National Park Service
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Natural Resource Stewardship and Science

Air Quality Related Values (AQRVs) for National Capitol Region Network (NCRN) Parks

Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics

Natural Resource Report NPS/NCRN/NRR—2016/1172




ON THE COVER
Photograph of air quality related values within various National Park units. Wildflowers, clear views, aquatic species, and lichens may all be threatened by air pollution.
Photographs courtesy of the National Park Service

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Summary

This report describes the Air Quality Related Values (AQRVs) of the National Capitol Region Network (NCRN). AQRVs are those resources sensitive to air quality and include "*visibility or a specific scenic, cultural, physical, biological, ecological, or recreational resource identified by the Federal Land Manager for a particular area*". The NCRN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Antietam National Battlefield (ANTI), Catoctin Mountain Park (CATO), Chesapeake and Ohio Canal National Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest Park (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR).

Sullivan et al. (2011a, 2011b) and Kohut (2007) conducted risk assessments for acidification, eutrophication, and ozone (O_3) for the NCCN parks; their results are described in this report. This report also describes air pollutant emissions and air quality, and their effects on AQRVs in the NCRN. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]); ground-level O_3; haze-causing particles; and airborne toxics. Background for this section can be found in "Air Quality Related Values (AQRVs) in National Parks. Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics" (Sullivan 2016).

Many of the park lands in the NCRN region are heavily influenced by human activities, and air quality is affected by emissions from large power plants and urban, industrial, and agricultural sources. Some parks are in and around the Washington, DC urban area; others are located further to the west. The eastern third of the network area is densely populated. There are many monuments and stoneworks in the NCRN that are sensitive to soiling, pitting, and other forms of deterioration. However, this document focuses primarily on effects on natural, rather than cultural, resources.

Atmospheric N and S pollutants can cause acidification of streams, lakes, and soils. Emissions of N and S air pollutants are relatively high in the NCRN region. Annual county-level N emissions were more than 5 tons per square mile per year (tons/mi^2/yr) in 2002 throughout most of the network region, and more than 20 tons/mi^2/yr in the eastern portion of the network region. Sulfur emissions are also quite high. As a result, both N and S deposition are relatively high to the parks in the NCRN. Total N deposition within the network region generally ranged from 10 to 15 kg N/ha/yr to as high as 15 to 20 kg N/ha/yr in 2002, with the higher values mainly in and around Washington, DC. Total S deposition was also high, between 10 and 20 kg S/ha/yr at most locations within the network region. Levels of S and N deposition at NCRN parks decreased substantially between 2001 and 2011.

Most of the streams in NCRN parks have levels of acid-neutralizing capacity (ANC) adequate to buffer acidic N and S deposition, although some in PRWI have ANC and pH levels considered to be close to concern thresholds for acidification (Norris et al. 2007). Acidification may affect sensitive fish and aquatic invertebrates in this park. Terrestrial species may also be affected. Sugar maple (*Acer saccharum*), a tree species known to be sensitive to acidification, occurs in most of the NCRN

parks. Acidification of soils and calcium depletion have been linked to sugar maple decline in eastern forests at several locations.

In addition to contributing to acidification, N deposition can also cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species diversity and soil nutrient cycling. Research from other areas suggests that current levels of N deposition in the NCRN area may be at levels sufficient to affect forest health and lichen diversity.

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to plant foliage. Atmospheric O_3 concentrations are high in the NCRN area. EPA's national O_3 standard to protect human health and the environment is exceeded at times, and all of the NCRN parks are in counties designated as nonattainment for the O_3 standard. Seasonal O_3 exposure levels are also elevated and risk to vegetation is considered high in the network parks.

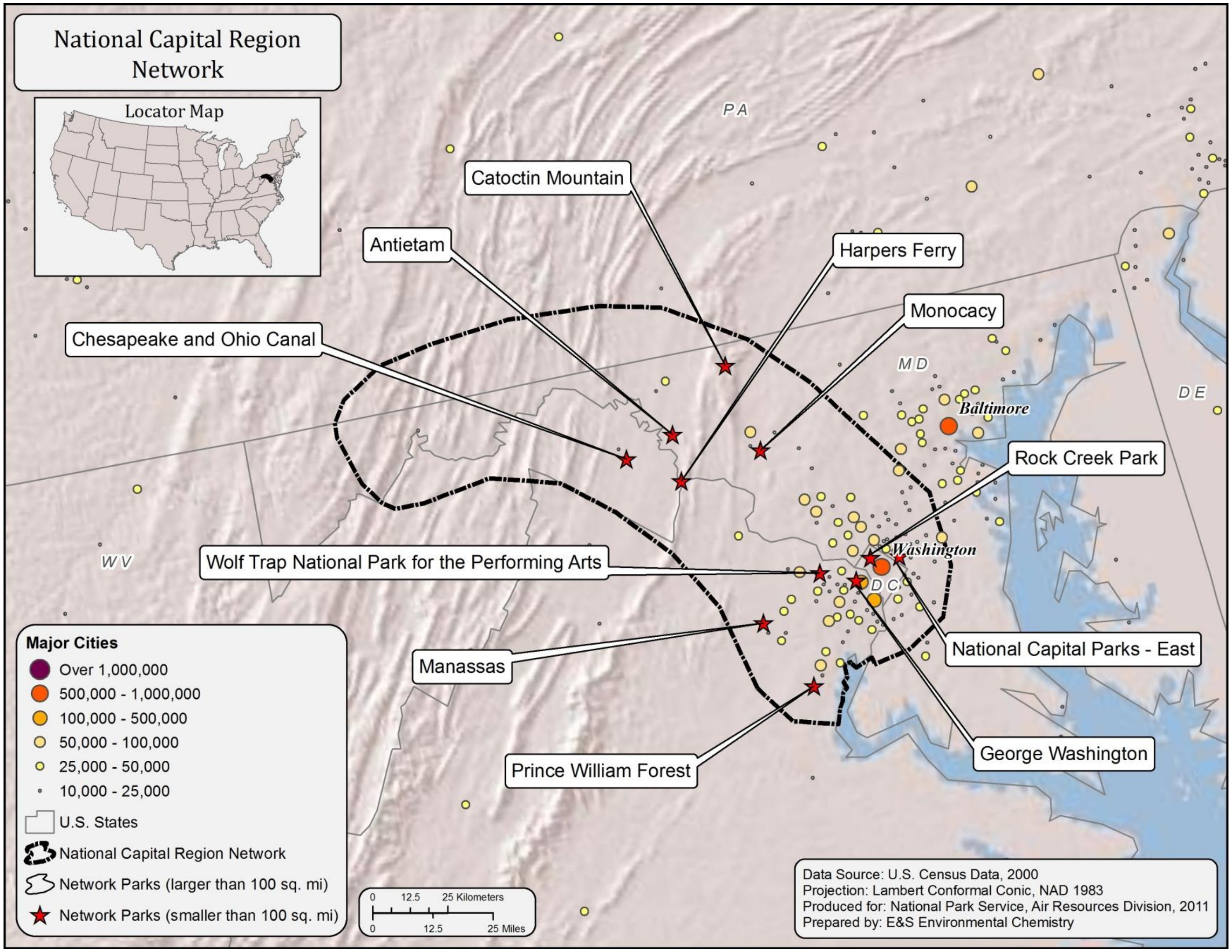
Particulate pollution is an important component of haze, reducing visibility. Haze has been estimated by IMPROVE in the NCRN region at a site in Washington, DC. Haze levels are high, with the majority of haze caused by SO_4^{2-} formed from sulfur dioxide (SO_2) emissions from power plants. Nitrate, organics, and light-absorbing carbon were also important contributors to haze in this network.

