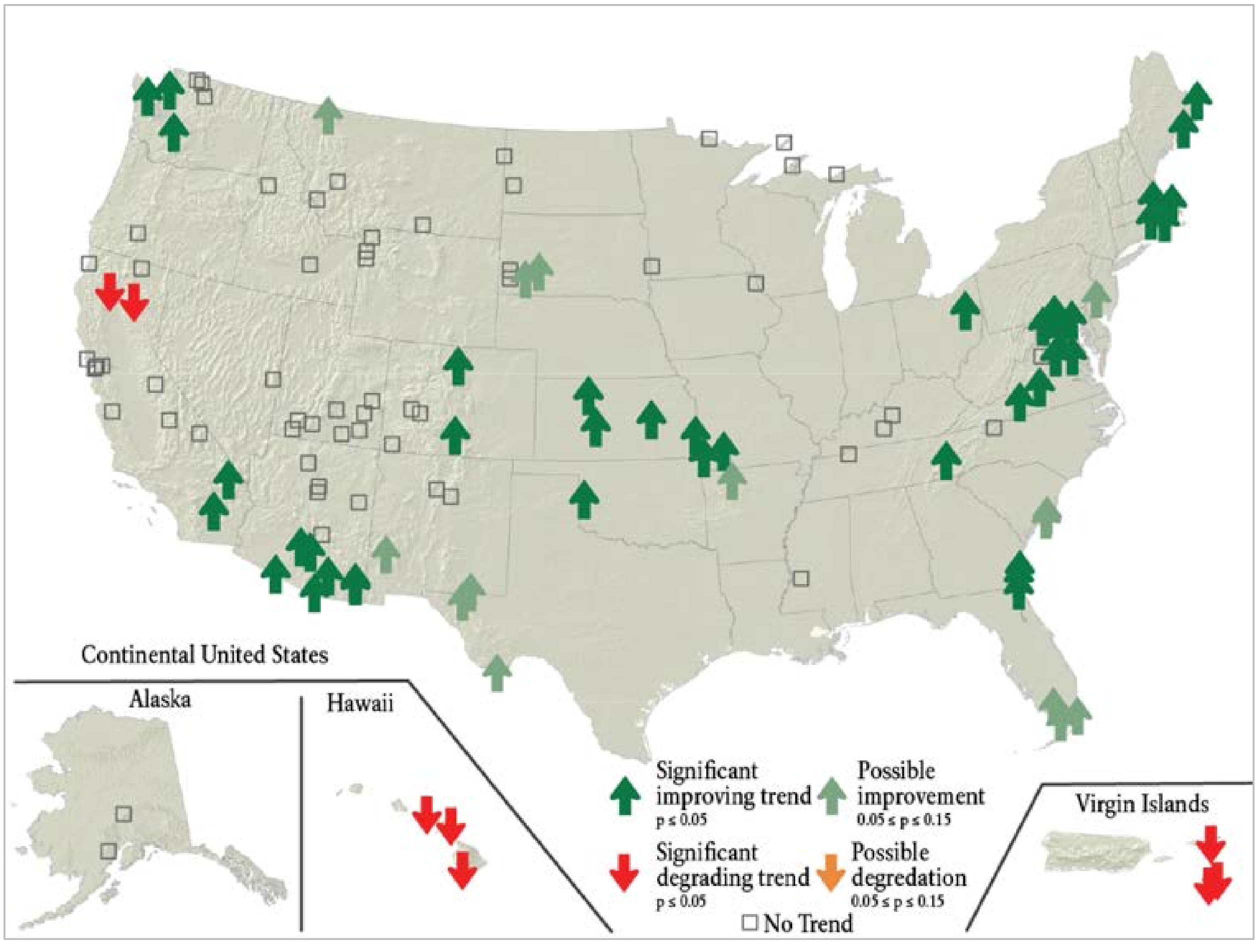

Figure 4-49 Visibility trends measured by the haze index (deciview) on haziest days, 2000-2009 (NPS ARD).

Particulate Matter

Description

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. 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 and 28 percent respectively (U.S. EPA 2012).

Data and methods

Data was obtained from the Interagency Monitoring of Protected Visual Environments (IMPROVE) database through the U.S. EPA AirData interface for the three sampling locations closest to GWMP. These included sites 510595001 (McLean, VA) 511071005 (Broad Run High School, VA) and 510590030 (Lee District Park, VA) (**Table 4-26**, **Figure 4-39**).

Data were 24-hour averages; three-year averages of the annual mean concentrations were calculated. The median of all these values was taken and assessed against the three reference condition ranges described in **Table 4-27**.

The current National Ambient Air Quality Standards (NAAQS) particulate matter regulatory threshold is a concentration of 35µg/m^3 (NAAQS 2008). The annual standard for PM 2.5 is met (air condition is considered acceptable) when the three-year average of the annual mean concentration ≤ 15.0 µg/m^3 (NAAQS 2008; U.S. EPA 2012). The annual standard (≤ 15.0 µg/m^3) was used as the reference condition in the current assessment (**Table 4-27**).

Good condition (or 100% attainment) for particulate matter presents 80% or less (or ≤ 12.0 µg/m3) of the current standard. Values > 15 µg/m^3 indicated significant concern (or 0% attainment). Values of 12.0-15.0 µg/m^3 indicated moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (**Table 4-27**).

Condition and trend

The three sites closest to GWMP had a median of 13.4 µg/m^3 between 2002 and 2012, with 55.17% attainment of the reference condition, or moderate condition (**Table 4-28**).

Over the data range available, there appears to be a decreasing trend in PM2.5 at both sites. Both sites showed a significant improving trend of particulate matter over the past decade (p value < 0.01) (**Figure 4-50**).

Sources of expertise

Interagency Monitoring of Protected Visual Environments (IMPROVE). http://vista.cira.colostate.edu/improve/

U.S. EPA PM Standards. http://www.epa.gov/airquality/particlepollution/

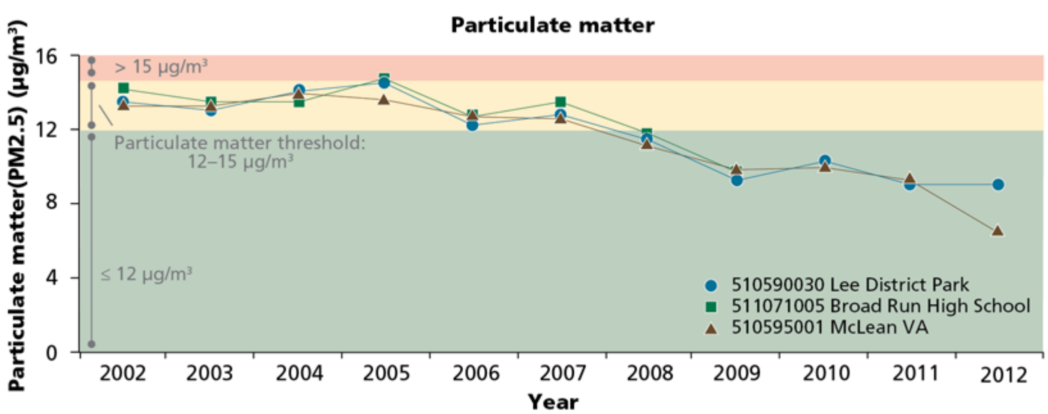

Figure 4-50 Particulate matter (µg/m^3) at the two sites closest to GWMP. Reference conditions are shown in gray. Data show the annual mean concentrations.

Mercury deposition

Description

Atmospheric mercury (Hg) comes from the natural sources, including volcanic and geothermal activity, geological weathering, and anthropogenic sources such as burning of fossil fuels, processing of mineral ores, and incineration of certain waste products (UNEP 2008). At a global scale, annual anthropogenic emissions of Hg 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 Hg 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. Measured trends in Hg 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 threshold is currently established (Meili et al. 2003).

Data and methods

Data was obtained from the National Atmospheric Deposition Program, Mercury Deposition Network for two sites, MD99 (Beltsville, MD) and VA28 (Shenandoah-Big Meadows) (**Table 4-26**, **Figure 4-39**). Samples are collected weekly and within 24 hours of a precipitation event and analyzed for Hg concentration, measured in nanograms per liter (ng/L) of Hg. Annual mean Hg concentrations were calculated for each sampling site.

There are no published thresholds for wet deposition of Hg, so this indicator was not included in the overall assessment of GWMP, but was included for informational purposes only.

Condition and trend

Annual mercury concentrations in precipitation from two sites in the region of GWMP over the past decade range from ~0.53 to 96.41 ng/L. The Mid-Atlantic region in general has relatively moderate levels of Hg deposition (**Figure 4-51**). 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 that range observed in precipitation. The U.S. EPA does provide an Hg -related National Recommended Water Quality Criteria for the protection of aquatic life. Criteria for total dissolved Hg 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, Hg has not been included in the overall assessment.

Over the data range available, no significant trend was present (p-value >0.01) (**Figure 4-52**).