Airborne contaminants, including mercury (Hg) and other heavy metals, can accumulate in food webs, reaching toxic levels in top predators. There are a number of industrial facilities in the NCRN region that release toxic chemicals and coal-burning power plants in the region emit Hg. A number of sites in the region have been designated as Superfund sites on EPA's National Priorities List because of contamination by toxic chemicals. Fish consumption advisories for Hg and other toxics have been issued for many streams in the region (Rattner and Ackerson 2006).

Background

There are 11 parks in the NCRN: Antietam National Battlefield (ANTI), Catoctin Mountain Park (CATO), Chesapeake and Ohio Canal National Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest Park (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR). Some parks are in and around the Washington, DC urban area; others are located further to the west. The eastern third of the network region is densely populated; the western two-thirds is not. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people.

There are many monuments and a substantial amount of stonework in the NCRN. Although outside the scope of this analysis, these cultural resources are known to be sensitive to air pollution damage and soiling. It is difficult to determine the extent to which stone deterioration is attributable to atmospheric contaminants as opposed to natural weathering. It is known, however, that dry deposition is an important cause of damage and that sulfur dioxide (SO_2) is more important than the various N species in this regard (Charola 1998). Additional important aspects of damage to stone include the susceptibility of the stone to attack by SO2 and the amount of moisture in the stone pores.



Map 1. Network boundary and locations of parks and population centers with more than 10,000 people around the NCRN region.

Atmospheric Emissions and Deposition

County-level sulfur (S) emissions within the NCRN region generally ranged from less than 1 ton per square mile per year (ton/mi^2/yr) to more than 50 tons/mi^2/yr of sulfur dioxide (SO_2; Sullivan et al. 2011b). There were no SO_2 point sources of great magnitude within the network area, but there were several large point sources further to the west. In general, individual SO_2 point sources were less than 5,000 tons per year (tons/yr) throughout the network area, with only two sources in the range of 5,000 to 20,000 tons/yr.

In general, annual county nitrogen (N) emissions were more than 5 tons/mi^2/yr throughout most of the network region, and more than 20 tons/mi^2/yr in the eastern portion of the network region. There were no large (larger than 2,000 tons/yr) point sources of N within the network region, but several outside the network, especially to the west.

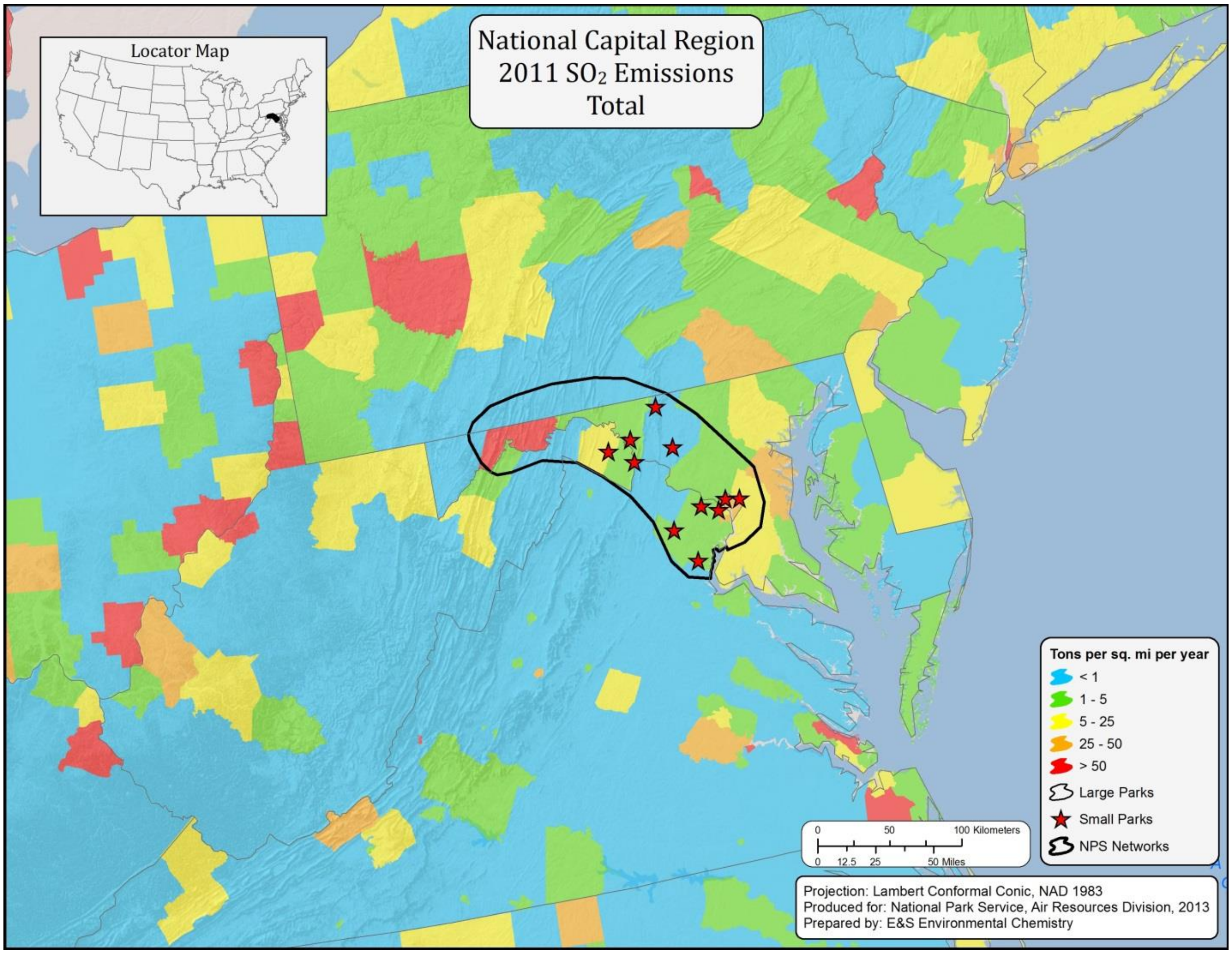
County-level emissions near the NCRN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO_2, oxidized N (NO_x), and reduced N (NH_3), respectively. Many counties to the north and west of NCRN parks had relatively high SO_2 emissions (> 50 tons/mi^2/yr; Map 2). Spatial patterns in NO_x emissions were generally similar, with highest values near and to the north of NCRN parks (Map 3). Emissions of NH_3 near NCRN parks were somewhat lower, with all counties showing emissions levels below 8 tons/mi^2/yr (Map 4).

Total S deposition within the network has been quite high; it generally ranged from 10 to 20 kg/ha/yr in 2002, with several small areas in the range of 20 to 30 kg/ha/yr. Total N deposition within the network was also high, and generally ranged from 10 to 15 kg N/ha/yr, to as high as 15 to 20 kg N/ha/yr, with the higher values mainly in and around Washington, DC.

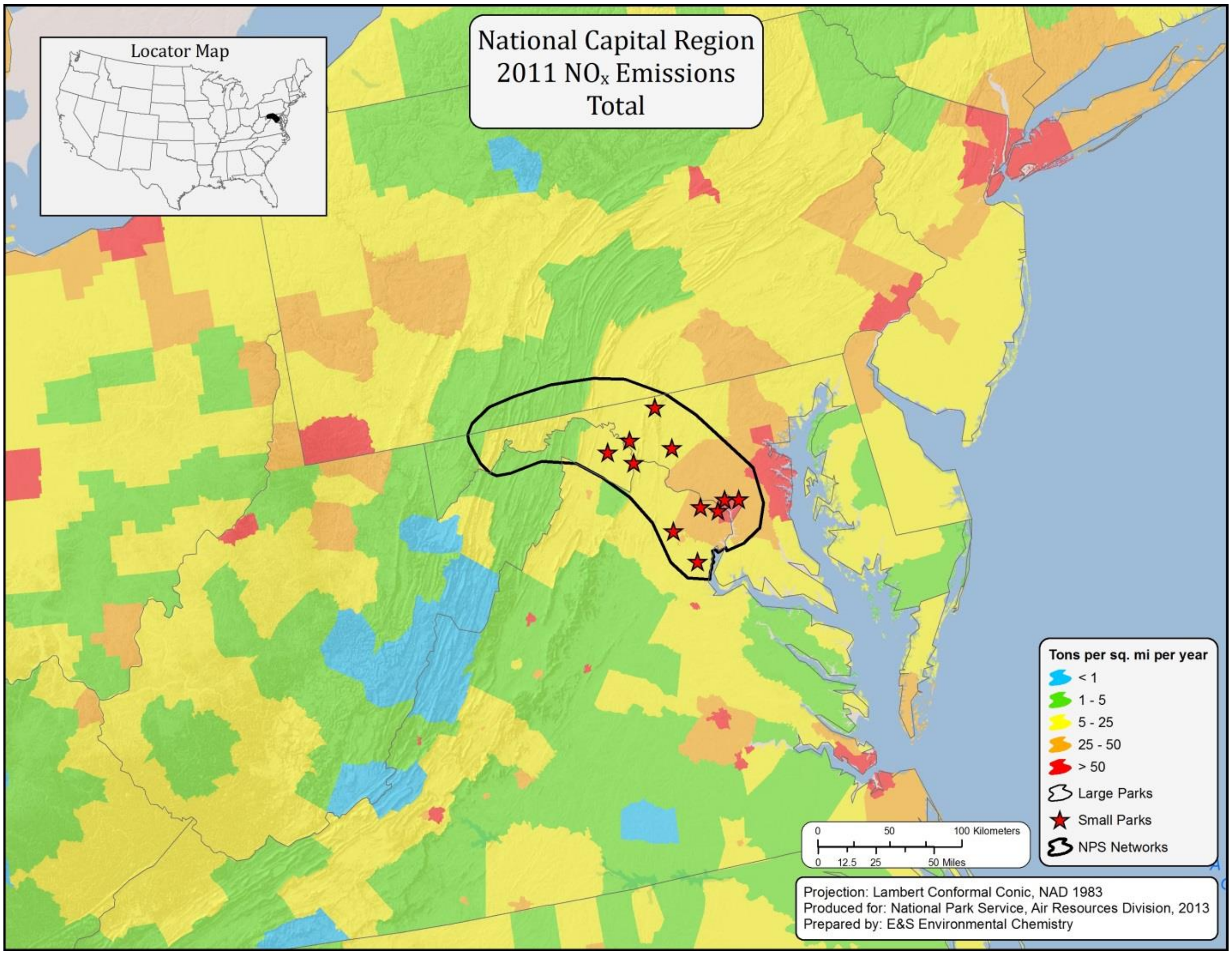
Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data. Modeling was accomplished using the Community Multiscale Air Quality (CMAQ) model (Byun and Schere 2006). Priority was given to measured data near the locations of the monitors and to modeled data where monitoring data were not available. In addition, CMAQ data were used for N species that are not routinely measured in the monitoring programs: peroxyacetyl nitrate, N_2O_5, NO, NO_2, HONO, and organic NO_3. The total deposition estimates are considered to be dynamic, with updates planned as new information becomes available. TDEP data reported here were developed in late 2013 and are designated version 2013.02.