Sources of expertise

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

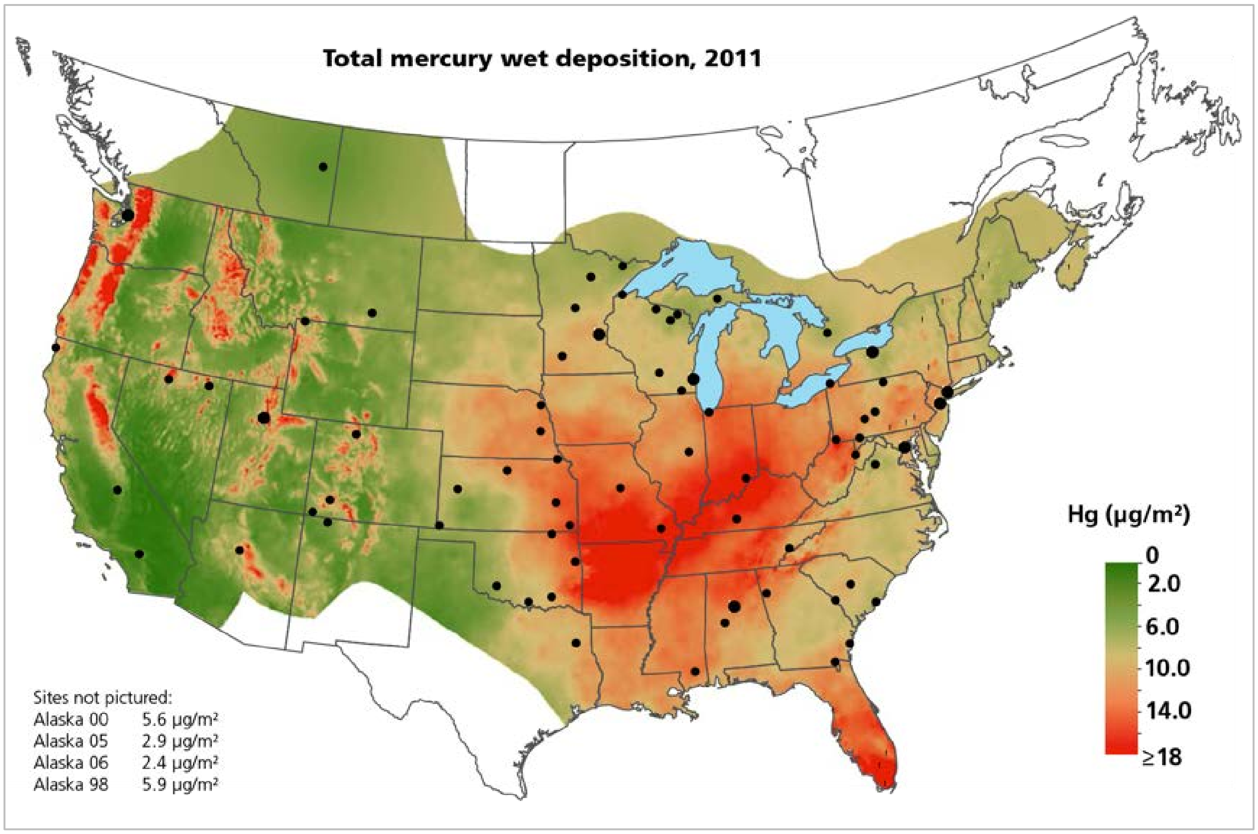

Figure 4-51 Total mercury wet deposition across the United States in 2011 (NADP/MDN 2013).

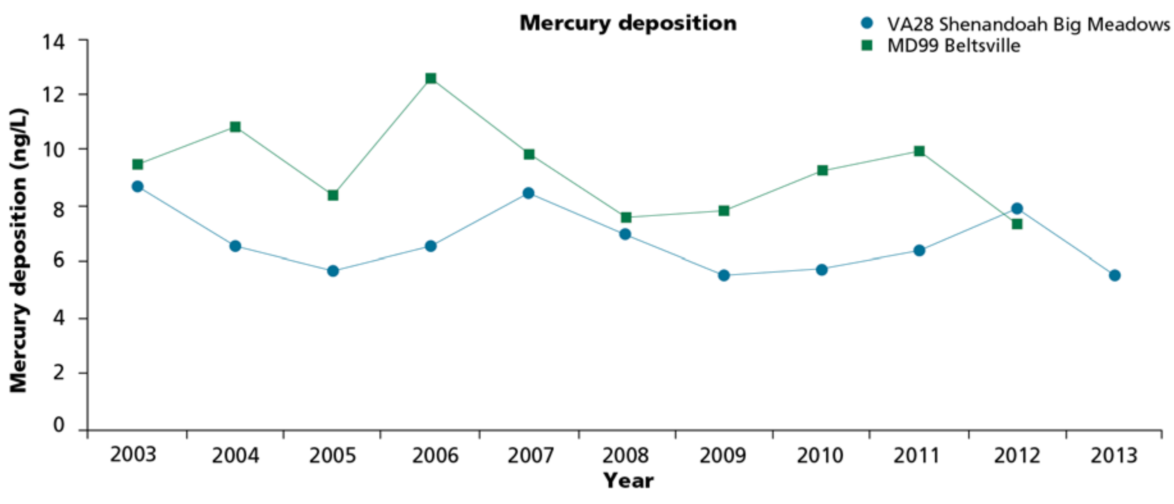

Figure 4-52 Median annual mercury concentrations (ng/L) in precipitation from two sites in the region of GWMP.

Discussion

Park natural resource condition summary

Overall, the natural resources of George Washington Memorial Parkway were classified as in ***degraded condition***, with 28% achievement of reference conditions. The good condition of water resources and moderate condition of biological integrity were offset by very degraded conditions for air resources and landscape dynamics (**Table 5-1**). The very degraded condition for landscape dynamics was not unexpected for a metropolitan motorway park with extensive landscape manipulation. Similarly, the very degraded condition for air resources is largely driven by external forces and cannot be expected to be improved though management actions within the park. Despite these findings, it is widely recognized that GWMP adds critical green space in an increasingly urbanized region, provides refuge for many species, serves as a migration rest stop for wildlife, and is a welcome escape from the traditional driving experience for motorists.

Table 5-1 Natural resource condition assessment of GWMP.

Vital sign	Reference attainment	Condition
Water resources	60%	Good
Biological integrity	42%	Moderate
Landscape dynamics	2%	Very degraded
Air quality	9%	Very degraded
GWMP Overall	**28%**	**Degraded**

Water resources

Water resources within GWMP were in a ***good condition*** (though bordered moderate condition), with 60% attainment of reference conditions (**Table 5-2**). Water resources were characterized by very good pH, dissolved oxygen, water temperature and acid neutralizing capacity. A higher overall attainment was, however, offset by very degraded conditions for total phosphorus and benthic index of biotic integrity (BIBI), and degraded conditions for specific conductance and the Physical Habitat Index (PHI). Management implications and recommended next steps are outlined in **Table 5-3**.

Water quality is measured at four sites within the park—Minnehaha Creek, Mine Run, Pimmit Run, and Turkey Run. Of these four streams, only Mine Run originates within the park. Because Minnehaha Creek, Pimmit Run, and Turkey Run do not originate in the park and only run through the park for a short distance, it would be informative to monitor water as it both enters and leaves the park.

Climate change

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

Table 5-2 Summary of stream water resources in GWMP.

Indicator	Percent attainment	Condition
pH	96%	Very good
Dissolved oxygen	95%	Very good
Water temperature	100%	Very good

Indicator	Percent attainment	Condition
Acid neutralizing capacity	100%	Very good
Specific conductance	25%	Degraded
Total nitrate	58%	Moderate
Total phosphorus	2%	Very degraded
Benthic Index of Biological Integrity	17%	Very degraded
Physical Habitat Index	49.5%	Moderate
Water resources	**60.24%**	**Good**

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

Key findings	Management implications	Recommended next steps
Very good condition for water temperature	Affects stream flora and fauna. Can impact quality of visitor experience.	Maintain riparian shading of streams to maintain temperatures.
Very degraded condition for stream total phosphorus	Nutrient enrichment affects stream flora and fauna (eutrophication). Visible signs of eutrophication reduces quality of visitor experience.	Determine cause of elevated phosphorus within the region. Determine if elevated phosphorus levels are negatively impacting stream flora and fauna. Minimize soil disturbance. Implement best management practices such as riparian buffers and no-mow areas.
Very degraded condition for Benthic Index of Biotic Integrity (BIBI)	Affects stream flora and fauna (food chain implications). Reduces quality of visitor experience.	Implement stream restoration and manage volume and velocity of water from impervious surfaces (e.g. swales, riparian buffers and no-mow areas). Implement monitoring to identify sources and patterns and then develop management alternatives. Work collaboratively with adjacent neighbors on education and identify strategies to help water quality before streams enter park.
Degraded condition for specific conductance	Affects stream flora and fauna. Reduces quality of visitor experience.	Identify source (e.g. salting of roads) and conductance-sensitive organisms and locations for management initiatives. Continuous monitoring of conductance/salinity levels throughout year. Identify areas of park more susceptible to salt runoff (sensitive areas). Implement best management practices (salt alternatives).
Degraded Physical Habitat Index	Affects stream flora and fauna. Reduces quality of visitor experience.	Implement stream restoration and manage volume and velocity of water entering the park (e.g. swales, riparian buffers and no-mow areas). Implement monitoring to identify sources and patterns and then develop management alternatives.

Table 5-4 Data gaps, justification, and research needs for water resources in GWMP.

Data gaps	Justification	Research needs
Origins of nitrogen and phosphorus inputs are uncertain	Nutrient enrichment affects stream flora and fauna (eutrophication). Visible signs of eutrophication reduces quality of visitor experience.	Identify sources of excess nutrient inputs.

Biological integrity

Biological integrity was in ***moderate condition***, with 42% attainment of reference conditions. Conditions for the seven biological integrity indicators ranged from very good (i.e. limited exotic trees and forest pest species) to very degraded (i.e. widespread coverage of exotic herbaceous species, high deer density and poor index of biological integrity scores for fish) (**Table 5-5**). Management implications and recommended next steps are outlined in **Table 5-6**.

Table 5-5 Summary of biological integrity in GWMP.

Indicator	Percent attainment	Condition
Cover of exotic herbaceous species	20%	Very degraded
Area of exotic tree & saplings	90%	Very good
Presence of forest pest species	100%	Very good
Stocking index	30%	Degraded
Fish Index of Biological Integrity	17%	Very degraded
Bird Community Index	38%	Degraded
Deer Density	0%	Very degraded
Biological Integrity	**42%**	**Moderate**

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

Key findings	Management implications	Recommended next steps
Overall, the forest community was represented well by native plant species, though seedling regeneration is a problem.	Future lack of forest regeneration and subsequent habitat.	Manage deer over-browse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park). Implement planting initiatives.
Very degraded cover of exotic herbaceous species	Displacement of native species, reducing biodiversity.	Prioritize species and locations for implementing control measures Restore and maintain native species and communities. Identify and map areas of exotic invasion that are not reflected in I&M monitoring (e.g. floodplain areas are not currently represented); and initiate park monitoring.
Fish index of biological integrity was in poor condition.	Fish are an important ecosystem component.	Identify sensitive locations and analyze FIBI scores to identify which components are showing degraded condition. Increase the number of fish monitoring sites.
Deer overpopulation may be impacting forest regeneration and be a hazard to vehicular traffic throughout park.	Increased herbivory reducing seedling density. More road collisions. Potential for spread of chronic wasting disease. Deer overbrowse can contribute to introduction of invasive species.	Continue with ongoing population size assessments.

Table 5-7 Data gaps, justification, and research needs for biological integrity in GWMP.

Data gaps	Justification	Research needs
Limited knowledge on how habitats may change in light of new and future stressors (climate change, pests, and diseases).	These stressors are already present, or will be present in the near future.	Research and modeling into the effects of these stressors on the region's habitats.

Landscape Dynamics

Landscape dynamics within George Washington Memorial Parkway were in ***very degraded*** condition, with 2% attainment of reference conditions (**Table 5-8**). Conditions were very degraded for forest interior area, forest cover and road density (**Table 5-9**). Management implications and recommended next steps for landscape dynamics are outlined in **Table 5-10**.

Table 5-8 Summary of landscape dynamics in GWMP.

Indicator	Percent attainment	Condition
Forest interior area (within park)	16%	Very degraded
Forest interior area (within park + 5x buffer)	6%	Very degraded
Forest cover (within park)	0%	Very degraded
Forest cover (within park + 5x buffer)	0%	Very degraded
Impervious surface (within park)	100%	Very good
Impervious surface (within park + 5x buffer)	0%	Very degraded
Road density (within park)	0%	Very degraded
Road density (within park + 5x buffer)	0%	Very degraded
Landscape Dynamics	**2%**	**Very degraded**

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

Key findings	Management implications	Recommended next steps
Very degraded forest interior area and forest cover – within and outside the park boundary	Reduction in breeding habitat for birds. Reduction in birds fledged each year. Increased predation on nests.	Improve quality of existing forest habitat by managing for exotic species and seedling stocking levels. Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.
Large areas of impervious surface – outside the park boundary	Increased rainfall runoff volume, temperature, and velocity (with pollutants).	Work collaboratively with neighbors to assess impervious surfaces around the park. Change asphalt parking lots to porous surfaces (e.g. pervious pavers, grass). Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.
High road density	Road density increases surface runoff. As runoff and stormwater enters park water resources, it may decrease water quality conditions, resulting in lower water quality and biological integrity. Affects area of forest interior and disrupts habitat.	Difficult to manage. Potential traffic calming/reduction measures. Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.

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

Data gaps	Justification	Research needs

Implications of external land use changes on park resources	Connectivity of ecological processes from park to watershed	Landscape analysis at multiple scales
Impacts of climate change on habitat connectivity	The park acts as a habitat cooridor throughout the region	Modeling of the potential effects of climate change on habitats within the park and surrounding region.

Air quality

Air quality conditions at GWMP were in a ***very degraded*** condition with 9% attainment of reference conditions (**Table 5-11**). As GWMP is a motorway, it was expected that air quality from automobiles would result in degraded air quality. However, it must be noted that 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 of poor air quality 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 5-12**.

Table 5-11 Summary of air quality in GWMP.

Metric	Percent attainment	Condition
Wet sulfur deposition	0%	Very degraded
Wet nitrogen deposition	0%	Very degraded
Ozone (ppb)	0%	Very degraded
Ozone (W126)	0%	Very degraded
Visibility	0%	Very degraded
Particulate matter	55%	Moderate
Overall Air Quality	**9%**	**Very degraded**

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

Key findings	Management implications	Recommended next steps
Air quality is very degraded and is a regional problem	Specific 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 to support regional air quality initiatives such as Climate Friendly Parks (www.nps.gob/climatefriendlyparks). Develop park-specific management actions. 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.	Use transport and deposition models to estimate air quality indicator conditions. Implement park-scale air quality monitoring for better insight into park-level air quality condition and possible effects on park habitats and species.
Minimal soundscape information	Traffic noise from roadway potentially affects wildlife behavior and distribution, and visitor recreational experience. Effect greater in fall and winter when foliage absent.	Noise/soundscape study.

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

Data gaps	Justification	Research needs
Ecological thresholds for mercury wet deposition	Wet deposition is monitored but the only available guideline is for fish tissue.	Relate fish tissue concentrations to wet deposition.
Park-scale air quality data	Need to implement park-specific management actions.	Use transport and deposition models.
Effects of poor air quality on park habitats and species	Need to implement park-specific management actions.	Investigate effects of poor air quality on sensitive habitats and species within the park.

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Appendix A: Raw Data

Table A-1 Particulate matter (PM2.5 g/m^3) site locations are shown in **Figure 4-39** and thresholds are shown in **Table 4-27**.

Site	Years	Median
510590030	2000-2002	13.9
	2001-2003	13.6
	2002-2004	13.4
	2003-2005	13.6
	2004-2006	13.4
	2005-2007	13.0
	2007-2008	12.1
	2007-2009	11.1
	2008-2010	10.3
	2009-2011	9.6
	2010-2012	8.5
511071005	2000-2002	13.8
	2001-2003	13.5
	2002-2004	13.6
	2003-2005	13.9
	2004-2006	13.6
	2005-2007	13.2
	2007-2008	12.2
	2007-2009	11.2
	2008-2010	10.3
	2009-2011	9.5
	2010-2012	9.5
510595001	2000-2002	14.6
	2001-2003	14.1
	2002-2004	13.8
	2003-2005	14.0
	2004-2006	13.7
	2005-2007	13.7
	2006-2008	12.7
	2007-2009	11.7
Overall median	2000-2012	13.4

Table A-2 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
GWMP_MICR	6/8/05	7.81	9.39	18.8	1624	650.00	2.5	0.5155
GWMP_MICR	9/27/05	7.41	3.7	19.55	1208	679.00	2.2	0.2447
GWMP_MICR	11/1/05	7.76	10.67	10.3	220	690.00	2.8	0.0620
GWMP_MICR	12/5/05	7.71	10.32	4.8	1320	3629.00	0.5	0.0979
GWMP_MICR	1/5/06	7.37	4.85	6.9	1980	735.00	1.9	0.3524
GWMP_MICR	2/16/06	7.45	10.27	4.8	712	1544.00	1.3	0.0163
GWMP_MICR	3/13/06	7.97	5.65	12.4	1824	714.00	2.3	0.0914
GWMP_MICR	4/6/06	7.88	2.75	9.9	1928	700.00	1.5	0.0653
GWMP_MICR	5/2/06	7.85	1.88	12	1952	678.00	2.4	0.0979

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_MICR	6/15/06	7.73	5.51	17.3	1848	593.00	1.0	0.0228
GWMP_MICR	7/12/06	7.62	5.98	21.8	2000	722.00	2.7	0.1599
GWMP_MICR	8/7/06	7.73	6.27	23.6	848	206.40	1.0	1.7684
GWMP_MICR	9/25/06	7.41	8.18	17.6	2136	812.00	2.8	0.3230
GWMP_MICR	10/19/06	7.84	6.92	15.5	1900	512.50	2.1	1.0225
GWMP_MICR	12/5/06	8.075	9.55	3.8	1820	706.00	2.7	1.0401
GWMP_MICR	1/12/07	7.93	10.7755	4.9	1808	646.50	4.1	1.8793
GWMP_MICR	2/16/07							0.2055
GWMP_MICR	4/2/07	7.9	9.38	11.6	1136	1074.00	1.89	0.2382
GWMP_MICR	5/9/07	7.88	8.05	14.5	1984	769.50	2.91	
GWMP_MICR	6/7/07	7.97	7.53	18.0	1992	755.00	1.54	0.0555
GWMP_MICR	7/24/07	7.65	5.72	19.9	2272	791.00	1.3	0.0163
GWMP_MICR	8/22/07	7.88	7.55	19.0	2120	492.00	0.6	0.0718
GWMP_MICR	1/31/08	7.66	13.11	2.25	2176	1691.00	3.2	
GWMP_MICR	2/27/08	8.14	11.12	4.9	2112	3528.00	3.3	
GWMP_MICR	3/19/08	8.53	11.8	10.1	2184	859.00	2.8	
GWMP_MICR	6/23/08	7.98	9.82	21.15	2220	769.00	3.4	
GWMP_MICR	8/26/08	8.06	7.84	19.9	594	837.00	2.6	
GWMP_MICR	10/22/08	7.94	14.5	11.1	2140	612.50	2.5	
GWMP_MICR	11/19/08	7.93	11.96	6.05	2280	587.50	1.8	
GWMP_MICR	2/4/09	7.92	19.8	2.5	1912	2754.50	3.7	0.0750
GWMP_MICR	4/6/09	8.28	9.26	13.7	2096	749.50	3.0	0.0783
GWMP_MICR	6/9/09	7.93	8.2	21.2	1600	387.00	2.0	0.1468
GWMP_MICR	7/8/09	8.02	9.1	18.8	2184	698.00	3.6	0.1044
GWMP_MICR	7/21/09	8.07	8.1	20.5	2240	728.00	3.4	0.1077
GWMP_MICR	8/17/09	8.01	7.6	22.4	2232	722.00	3.0	0.0783
GWMP_MICR	9/15/09	7.95	8.6	19.0	1680	707.00	6.3	0.2023
GWMP_MICR	10/13/09	7.94	9.7	13.0	2032	717.00	3.0	0.1240
GWMP_MICR	11/10/09	8.06	10.5	12.4	2280	675.00	1.3	0.0946
GWMP_MICR	12/8/09	8.18	13.0	6.4	1952	1126.00	2.9	0.0750
GWMP_MICR	1/12/10	8.15	14.5	1.9	1888	1270.00	3.1	0.0555
GWMP_MICR	3/9/10	8.95	12.3	9.4	1744	909.00	1.5	0.1240
GWMP_MICR	4/6/10	8.98	10.1	19.0	1832	822.00	2.6	0.1958
GWMP_MICR	5/4/10	7.87	8.0	19.0	1920	777.00	2.0	0.1664
GWMP_MICR	6/8/10	7.95	9.1	19.0	2112	774.00	2.7	0.0816
GWMP_MICR	7/13/10	7.88	7.8	22.6	1080	464.50	1.8	0.1599
GWMP_MICR	8/9/10	7.94	8.0	23.2	2200	781.00	2.9	0.1109
GWMP_MICR	9/15/10	7.71	8.9	17.6	1984	796.00	3.2	0.2088
GWMP_MICR	10/13/10	7.33	9.49	15.1	1120	796.00	4.8	0.1925
GWMP_MICR	11/8/10	7.95	11.3	8.6	2040	745.00	2.5	0.2284
GWMP_MICR	12/6/10	8.16	13.8	3.0	1656	795.70	3.7	0.2088
GWMP_MICR	1/5/11	7.92	12.9	8.1	1848	971.00	3.7	0.1272
GWMP_MICR	2/7/11	7.98	13.8	4.9	1656	1064.00	1.9	0.1175
GWMP_MICR	3/9/11				*Non-detect			
GWMP_MICR	4/4/11	8.77	12.0	12.9	1808	824.00	2.7	0.1109
GWMP_MICR	5/2/11	8.09	9.7	15.6	2008	836.00	2.7	0.1892
GWMP_MICR	6/8/11	7.86	8.2	19.9	1776	792.00	2.1	0.1860
GWMP_MICR	7/12/11	7.9	7.1	23.4	2096	440.60	1.1	0.0979
GWMP_MICR	8/8/11	7.74	6.8	28.0	2200	445.20	0.8	0.1305
GWMP_MICR	9/13/11	7.94	8.6	20.4	1496	815.00	2.7	0.1827
GWMP_MICR	10/20/11	7.58	8.8	15.2	1760	435.00	1.1	0.0979