Atmospheric S deposition levels have declined at all NCRN parks since 2001, based on TDEP estimates (Table 1). Decreases in total S deposition over the previous decade for the parks in this network were commonly in the range of 40% to 50%. Estimated total N deposition decreased over that same time period at all parks except CATO (which showed an increase of 3.1%). Oxidized and reduced N showed opposite patterns, with oxidized N decreasing and reduced N increasing at all of the parks in the network since the monitoring period 2000-2002.

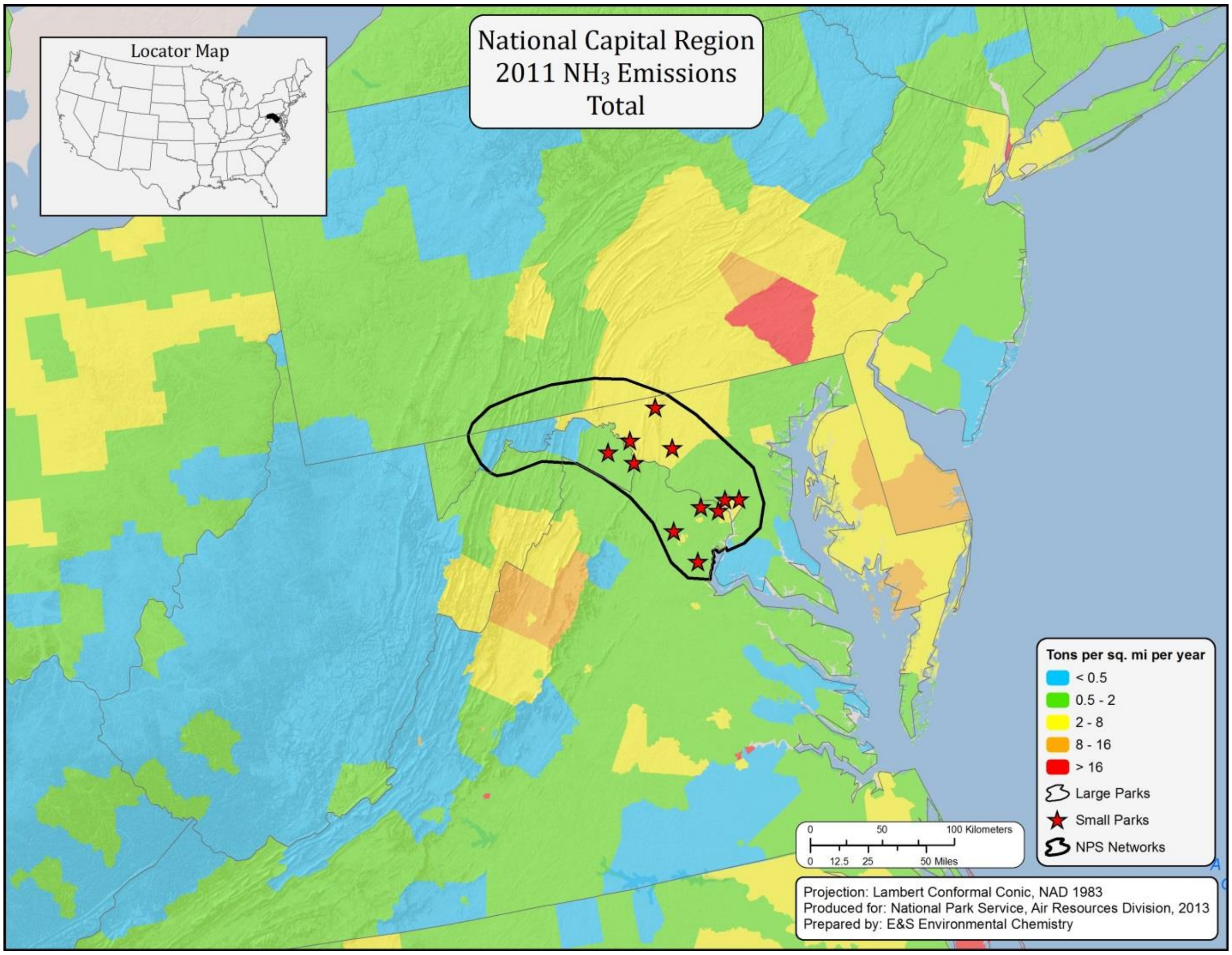
Total S deposition in and around the NCRN for the period 2010-2012 was generally in the range of 5-10 kg S/ha/yr at park locations and higher to the west (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was in the range of 5-10 kg N/ha/yr throughout the park lands within the NCRN (Map 6). Most areas received less than 10 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7). Total N deposition was high, more than 10 kg N/ha/yr at most park locations (Map 8).



Map 2. Total SO_2 emissions, by county, near the NCRN for the year 2011. Data from EPA's National Emissions Inventory.



Map 3. Total NO_x emissions, by county, near the NCRN for the year 2011. Data from EPA's National Emissions Inventory.