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_MICR	11/8/11	7.87	11.5	8.6	2120	834.00	2.7	0.1697
GWMP_MICR	12/6/11	7.74	9.7	12.1	1776	570.80	2.6	0.2643
GWMP_MICR	1/10/12	8.00	13.1	5.7	1848	904.00	4.1	0.0914
GWMP_MICR	2/7/12	8.31	13.2	6.7	2016	1757.00	3.0	0.1827
GWMP_MICR	3/6/12	8.13	13.9	6.6	2032	768.30	4.1	0.1272
GWMP_MICR	4/10/12	8.70	11.4	12.6	1928	754.00	3.0	0.0881
GWMP_MICR	5/10/12	7.96	9.3	15.5	1744	176.30	1.3	0.0816
GWMP_MICR	6/13/12	7.83	8.8	19.6	1520	477.90	1.1	0.1077
GWMP_MICR	7/12/12	7.92	7.4	21.5	2088	560.00	0.9	0.0946
GWMP_MICR	8/9/12	7.94	7.7	23.0	2528	784.00	1.4	0.1175
GWMP_MICR	9/13/12	8.05	9.2	17.7	2288	784.00	2.1	0.1599
GWMP_MICR	10/4/12	7.95	9.3	19.6	2168	705.00	2.1	0.1370
GWMP_MICR	11/5/12	8.14	11.3	11.9	1320	399.80	1.8	0.2577
GWMP_MICR	12/4/12	8.21	11.7	10.7	2272	737.00	2.2	0.1958
GWMP_MICR	1/8/13	8.28	14.4	4.6	2096	729.50	3.6	0.1436
GWMP_MICR	2/6/13	8.57	14.8	4.8	1968	887.00	3.4	0.1077
GWMP_MICR	3/5/13	8.63	12.8	5.2	2040	739.10	2.4	0.0392
GWMP_MICR	4/2/13	8.87	12.0	9.6	1936	782.00		
GWMP_MICR	4/30/13	7.95	10.25	14.3	1904	604.85		
GWMP_MIRU	6/14/05	7.66	8.48	22.05	554	132.80	1.3	0.1403
GWMP_MIRU	9/27/05	7.35	7.47	18.85	396	136.50	0.8	0.0848
GWMP_MIRU	11/1/05	7.33	8.91	10.0	Present <QL	139.80	1.4	0.3002
GWMP_MIRU	12/5/05	7.12	9.19	4.05	482	197.40	1.3	0.0816
GWMP_MIRU	1/10/06		4.43	6.2	624	147.70	1.4	
GWMP_MIRU	2/16/06	6.83	11.36	4.6	Present <QL	128.10	1.5	0.0555
GWMP_MIRU	3/13/06	7.79	4.43	13.75	584	132.20	2.0	0.3524
GWMP_MIRU	4/6/06	7.6	3.82	11.35	648	130.10	1.1	
GWMP_MIRU	5/2/06	7.63	2.22	13.0	616	129.60	1.4	0.3393
GWMP_MIRU	6/15/06	7.53	7.57	17.5	796	137.40	1.4	0.3230
GWMP_MIRU	7/12/06	7.29	6.31	22.5	664	127.60	1.3	
GWMP_MIRU	8/7/06	7.48	6.95	22.5	712	133.90	1.3	0.3622
GWMP_MIRU	9/25/06	7.38	7.98	17.4	664	137.20	1.3	1.4323
GWMP_MIRU	10/19/06	7.56	9.1	15.05	288	136.90	1.2	0.4209
GWMP_MIRU	12/5/06	8.04	11.06	4.1	560	134.50	1.9	0.2316
GWMP_MIRU	1/11/07	7.36	11.64	3.35	576	133.00	2.8	0.2480
GWMP_MIRU	4/2/07	8.09	8.46	14.425	600	142.93	1.58	0.0424
GWMP_MIRU	5/9/07	7.5	8.015	15.3	776	142.18	2.1	0.0196
GWMP_MIRU	6/7/07	7.55	6.125	18.05	840	143.05	1.57	0.1142
GWMP_MIRU	7/24/07	7.32	6.24	19.6	912	138.00	1.0	
GWMP_MIRU	8/22/07	7.51	6.88	18.8	848	168.50	0.8	
GWMP_MIRU	9/25/07	7.4	6.31	17.6	896	133.80	1.7	
GWMP_MIRU	10/23/07	7.16	4.81	16.2	1112	135.90	1.1	
GWMP_MIRU	11/19/07	7.54	6.92	8.1	976	143.50	2.4	
GWMP_MIRU	12/17/07	7.55	10.64	3.2	896	149.80	2.3	
GWMP_MIRU	1/31/08	7.45	10.87	2.6	952	155.25	2.7	
GWMP_MIRU	2/27/08	7.7	10.36	5.1	976	143.10	1.9	
GWMP_MIRU	3/19/08	7.77	9.89	10.35	904	153.55	2.1	
GWMP_MIRU	4/23/08	7.5	8.52	17.05	904	129.35	1.9	
GWMP_MIRU	5/15/08	7.56	7.53	15.5	824	122.20	2.4	

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_MIRU	6/23/08	7.59	7.31	20.85	928	143.25	1.6	
GWMP_MIRU	7/28/08	7.7	6.04	20.9	714	139.45	1.5	
GWMP_MIRU	8/26/08	7.68	7.75	19.7	Present <QL	145.95	1.5	
GWMP_MIRU	9/23/08	7.41	8.09	17.7	720	121.90	1.3	
GWMP_MIRU	10/23/08	7.55	10.39	8.6	824	143.20	1.6	
GWMP_MIRU	11/17/08	7.36	10.53	7.8	856	143.55	1.5	
GWMP_MIRU	1/22/09	7.09		0.2	680	156.46	3.2	0.0587
GWMP_MIRU	3/30/09	7.37	10.74	9.0	204	144.20	2.1	0.0620
GWMP_MIRU	4/27/09	7.47	8.41	18.0	936	145.50	1.7	0.0750
GWMP_MIRU	5/27/09	7.59	9.2	16.5	744	115.60	1.8	0.1403
GWMP_MIRU	7/6/09	7.63	8.5	18.1	800	135.60	1.7	0.0718
GWMP_MIRU	7/29/09	7.6	8.05	22.1	984	150.25	1.8	0.0653
GWMP_MIRU	8/27/09	7.6	7.8	21.55	1104	134.85	1.7	0.0620
GWMP_MIRU	9/24/09	7.52	8.2	19.9	832	141.50	1.9	0.0620
GWMP_MIRU	10/22/09	7.52	10.4	11.2	1488	146.10	1.4	0.1011
GWMP_MIRU	11/19/09	7.62	10.2	11.9	808	146.95	1.5	0.0457
GWMP_MIRU	12/10/09	7.47	12.4	5.65	616	139.75	1.4	0.2186
GWMP_MIRU	1/21/10	7.65	14.0	3.2	720	165.70	2.6	0.1468
GWMP_MIRU	3/18/10	7.62	11.95	8.3	856	163.00	1.8	0.0555
GWMP_MIRU	4/15/10	7.56	11.35	11.2	920	162.85	2.2	0.0620
GWMP_MIRU	5/13/10	7.68	9.4	14.0	760	158.65	2.1	0.0555
GWMP_MIRU	6/17/10	7.63	7.85	20.9	760	157.15	1.9	0.0685
GWMP_MIRU	7/19/10	7.63	7.4	24.0	576	141.50	1.9	0.0979
GWMP_MIRU	8/19/10	7.6	7.3	22.2	792	146.10	1.3	0.0914
GWMP_MIRU	9/22/10	7.57	7.9	17.3	896	149.40	2.2	0.2219
GWMP_MIRU	10/20/10	7.13	9.73	12.2	944	140.00	2.1	0.0424
GWMP_MIRU	11/10/10	7.54	10.9	8.8	872	151.60	2.0	0.0587
GWMP_MIRU	12/9/10	7.58	14.5	0.25	808	164.60	2.6	0.1142
GWMP_MIRU	1/13/11	7.8	16.6	7.4	3376	168.60	3.3	0.0555
GWMP_MIRU	2/14/11	7.66	13.15	6.6	968	166.50	1.7	0.1403
GWMP_MIRU	4/13/11	7.46	9.8	12.8	840	137.55	1.2	0.1403
GWMP_MIRU	5/9/11	7.58	9.05	14.4	792	162.55	1.9	0.0457
GWMP_MIRU	6/15/11	7.6	8.45	17.0	1144	161.65	1.2	0.0816
GWMP_MIRU	7/20/11	7.55	7.3	22.9	912	161.80	1.4	0.0881
GWMP_MIRU	8/18/11	7.51	7.3	21.2	952	166.10	1.2	0.0555
GWMP_MIRU	9/15/11	7.48	7.8	20.1	832	134.00	1.8	0.1566
GWMP_MIRU	10/20/11	7.25	8.3	15.3	888	136.80	1.5	0.0587
GWMP_MIRU	11/14/11	7.56	10.2	11.45	880	170.90	2.0	0.0424
GWMP_MIRU	12/8/11	7.35	10.9	7.6	664	111.85	1.7	0.1109
GWMP_MIRU	1/19/12	7.31	13.7	4.6	824	148.70	2.6	0.0261
GWMP_MIRU	2/13/12	7.8	11.5	8.9	912	163.80	2.6	0.1175
GWMP_MIRU	3/8/12	7.58	11.6	10.5	840	159.20	2.2	0.0489
GWMP_MIRU	4/17/12	7.79	9.3	16.9	896	164.20	1.7	0.0653
GWMP_MIRU	5/21/12	7.61	8.7	17.7	1048	142.50	1.3	0.2088
GWMP_MIRU	6/18/12	7.7	8.6	17.7	896	152.40	1.4	0.2121
GWMP_MIRU	7/16/12	7.68	7.4	22.5	1104	157.50	1.5	0.0750
GWMP_MIRU	8/16/12	7.74	7.8	20.8	984	179.90	1	0.1338
GWMP_MIRU	9/13/12	7.62	8.8	16.3	1000	177.90	1.1	0.1631
GWMP_MIRU	10/10/12	7.64	9.4	13.6	1120	154.70	1.1	0.2088
GWMP_MIRU	11/8/12	7.93	12.9	6.5	880	144.80	2.1	0.2284