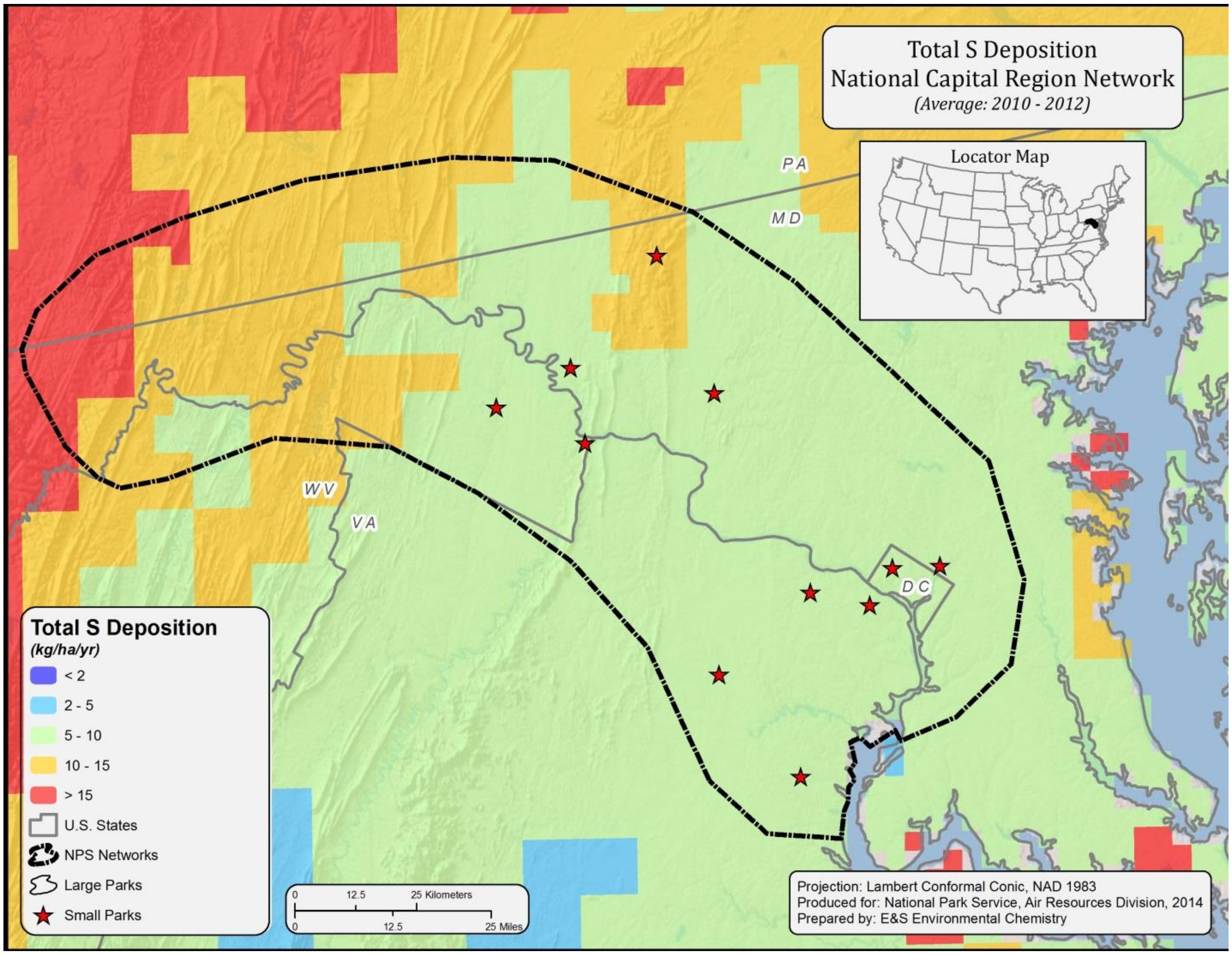
Map 4. Total NH_3 emissions, by county, near the NCRN for the year 2011. Data from EPA's National Emissions Inventory.

Table 1. Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCRN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, maximum, and range of 2011 S and N deposition within each park are also shown.