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_MIRU	12/13/12	7.78	13.55	5.4	920	154.90	2.2	0.1533
GWMP_MIRU	1/29/13	8.13	14.5	5.4	840	161.10	2.3	0.0979
GWMP_MIRU	2/25/13	7.83	12.8	6.2	800	160.10	2	0.0392
GWMP_MIRU	3/28/13	7.94	11.9	7.6	880	169.05	2	0.0946
GWMP_MIRU	4/23/13	7.94	10.9	11.6	864	164.70		
GWMP_MIRU	5/21/13	7.65	8.9	18.4	880	142.80		
GWMP_PIRU	6/6/05	7.77	7.89	22.65	720	298.50	2.4	0.5155
GWMP_PIRU	9/27/05	7.8	7.8	20.15	332	325.80	1.1	0.0457
GWMP_PIRU	11/1/05	7.83	10.81	12.7	Present <QL	295.20	2.3	0.2741
GWMP_PIRU	12/5/05	7.57	8.34	3.85	604	624.50	1.4	0.0555
GWMP_PIRU	1/10/06		6.37	6.6	750	321.00	1.9	0.1044
GWMP_PIRU	2/16/06	7.56	11.5	6.1	540	861.70	0.8	0.0131
GWMP_PIRU	3/13/06	9.19	6.2	16.37	832	300.10	1.9	0.1011
GWMP_PIRU	4/6/06	8.02	4.36	14.25	904	327.40	1.7	0.1599
GWMP_PIRU	5/2/06	8.09	1.99	16.9		293.00	2.2	0.3328
GWMP_PIRU	6/15/06	7.94	7.76	20.5	952	268.60	1	0.7308
GWMP_PIRU	7/12/06	8.89	6.7	25.9	872	289.90	1.5	0.3295
GWMP_PIRU	8/7/06	7.58	5.56	26.5	584	199.30	1.5	1.2659
GWMP_PIRU	9/25/06	7.78	6.98	18.9	1064	349.57	1.8	0.8940
GWMP_PIRU	10/19/06	7.88	8.24	16.1	720	214.27	1.4	0.5351
GWMP_PIRU	12/5/06		11.037	4.733	1194	301.90	2.5	0.2773
GWMP_PIRU	1/12/07	7.68	10.847	4.4	816	282.30	3.3	0.3067
GWMP_PIRU	4/2/07	9.3	7.883	17.2	848	344.60	1.73	0.0620
GWMP_PIRU	5/14/07	7.547	6.247	16.6	984	296.15	1.78	0.0653
GWMP_PIRU	6/7/07	7.617	5.95	17.8	1064	316.12	1.54	0.1305
GWMP_PIRU	7/24/07	7.52	5.36	20.5	1200	351.30	0.7	
GWMP_PIRU	8/22/07	6.89	7.3	19.5	688	172.10	1.3	
GWMP_PIRU	9/25/07	7.31	6.68	18.2	1224	370.20	1.7	
GWMP_PIRU	10/23/07	7.02	4.99	16.9	1088	303.00	1.7	
GWMP_PIRU	11/19/07	7.11	6.93	8.2	1192	245.70	2.9	
GWMP_PIRU	12/17/07	7.8	9.9	3.0	936	403.00	2	
GWMP_PIRU	1/31/08	7.76	14.77	1.38	1160	428.15	3.1	
GWMP_PIRU	2/27/08	8.15	11.88	4.52	1192	969.67	3	
GWMP_PIRU	3/19/08	7.98	10.3	9.53	1280	351.20	2.5	
GWMP_PIRU	4/23/08	7.79	10.42	15.3	1320	276.35	2.2	
GWMP_PIRU	5/15/08	7.73	8.28	15.15	1320	307.20	3	
GWMP_PIRU	6/23/08	7.71	8.69	21.22	1064	246.93	1.8	
GWMP_PIRU	7/28/08	7.49	6.77	21.78	850	265.05	2	
GWMP_PIRU	8/26/08	7.86	6.96	21.2	1112	415.57	1.3	
GWMP_PIRU	9/23/08	7.43	8.31	18.69	992	345.24	1.7	
GWMP_PIRU	10/23/08	7.41	10.96	8.36	1072	358.53	1.7	
GWMP_PIRU	11/17/08	7.31	9.15	7.44	1224	211.24	0.8	
GWMP_PIRU	1/22/09	7.61	17.5	0.15	960	341.95	4.1	0.0587
GWMP_PIRU	3/30/09	7.67	9.65	9.5	278	445.70	1.8	0.0522
GWMP_PIRU	4/27/09	7.42	8.44	18.4	1216	343.50	2.3	0.0979
GWMP_PIRU	5/27/09	7.8	9.18	16.5	936	223.30	1.8	0.1175
GWMP_PIRU	7/6/09	7.78	8.2	18.5	1120	312.10	2.3	0.0914
GWMP_PIRU	7/29/09	7.83	7.28	23.7	1016	286.95	1.9	0.0718
GWMP_PIRU	8/27/09	7.75	7.72	22.42	1168	287.58	1.7	0.0685

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_PIRU	9/24/09	7.61	7.23	20.8	984	356.27	Present <QL	0.0555
GWMP_PIRU	10/22/09	7.67	10.65	10.9	848	284.80	2.2	0.0489
GWMP_PIRU	11/19/09	7.79	10.05	11.5	1072	313.55	1.8	0.8711
GWMP_PIRU	12/10/09	7.77	12.8	6	960	327.65	1.5	0.1697
GWMP_PIRU	1/21/10	7.84	13.85	3.02	992	497.98	2.5	0.1272
GWMP_PIRU	3/18/10	7.67	11.8	8.05	1312	384.45	2.1	0.0457
GWMP_PIRU	4/15/10	7.66	11.12	10.9	1240	360.20	3	0.0587
GWMP_PIRU	5/13/10	7.78	9.4	14.2	1000	359.35	2.2	0.0555
GWMP_PIRU	6/17/10	7.57	7.38	21.38	1000	307.18	2.2	0.0587
GWMP_PIRU	7/19/10	7.56	7.45	24.7	392	128.35	1.6	0.1468
GWMP_PIRU	8/19/10	7.57	7.63	22	728	183.17	2.2	0.1240
GWMP_PIRU	9/22/10	7.6	7.4	17.7	1064	360.47	3.3	0.2708
GWMP_PIRU	10/20/10	7.22	8.41	12.9	1272	336.48	3.1	0.1599
GWMP_PIRU	11/10/10	7.78	11.27	8.3	1072	358.43	2.7	0.0946
GWMP_PIRU	2/14/11	8.16	14.35	4.43	1096	531.80	1.9	0.0946
GWMP_PIRU	4/13/11	7.43	10.0	12.2	968	144.60	1	0.2675
GWMP_PIRU	5/9/11	7.64	9.23	14.7	1064	369.15	2.5	0.0489
GWMP_PIRU	6/15/11	7.65	8.22	17.98	1040	329.60	1.6	0.0620
GWMP_PIRU	7/20/11	7.94	7.2	25.4	1096	343.30	1.4	0.0489
GWMP_PIRU	8/18/11	7.77	6.65	22.65	920	254.80	1.1	0.0620
GWMP_PIRU	9/15/11	7.82	7.93	20.9	1088	373.27	2.2	0.1533
GWMP_PIRU	10/20/11	7.56	8.5	16	976	200.00	1.7	0.0848
GWMP_PIRU	11/14/11	8.28	11.4	10.3	1200	396.90	1.7	0.0489
GWMP_PIRU	12/8/11	7.45	10.85	7.5	792	161.10	1.7	0.1468
GWMP_PIRU	1/19/12	7.29	12.6	5.8	1024	281.70	2.4	0.0326
GWMP_PIRU	2/13/12	7.7	12.1	8.4	1128	485.90	2.4	0.1729
GWMP_PIRU	3/8/12	8.02	12.67	9.3	1104	362.07	2.7	0.0457
GWMP_PIRU	4/17/12	8.3	9.38	17.88	1232	348.52	2.3	0.0587
GWMP_PIRU	5/21/12	7.86	8.8	18.7	1176	155.10	1.8	0.3393
GWMP_PIRU	6/18/12	7.8	8.4	19.1	1000	298.20	1.9	0.2088
GWMP_PIRU	7/16/12	7.85	6.67	24.17	1216	282.67	1	0.1011
GWMP_PIRU	8/16/12	7.63	5.63	22.03	1176	300.87	0.8	0.0881
GWMP_PIRU	9/13/12	7.81	8.8	16.9	1568	280.65	0.6	0.1207
GWMP_PIRU	10/10/12	7.69	10.0	13.8	1120	255.75	1.2	0.1077
GWMP_PIRU	11/8/12	7.71	13.0	5.9	1104	338.75	2.3	0.0750
GWMP_PIRU	12/13/12	7.6	13.7	4.9	1232	292.40	1.4	0.1207
GWMP_PIRU	1/29/13	8.14	14.75	4.3	968	2130.00	2.3	0.2447
GWMP_PIRU	2/25/13	7.9	12.7	6.3	1040	511.20	2.1	0.0522
GWMP_PIRU	3/28/13	8.05	12.5	7.9	1096	651.40	2.3	0.0979
GWMP_PIRU	4/23/13	8.4	10.25	13.8	1200	332.90		
GWMP_PIRU	5/21/13	8.02	8.4	22.7	1232	351.50		
GWMP_TURU	6/6/05	7.6	9.31	17.65	1172	307.10	2	0.6917
GWMP_TURU	9/27/05	7.67	7.79	18.45	1024	400.50	1	0.3230
GWMP_TURU	11/1/05	7.98	10.88	12.6	Present <QL	337.70	1.9	0.2512
GWMP_TURU	12/5/05	7.835	8.79	3.575	1038	729.00	1.2	0.2643
GWMP_TURU	1/10/06		4.31	6.4	1320	331.50	1.4	0.1827
GWMP_TURU	2/16/06	7.825	10.9	4.9	1096	432.75	0.8	0.2219
GWMP_TURU	3/13/06	8.74	4.58	14.8	1096	306.30	1.1	0.1109
GWMP_TURU	4/6/06	8.85	4.31	12.85	1216	304.90	0.9	0.2023