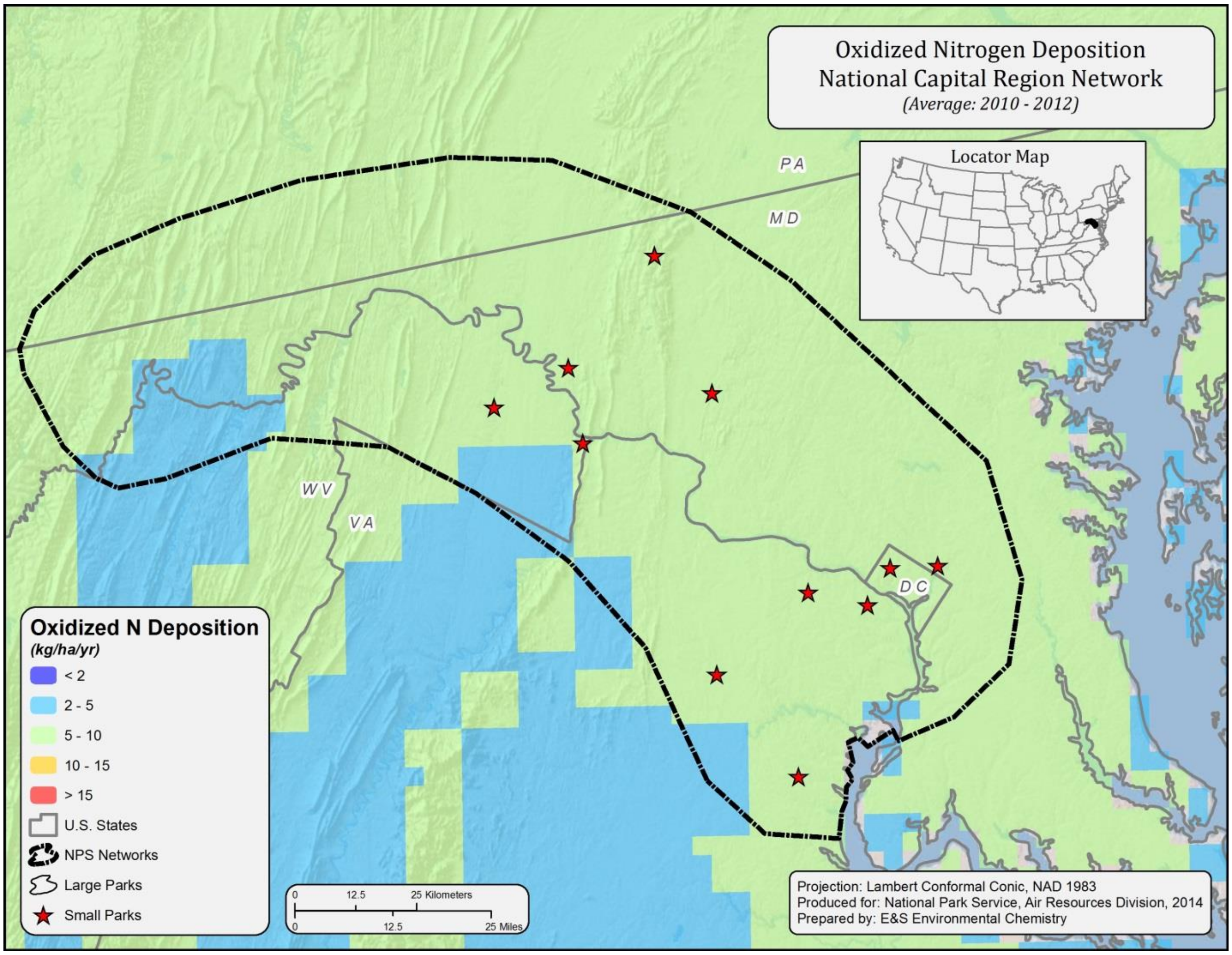
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
ANTI	Antietam	Total S	16.86	8.26	-8.60	-51.0%	7.87	9.16	1.29
		Total N	15.40	11.27	-4.13	-26.9%	10.71	12.59	1.88
		Oxidized N	10.40	5.32	-5.08	-48.9%	5.12	5.79	0.67
		Reduced N	5.01	5.95	0.95	18.8%	5.59	6.80	1.21
CATO	Catoctin Mountain	Total S	19.01	13.40	-5.61	-29.5%	13.30	13.43	0.12
		Total N	17.17	17.71	0.54	3.1%	17.56	17.74	0.18
		Oxidized N	11.28	8.32	-2.96	-26.2%	8.25	8.33	0.08
		Reduced N	5.89	9.39	3.50	59.5%	9.31	9.41	0.10
CHOH	Chesapeake and Ohio Canal	Total S	17.15	9.06	-8.09	-47.3%	7.28	11.36	4.08
		Total N	14.05	10.05	-4.00	-28.7%	7.39	13.29	5.90
		Oxidized N	9.99	5.55	-4.44	-44.3%	4.46	8.05	3.60
		Reduced N	4.07	4.50	0.44	9.7%	2.88	6.73	3.85
GWMP	George Washington	Total S	14.69	7.95	-6.74	-45.9%	7.26	8.36	1.10
		Total N	14.44	12.51	-1.93	-13.3%	10.83	13.29	2.47
		Oxidized N	10.76	7.64	-3.13	-29.0%	6.56	8.05	1.49
		Reduced N	3.67	4.87	1.20	32.6%	4.16	5.24	1.08
HAFE	Harpers Ferry	Total S	15.58	8.62	-6.96	-44.7%	7.60	8.87	1.27
		Total N	13.56	10.97	-2.59	-19.1%	9.71	11.53	1.82
		Oxidized N	9.51	5.69	-3.82	-40.2%	4.97	5.87	0.89
		Reduced N	4.05	5.29	1.23	30.3%	4.74	5.66	0.92
MANA	Manassas	Total S	13.75	7.00	-6.75	-49.1%	6.88	7.23	0.35
		Total N	14.01	9.64	-4.37	-31.2%	9.53	9.71	0.19
		Oxidized N	10.44	5.67	-4.77	-45.7%	5.61	5.77	0.16
		Reduced N	3.57	3.96	0.39	11.1%	3.92	3.97	0.06

Table 1 (continued). Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCRN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, maximum, and range of 2011 S and N deposition within each park are also shown.