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_TURU	5/2/06	8.05	1.91	14	1216	311.00	1.7	0.5971
GWMP_TURU	6/15/06	7.84	8.14	17.5	1392	343.00	1.5	0.9299
GWMP_TURU	7/12/06	7.96	7.3	22.7	1280	330.80	1.7	0.4372
GWMP_TURU	8/7/06	7.86	6.27	23.2	1016	238.80	1.6	0.3719
GWMP_TURU	9/25/06	7.66	6.21	17.5	1392	348.17	1.9	1.8630
GWMP_TURU	10/19/06	7.87	8.45	15.1	1460	331.30	1.5	0.5057
GWMP_TURU	12/5/06	7.66	11.24	3.7	1200	334.40	2	0.5024
GWMP_TURU	1/12/07	8.675	11.57	4.35	1152	305.40	2.3	0.2643
GWMP_TURU	4/2/07	9.277	8.737	17.133	1224	333.48	0.62	0.0783
GWMP_TURU	5/9/07	8.04	7.47	15.433	1360	363.48	2.07	0.0424
GWMP_TURU	6/7/07	7.87	6.673	15.8	1520	360.27	1.81	0.1011
GWMP_TURU	7/24/07	7.74	7.42	18.7	1512	370.60	1.1	
GWMP_TURU	8/22/07	7.72	7.3	18.8	1136	381.30	0.8	
GWMP_TURU	9/25/07	7.6	7.08	16.6	1560	385.90	1.6	
GWMP_TURU	10/23/07	7.5	5.82	16.2	1536	358.10	1.7	
GWMP_TURU	11/19/07	7.8	9.97	7.3	1672	359.30	2.2	
GWMP_TURU	12/17/07	7.66	11.57	3	888	394.10	2	
GWMP_TURU	2/27/08	7.89	11.59	5	1760	704.50	1.2	
GWMP_TURU	3/19/08	7.82	10.09	9.45	1544	507.00	2.2	
GWMP_TURU	4/23/08	7.94	10.54	14.3	1560	274.82	1.8	
GWMP_TURU	5/15/08	7.8	6.54	14.25	1248	288.45	2.6	
GWMP_TURU	6/23/08	7.78	7.61	19.5	1648	343.28	1.9	
GWMP_TURU	7/28/08	7.62	6.1	20.55	1260	257.40	1.6	
GWMP_TURU	8/26/08	7.89	5.93	19.08		348.10	1.7	
GWMP_TURU	9/23/08	7.75	7.8	17.5	1480	350.45	2.2	
GWMP_TURU	10/23/08	7.64	9.52	7.78	1536	375.65	1.9	
GWMP_TURU	11/17/08	7.68	10.26	7	1568	311.52	1	
GWMP_TURU	1/22/09	7.72		0.15	1336	347.19	3.4	0.0620
GWMP_TURU	3/30/09	7.73	8.86	8.5	360	347.10	2.2	0.0555
GWMP_TURU	4/27/09	7.61	9.19	16.9	1792	322.00	1.4	0.0750
GWMP_TURU	5/27/09	7.8	9.25	14.9	1440	288.05	2.4	0.0979
GWMP_TURU	7/6/09	7.84	9	16.9	1480	316.25	2.3	0.0946
GWMP_TURU	7/29/09	7.78	7.55	21	1112	342.20	2.3	0.0750
GWMP_TURU	8/27/09	7.8	6.85	20.8	1480	345.25	2.3	0.0848
GWMP_TURU	9/24/09	7.68	7.55	19.25	1256	347.20	2.3	0.0392
GWMP_TURU	10/22/09	7.65	10.35	10.6	1024	359.45	2.4	0.0914
GWMP_TURU	11/19/09	7.68	9.55	11.45	1512	360.10	2.6	
GWMP_TURU	12/10/09	7.73	12.35	5.7	1184	264.10	1.1	0.1207
GWMP_TURU	1/21/10	7.92	13.7	2.35	1424	395.85	2.4	0.1207
GWMP_TURU	3/18/10	7.76	12.25	6.6	1424	313.60	2	0.0392
GWMP_TURU	4/15/10	7.81	11.3	9.6	1664	348.05	2	0.0424
GWMP_TURU	5/13/10	7.72	9.3	12.7	1440	338.55	1.8	0.0848
GWMP_TURU	6/17/10	7.7	7.65	19.3	1440	373.90	2.8	0.1109
GWMP_TURU	7/19/10	7.58	6.85	22.1	688	224.85	2	0.1794
GWMP_TURU	8/19/10	7.52	7	20.4	976	238.35	2.1	0.0946
GWMP_TURU	9/22/10	7.71	8.6	16.55	1464	358.55	3.6	0.2316
GWMP_TURU	10/20/10	7.18	8.36	12.05	1560	330.80	3.4	0.0750
GWMP_TURU	11/10/10	7.72	10.15	8.3	1480	354.10	2.3	0.0783
GWMP_TURU	2/14/11	7.79	12.6	6.1	1056	355.25	1.5	0.1762
GWMP_TURU	4/13/11	7.42	10	11.5	864	137.90	0.8	0.1990
GWMP_TURU	5/9/11	7.64	9.25	13.15	1696	380.10	2.5	0.0555

Site	Date	pH	DO	Temp	ANC	Cond	NO_3	TP
GWMP_TURU	6/15/11	7.74	8.7	16.1	1560	387.70	1.7	0.0848
GWMP_TURU	7/20/11	7.67	7.45	22.5	1584	386.65	1.9	0.0783
GWMP_TURU	8/18/11	7.52	7.05	20.75	1544	374.55	1.3	0.0750
GWMP_TURU	9/15/11	7.7	8.2	19.1	1448	356.40	2.4	0.2153
GWMP_TURU	10/20/11	7.42	7.75	14.85	1392	302.70	1.2	0.0718
GWMP_TURU	11/14/11	7.88	10.65	11.3	1584	400.50	1.8	0.0750
GWMP_TURU	12/8/11	7.14	10.8	7.4	1048	209.40	1.2	0.1044
GWMP_TURU	1/19/12	7.24	13.6	5	1456	363.00	2.6	0.0326
GWMP_TURU	2/13/12	7.68	11.2	7.8	1544	443.70	2.3	0.2414
GWMP_TURU	3/8/12	7.95	11.55	9.35	1408	367.25	2	0.0587
GWMP_TURU	4/17/12	7.88	8.45	16.1	1824	376.55	1.8	0.0522
GWMP_TURU	5/21/12	7.79	8.35	16.8	1640	333.85	2.2	0.2480
GWMP_TURU	6/18/12	7.94	7.75	16.95	1624	1866.25	2.2	0.1664
GWMP_TURU	7/16/12	7.82	5.9	21.75	1752	345.15	1.9	0.1011
GWMP_TURU	8/16/12	7.91	5.95	20.2	1632	401.90	1.4	0.1207
GWMP_TURU	9/13/12	7.84	9.45	15.6	1608	412.30	1.5	0.3589
GWMP_TURU	10/10/12	7.91	8.85	13.2	1736	327.20	2	0.1533
GWMP_TURU	11/8/12	8.32	12.45	6.15	1584	381.55	2.2	0.1240
GWMP_TURU	12/13/12	8.12	13.45	4.4	1680	403.45	1.8	0.2969
GWMP_TURU	1/29/13	8.25	13.9	6	1488	549.90	2.1	0.1403
GWMP_TURU	2/25/13	7.74	13.2	6.5	1424	367.85	2.1	0.0392
GWMP_TURU	3/28/13	8.36	11.95	7.3	1480	413.20	1.8	0.0750
GWMP_TURU	4/23/13	8.31	11.15	12.3	1568	348.15		
GWMP_TURU	5/21/13	7.8	8.1	19.1	1736	360.35		
Overall median		7.74	8.90	14.41	1152	338.13	1.90	0.11

Table A-3 Deer density (deer/km2) in GWMP. Deer counting routes are shown in **Figure 4-21** and reference conditions are shown in **Table 4-8**.

Year	Density
2001	33.90
2002	27.55
2003	36.42
2004	9.43
2005	47.47
2006	29.66
2007	46.81
2008	25.62
2009	47.49
2010	56.58
2011	36.53
2012	34.03
2013	13.26
2014	20.83
Overall median	33.97

Appendix B: Resource Brief

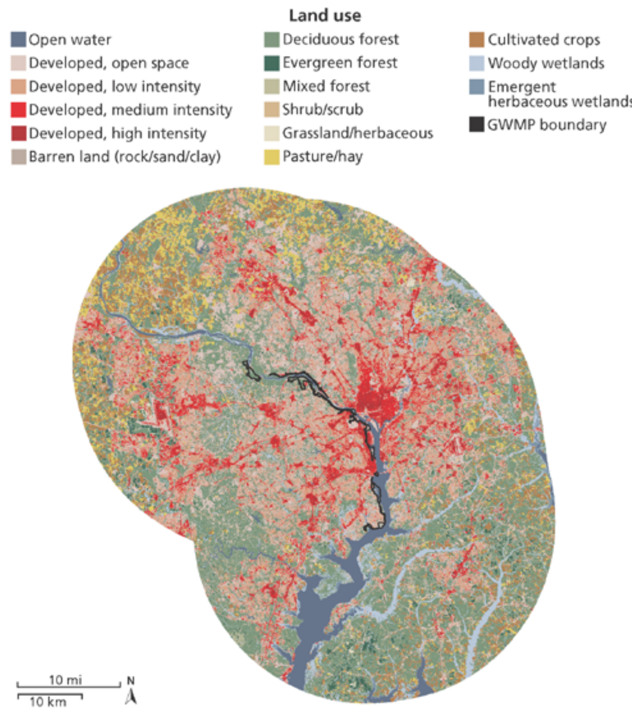
George Washington Memorial Parkway
Natural Resource Condition Assessment Brief

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 George Washington Memorial Parkway.

George Washington Memorial Parkway (GWMP) was developed as a scenic parkway to help preserve the Potomac River Gorge and shoreline while serving as a memorial to the first President of the United States, George Washington. The Potomac Gorge is one of the most significant natural areas in the United States, and is home to more than 400 occurrences of over 200 rare species and communities. The park houses several unique habitats, including a major river system with numerous tributaries, stands of upland forest, seeps and springs, and abundant wetlands. Today, GWMP occupies more than 7,300 acres (2954.2 ha), and extends 45 km (28 mi) connecting important historic, natural, and cultural sites from Mount Vernon to Great Falls Park, and providing a sanctuary for many rare and unique plant and animal species in the urbanized Washington, D.C. metropolitan area. Within the park there are 27 sites associated with George Washington's life, and the nation he helped establish. The parkway is a key transportation artery in northern Virginia, and although many local residents consider the parkway a commuter route, from its inception, the parkway was established as a recreational and environmental conservation area.

The natural resources of GWMP are challenged by multiple regional and local stressors. 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. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available to native flora and fauna. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion. Adverse recreational use within the park can lead to the trampling and loss of vegetation, potential introduction of non-native species, disturbance or displacement of flora and fauna. Exotic and invasive plants compete with native species, while insects and other pests cause damage to forest trees. Exotic plants are prevalent within the park. An overabundant population of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings.



Adjacent land use within a 30 km area surrounding George Washington Memorial Parkway in 2011 (Jin et al. 2013; NPS 2011b).

Features of, and threats to natural resources in George Washington Memorial Parkway.

Natural resource condition in George Washington Memorial Parkway

A total of 25 vital sign indicators were used to determine the natural resource condition of GWMP. 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.

KEY FINDINGS AND RECOMMENDATIONS

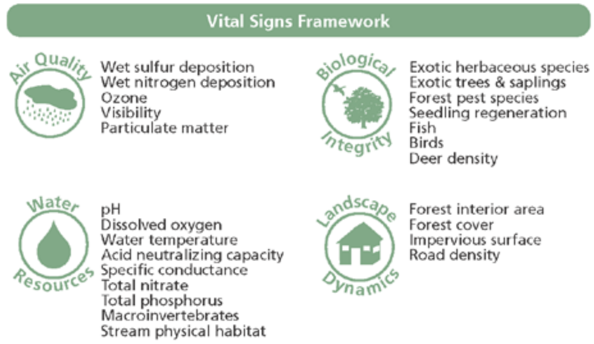
Overall, the natural resources of George Washington Memorial Parkway were in degraded condition.

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 begin beyond the park's borders, the specific implications to the habitats and species in the park are less well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts. The close connection between climate and air quality is reflected in the impacts of climate change on air pollution levels. In particular, the U.S. EPA has concluded that climate change could increase ozone concentrations and change the amount of particle pollution 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 offset by very degraded conditions for total phosphorus and macroinvertebrates, and degraded conditions for specific conductance and stream physical habitat. The majority of water inflows to the park originate from outside the park in developed/urban areas. Water quality is measured at four sites within the park—Minnehaha Creek, Mine Run, Pimmit Run, and Turkey Run. Of these four streams, only Mine Run originates within the park. Because the others do not originate in the park and only run through the park for a short distance, it would be informative to monitor water as it both enters and leaves the park.

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 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.

Landscape Dynamics Landscape dynamics were in very degraded condition overall. Very good condition for impervious surface was offset by very degraded conditions for forest interior area, forest cover and road density. 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.



The vital signs framework used to assess George Washington Memorial Parkway.

Vital Sign	Reference condition attainment	Current condition
Air Quality	9%	Very degraded
Water Resources	60%	Moderate
Biological Integrity	42%	Moderate
Landscape Dynamics	2%	Very degraded
GWMP	**28%**	**Degraded**

The overall reference condition attainment and current condition of each of the four vital signs within George Washington Memorial Parkway.

CONCLUSIONS

Natural resources in George Washington Memorial Parkway are in degraded 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.

Significant natural areas occur throughout GWMP that are extremely rich both in biodiversity and in historical context. The park provides islands of refuge for many rare and unique plant and animal species in the highly urbanized Washington, D.C. metropolitan area, protecting a variety of cultural and natural resources, including plant community types found nowhere else on earth. Finding species new to science is a regular occurrence within the park, and in the ten years of conducting its all taxa biotic index, 5,289 species have been documented, including 74 species new to science, 3 species new to North America, 84 new to Virginia, and 105 listed as rare in Virginia or Maryland. Additionally, GWMP provides opportunities for the public to foster awareness of the importance of species preservation, biological diversity, natural systems and processes, and the value of natural open space in an urban environment.

This brief is excerpted from: Walsh BM and Others. 2015. George Washington Memorial Parkway natural resource condition assessment: National Capital Region. Natural Resource Report NPS/PRWI/NRR—2015/XXX. National Park Service. Fort Collins, Colorado. Published Report-XXXXXX.

For more information, please visit the Park's Visitor Center or call (703) 289-2500.
George Washington Memorial Parkway
National Park Service
www.nps.gov/gwmp

Developed in collaboration with:

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

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

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Appendix C: Executive Summary

Background and context

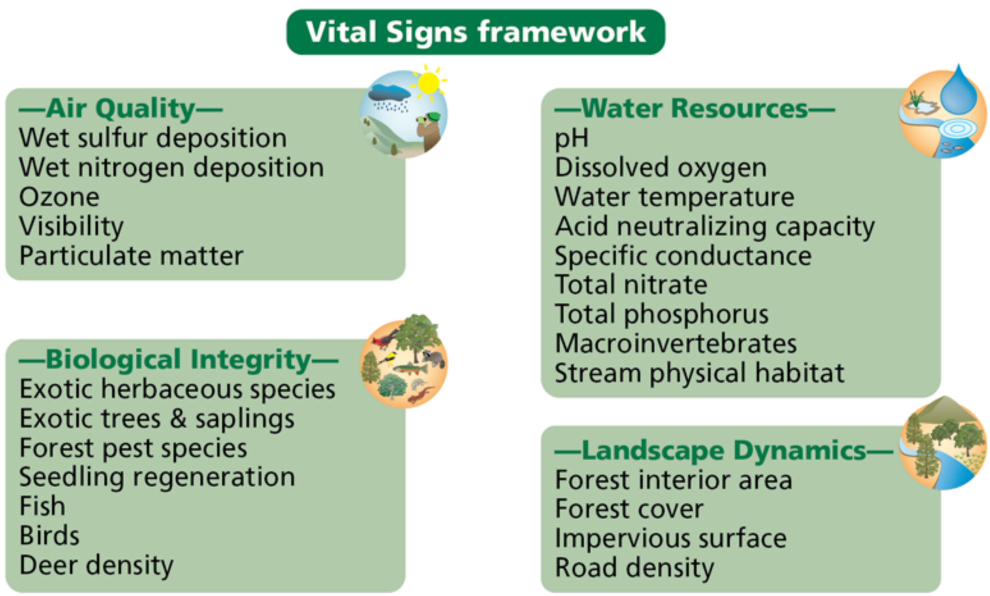
George Washington Memorial Parkway (GWMP) was developed as a scenic parkway to help preserve the Potomac River Gorge and shoreline while serving as a memorial to the first President of the United States, George Washington. The Potomac Gorge is one of the most significant natural areas in the United States, and is home to more than 400 occurrences of over 200 rare species and communities. The park also houses several unique habitats, including a major river system with numerous tributaries, noteworthy stands of upland forest, seeps and springs harboring rare groundwater fauna, and abundant wetlands (Allen and Flack 2001). Today, GWMP occupies more than 2,954 hectares (7,300 acres) of land, connecting some of the most important historic, natural, and cultural sites from Mount Vernon to Great Falls Park, and providing a sanctuary for many rare and unique plant and animal species in the urbanized Washington, D.C. metropolitan area (NPS 2014a). GWMP runs 45 km (28 mi) along the western shore of the Potomac River through the District of Columbia and portions of northern Virginia. Within the park there are 27 sites associated with George Washington's life, and the nation he helped establish. The parkway is a key transportation artery in northern Virginia, providing access to Washington, D.C., Arlington County, Fairfax County, and the City of Alexandria. Many local residents consider the parkway a commuter route, however from its inception, the parkway was established as a recreational and environmental conservation area (NPS 2008).

Significant natural areas occur throughout GWMP and are extremely rich both in biodiversity and in historical context. The park provides islands of refuge for many rare and unique plant and animal species in the highly urbanized Washington, D.C. metropolitan area, protecting a variety of cultural and natural resources, including plant community types found nowhere else on earth. Finding species new to science is a regular occurrence within the park, and in the ten years of conducting its all taxa biotic index, 5,289 species have been documented, including 74 species new to science, 3 species new to North America, 84 new to Virginia, and 105 listed as rare in Virginia or Maryland. Additionally, GWMP provides opportunities for the public to foster awareness of the importance of species preservation, biological diversity, natural systems and processes, and the value of natural open space in an urban environment.

The natural resources of GWMP are challenged by multiple regional and local stressors. 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. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available to native flora and fauna. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion. Adverse recreational use within the park can lead to the trampling and loss of vegetation, potential introduction of non-native species, and disturbance or displacement of flora and fauna. Exotic and invasive plants compete with native species, while insects and other pests cause damage to forest trees. Exotic plants are prevalent with the park. Excessive numbers of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings.

Approach

The Vital Signs framework was used to assess natural resource condition within George Washington Memorial Parkway. 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. Twenty-five metrics were synthesized 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 justified ecological threshold values.



Features of George Washington Memorial Parkway

Significant natural areas occur throughout George Washington Memorial Parkway and are extremely rich in both biodiversity and in historical context. The park provides islands of refuge for many rare and unique plant and animal species in the highly urbanized Washington, D.C. metropolitan area, protecting a variety of cultural and natural resources, including plant community types found nowhere else on earth. Finding species new to science is a regular occurrence within the park, and in the ten years of conducting its All Taxa Biotic Index, 5,289 species have been documented, including 74 species new to science, 3 species new to North America, 84 new to Virginia, and 105 listed as rare in Virginia or Maryland. Additionally, GWMP provides opportunities to foster public awareness of the importance of species preservation, biological diversity, natural systems and processes, and the value of natural open space in an urban environment.