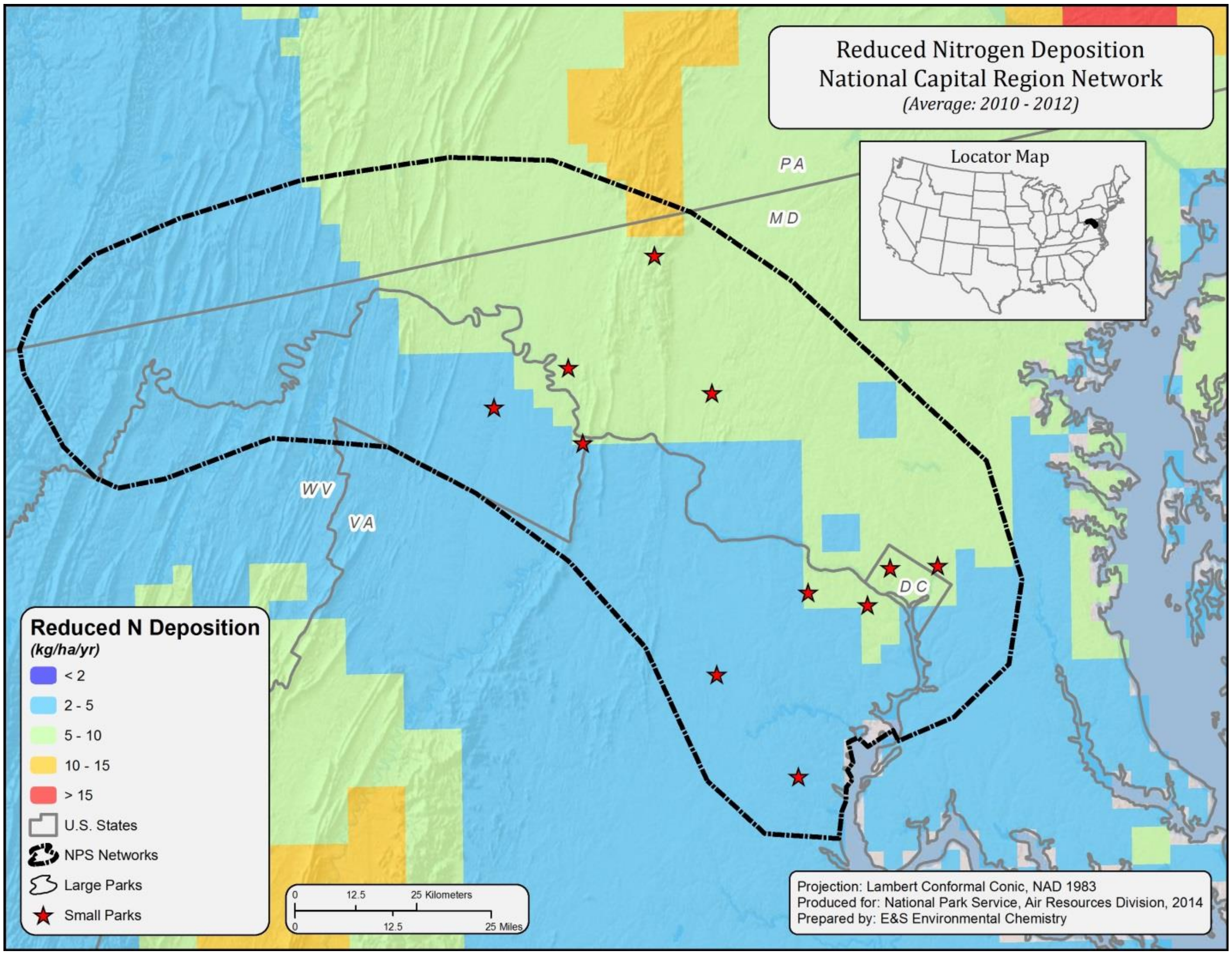
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
MONO	Monocacy	Total S	17.24	8.10	-9.14	-53.0%	8.09	8.32	0.23
		Total N	14.56	12.00	-2.57	-17.6%	11.94	13.24	1.30
		Oxidized N	10.38	5.68	-4.70	-45.3%	5.67	6.07	0.40
		Reduced N	4.18	6.32	2.13	51.2%	6.28	7.17	0.90
NACE	National Capital Parks - East	Total S	15.32	7.47	-7.85	-51.1%	7.26	7.92	0.67
		Total N	14.40	12.89	-1.50	-10.4%	12.02	13.62	1.61
		Oxidized N	10.70	7.68	-3.01	-28.2%	7.33	8.15	0.82
		Reduced N	3.70	5.21	1.51	40.9%	4.68	5.47	0.79
PRWI	Prince William Forest	Total S	14.84	7.33	-7.51	-50.4%	7.27	7.43	0.15
		Total N	12.82	9.57	-3.25	-25.3%	9.21	10.24	1.04
		Oxidized N	9.58	5.86	-3.72	-38.8%	5.68	6.29	0.61
		Reduced N	3.24	3.71	0.47	14.8%	3.53	3.98	0.45
ROCR	Rock Creek Park	Total S	14.92	7.87	-7.05	-47.2%	7.33	7.93	0.60
		Total N	14.69	13.29	-1.40	-9.5%	12.94	13.35	0.41
		Oxidized N	10.97	8.05	-2.92	-26.6%	7.63	8.08	0.45
		Reduced N	3.72	5.24	1.52	40.8%	5.16	5.35	0.19
WOTR	Wolf Trap National Park for the Performing Arts	Total S	14.94	8.33	-6.62	-44.3%	8.33	8.33	0.00
		Total N	14.51	13.00	-1.50	-10.4%	13.00	13.00	0.00
		Oxidized N	10.72	7.87	-2.85	-26.6%	7.87	7.87	0.00
		Reduced N	3.79	5.14	1.35	35.5%	5.14	5.14	0.00