Threats to George Washington Memorial Parkway

George Washington Memorial Parkway is among the ten most visited units of the National Park System. With the growth of Washington, D.C., and the surrounding areas, associated development pressures have consistently posed a significant problem for the parkway. Population and housing densities continue to increase in the areas adjacent to the park, which reduces the habitat available for native flora and fauna The effects of this intense visitation to the parkway and heavy demands for park services, from commuters on the parkway to bikers on the Mount Vernon Trail, place increasing demands on its protected areas. Off trail traffic by visitors threatens vegetation, can lead to the possible introduction of non-native species, and disturbance or displacement of wildlife. Some areas of George Washington Memorial Parkway are threatened by exotic invasive species that compete with native species. Some of the most prolific non-native species within GWMP were included on historical planting plans for the parkway developed by Wilbur Simonson in 1932. These include porcelainberry (*Ampelopsis brevipedunculata*), English ivy (*Hedera helix L.*), Japanese honeysuckle (*Lonicera japonica*), amur honeysuckle (*Lonicera maackii*), and linden viburnum (*Viburnum dilatatum*). Excessive numbers of white-tailed deer use the park as a refuge, resulting in overgrazing of native flora, particularly tree seedlings. In addition, collisions between wildlife and vehicles on the George Washington Memorial Parkway, now a high-speed commuter route in and out of the District of Columbia, are the major threat to top level predators and other large mammals in GWMP.

The walls of many of the river and tributary valleys along the parkway are high slopes, which make them hazardous because of the potential for rock falls, landslides, and slope creep. Historic quarrying for building stone along the Potomac Gorge has altered natural slopes. In addition, The Potomac River experiences daily 1 meter (3 feet) tidal fluctuations at Washington, D.C., which strongly influence the flow regime of the river and its subsequent channel morphology. Relative sea level rise and surges of water associated with hurricanes and storms affect the estuarine Potomac River and the shoreline of GWMP. Shoreline erosion is a continuing issue, especially in areas like dyke marsh, and as global sea levels continue to rise, these inundation issues will only become more prevalent at the parkway.

Key findings, recommendations and data gaps

Overall, the natural resources of George Washington Memorial Parkway were in degraded condition.

The good condition of water resources and moderate condition of biological integrity were offset by very degraded conditions for air resources and landscape dynamics. The very degraded condition for landscape dynamics was not unexpected for a metropolitan motorway park with extensive landscape manipulation. Similarly, the very degraded condition for air resources is driven largely by external forces and cannot be expected to be significantly improved through management actions within the park. Despite these findings, it is widely recognized that GWMP adds critical green space in an increasingly urbanized region, provides refuge for many species, serves as a migration rest stop for wildlife, and is a welcome escape from the traditional driving experience for motorists.

Vital sign	Reference attainment	Condition
Air quality	60%	Good
Water resources	42%	Moderate
Biological integrity	2%	Very degraded
Landscape dynamics	9%	Very degraded
GWMP Overall	**28%**	**Degraded**

Air Quality

Air quality conditions at GWMP were in a very degraded condition with 9% attainment of reference conditions. As GWMP is a motorway, it was expected that air quality from automobiles could result in degraded air quality. However, it must be noted that air quality is a problem throughout the eastern United States, the causes of which (e.g. power generation and mobile sources), are largely out of the park's control. Specific implications of poor air quality 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.

Key findings, management implications, and recommended next steps for air quality in GWMP.

Key findings	Management implications	Recommended next steps
Air quality is very degraded and is a regional problem	Specific 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 to support regional air quality initiatives such as Climate Friendly Parks (www.nps.gob/climatefriendlyparks). Develop park-specific management actions. 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.	Use transport and deposition models to estimate air quality indicator conditions. Implement park-scale air quality monitoring for better insight into park-level air quality condition and possible effects on park habitats and species.
Minimal soundscape information	Traffic noise from roadway potentially affects wildlife behavior and distribution, and visitor recreational experience. Effect greater in fall and winter when foliage absent.	Noise/soundscape study.

Data gaps, justification, and research needs for air quality in GWMP.

Data gaps	Justification	Research needs
Ecological thresholds for mercury wet deposition	Wet deposition is monitored but the only available guideline is for fish tissue.	Adopt standards once NPS Air Resources Division establishes mercury wet deposition reference.
Park-scale air quality data	Need to implement park-specific management actions.	Use transport and deposition models.
Effects of poor air quality on park habitats and species	Need to implement park-specific management actions.	Investigate effects of poor air quality on sensitive habitats and species within the park.

Water Resources

Water resources were in good condition (though bordered moderate condition), with 60% attainment of reference conditions. Water resources were characterized by very good pH, dissolved oxygen, water temperature, and acid neutralizing capacity. A higher overall attainment was, however, offset by very degraded conditions for specific conductance and the Physical Habitat Index.

Key findings, management implications, and recommended next steps for water resources in GWMP.

Key findings	Management implications	Recommended next steps
Very good condition for water temperature	Affects stream flora and fauna. Can impact quality of visitor experience.	Maintain riparian shading of streams to maintain temperatures.
Very degraded condition for stream total phosphorus	Nutrient enrichment affects stream flora and fauna (eutrophication). Visible signs of eutrophication reduces quality of visitor experience.	Determine cause of elevated phosphorus within the region. Determine if elevated phosphorus levels are negatively impacting stream flora and fauna. Minimize soil disturbance. Implement best management practices such as riparian buffers and no-mow areas.
Very degraded condition for Benthic Index of Biotic Integrity (BIBI)	Affects stream flora and fauna (food chain implications). Reduces quality of visitor experience.	Implement stream restoration and manage volume and velocity of water from impervious surfaces (e.g. swales, riparian buffers and no-mow areas). Implement monitoring to identify sources and patterns and then develop management alternatives. Work collaboratively with adjacent neighbors on education and identify strategies to help water quality before streams enter park.
Degraded condition for specific conductance	Affects stream flora and fauna. Reduces quality of visitor experience.	Identify source (e.g. salting of roads) and conductance-sensitive organisms and locations for management initiatives. Continuous monitoring of conductance/salinity levels throughout year. Identify areas of park more susceptible to salt runoff (sensitive areas). Implement best management practices (salt alternatives).
Degraded Physical Habitat Index	Affects stream flora and fauna. Reduces quality of visitor experience.	Implement stream restoration and manage volume and velocity of water entering the park (e.g. swales, riparian buffers and no-mow areas). Implement monitoring to identify sources and patterns and then develop management alternatives.

Data gaps, justification, and research needs for water resources in GWMP.

Key findings	Management implications	Recommended next steps
Origins of nitrogen and phosphorus inputs are uncertain	Nutrient enrichment affects stream flora and fauna (eutrophication). Visible signs of eutrophication reduces quality of visitor experience.	Identify sources of unknown nutrient inputs.

Biological Integrity

Biological integrity was in moderate condition, with 42% attainment of reference conditions. Conditions for the seven biological integrity indicators ranged from very good (i.e. limited exotic trees and forest pest species) to very degraded (i.e. widespread coverage of exotic herbaceous species, high deer density, and poor index of biological integrity for fish).

Key findings, management implications, and recommended next steps for biological integrity in GWMP.

Key findings	Management implications	Recommended next steps
Overall, the forest community was represented well by native plant species, though seedling regeneration is a problem.	Future lack of forest regeneration and subsequent habitat.	Manage deer over-browse through deer population control measures, repellant, tree tubes, barriers (e.g. fencing portions of the park). Implement planting initiatives.
Very degraded cover of exotic herbaceous species	Displacement of native species, reducing biodiversity.	Prioritize species and locations for implementing control measures Restore and maintain native species and communities. Identify and map areas of exotic invasion that are not reflected in I&M monitoring (e.g. floodplain areas are not currently represented); and initiate park monitoring.
Fish index of biological integrity was in poor condition.	Fish are an important ecosystem component.	Identify sensitive locations and analyze FIBI scores to identify which components are showing degraded condition. Increase the number of fish monitoring sites.
Deer overpopulation may be impacting forest regeneration and be a hazard to vehicular traffic throughout park.	Increased herbivory reducing seedling density. More road collisions. Potential for spread of chronic wasting disease. Deer overbrowse can contribute to introduction of invasive species.	Continue with ongoing population size assessments.

Landscape Dynamics

Landscape dynamics within George Washington Memorial Parkway were in very degraded condition, with 2% attainment of reference conditions. Conditions were very degraded for forest interior area, forest cover, and road density.

Key findings, management implications, and recommended next steps for landscape dynamics in GWMP.

Key findings	Management implications	Recommended next steps
Very degraded forest interior area and forest cover – within and outside the park boundary	Reduction in breeding habitat for birds. Reduction in birds fledged each year. Increased predation on nests.	Improve quality of existing forest habitat by managing for exotic species and seedling stocking levels.

Key findings	Management implications	Recommended next steps
		Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.
Large areas of impervious surface – outside the park boundary	Increased rainfall runoff volume, temperature, and velocity (with pollutants).	Work collaboratively with neighbors to assess impervious surfaces around the park. Change asphalt parking lots to porous surfaces (e.g. pervious pavers, grass). Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.
High road density	Road density increases surface runoff. As runoff and stormwater enters park water resources, it may decrease water quality conditions, resulting in lower water quality and biological integrity. Affects area of forest interior and disrupts habitat.	Difficult to manage. Potential traffic calming/reduction measures. Reassess legitimacy of indicator and/or reference condition for use in a metropolitan motorway park.

Data gaps, justification, and research needs for landscape dynamics in GWMP.

Data gaps	Justification	Research needs
Implications of external land use changes on park resources	Connectivity of ecological processes from park to watershed	Landscape analysis at multiple scales.
Impacts of climate change on habitat connectivity	The park acts as a habitat corridor throughout the region	Modeling of the potential effects of climate change on habitats within the park and surrounding region.

Conclusions

Natural resources in GWMP are in degraded condition overall and are under threat from surrounding land use, regionally poor air quality, and overpopulation of deer. Climate change is predicted to negatively affect many of the natural resources of the park, including increasing ozone levels and particle pollution, raising water temperature, changing forest composition, and affecting exotic species and forest pests and disease. Despite the degraded conditions, species new to science are regularly found in GWMP and the park provides habitat for over 100 rare species.

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