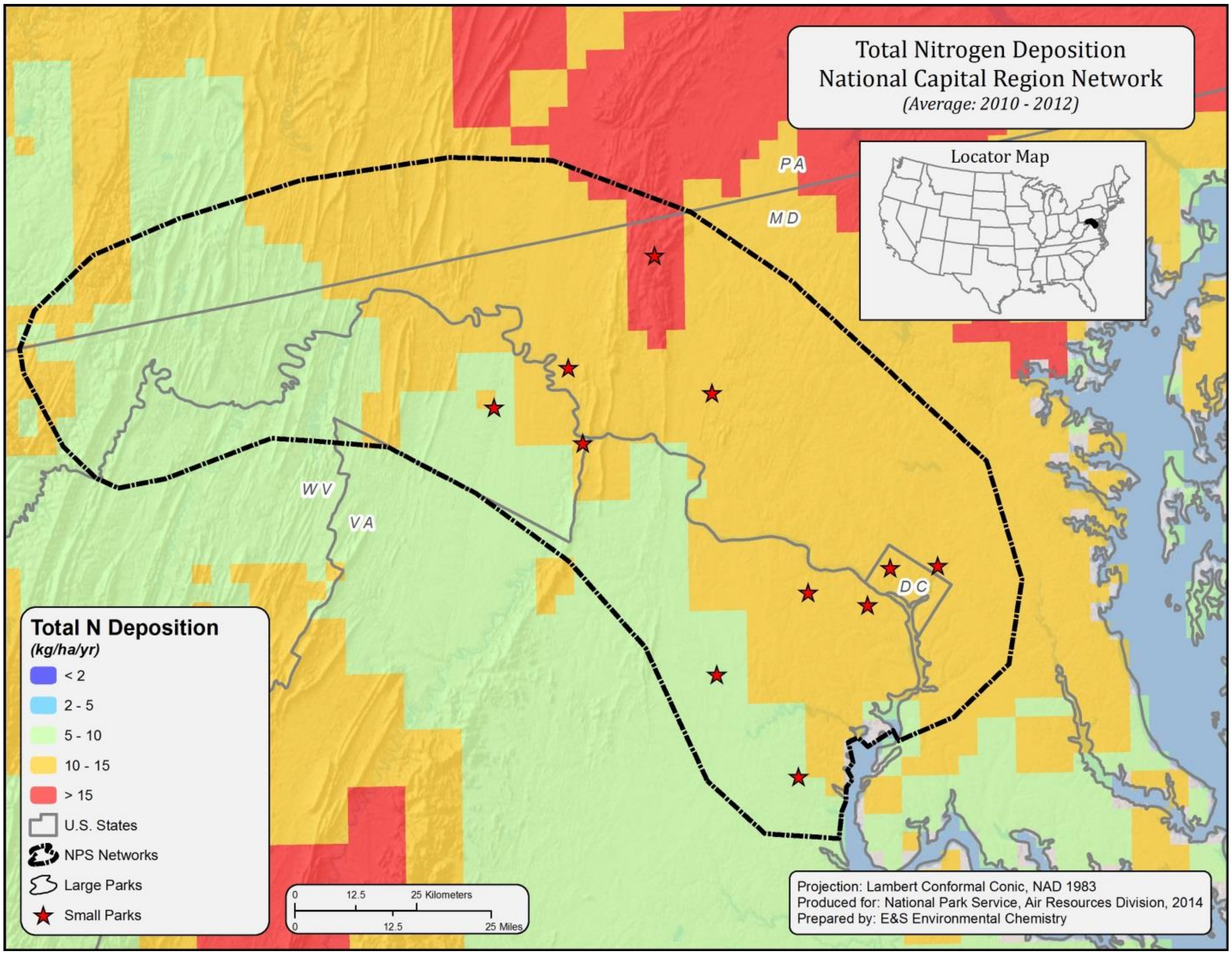
Map 5. Total S deposition for the three-year period centered on 2011 in and around the NCRN. (Source: Schwede and Lear 2014)



Map 6. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around the NCRN. (Source: Schwede and Lear 2014)



Map 7. Reduced inorganic N deposition for the three-year period centered on 2011 in and around the NCRN. (Source: Schwede and Lear 2014)



Map 8. Total N deposition for the three-year period centered on 2011 in and around the NCRN. (Source: Schwede and Lear 2014)

Acidification

The network rankings developed by Sullivan et al. (2011b) for a coarse screening assessment of acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking for the NCRN that was near the middle of the distribution among networks. This was despite having one of the highest acid Pollutant Exposure rankings of all 32 Inventory and Monitoring (I&M) networks. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

All parks in this network were ranked by Sullivan et al. (2011b) in the top quintile for acid Pollutant Exposure. The parks were ranked either in the highest quintile (four parks), second highest quintile (one park) or middle quintile (six parks) for Ecosystem Sensitivity to acidification (Table 2). The sensitivity rankings are based on coarse regional data. A better assessment of stream sensitivity can be obtained by examining actual stream chemistry data. Water quality data from 2005-2013 indicate that most of the streams in the NCRN parks have levels of ANC adequate to buffer acidic deposition, although ANC in some streams in PRWI and GWMP occasionally had levels less than 200 microequivalents per liter (μeq/L);waters with ANC < 200 μeq/L are considered potentially sensitive to episodic acidification. Levels of pH above 6 (and less than 9) are generally considered healthy, and some streams in PRWI were sometimes close to the lower threshold (Norris et al. 2011; http://science.nature.nps.gov/im/units/ncrn/monitor/water_quality/visualizer.cfm; data accessed October, 2014, Norris et al. 2007).

Table 2. Estimated I&M park rankings[1] according to risk of acidification impacts on sensitive natural resource receptors (Source: Sullivan et al. 2011a). The sensitivity of cultural resources was not assessed.

Park Name	Park Code	Estimated Acid Pollutant Exposure[1]	Estimated Ecosystem Sensitivity to Acidification[1]
Antietam	ANTI	Very High	Very High
Catoctin Mountain	CATO	Very High	Very High
Chesapeake and Ohio Canal	CHOH	Very High	Very High
George Washington	GWMP	Very High	Moderate
Harpers Ferry	HAFE	Very High	Very High
Manassas	MANA	Very High	Moderate
Monocacy	MONO	Very High	Moderate
National Capital Parks - East	NACE	Very High	High
Prince William Forest	PRWI	Very High	Moderate
Rock Creek Park	ROCR	Very High	Moderate
Wolf Trap National Park for the Performing Arts	WOTR	Very High	Moderate

[1] Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk). Note that actual stream chemistry data from the individual parks (i.e., Norris et al. 2007) provide a better indication of acid sensitivity than these coarse generalized rankings.

The Maryland Synoptic Stream Chemistry Survey (MSSCS) was conducted near the NCRN. It was designed to estimate the number and extent of acidic and relatively acid-sensitive streams in Maryland (Knapp et al. 1988). Based on this survey of 73 streams, the majority of potentially acid-sensitive streams in the state occur in the Southern Coastal Plain region surrounding the Chesapeake Bay and in the Appalachian Plateau ecoregion in western Maryland. Portions of the NCRN region overlap with these acid-sensitive areas. Streams on the Southern Coastal Plain of Maryland generally have relatively low ANC. Nearly three-fourths of the streams in this region included in the MSSCS had ANC less than 200 µeq/L (Janicki et al. 1995). Stream chemistry in this region may be detrimental to the health of fish in some of these streams (Klauda 1989, Morgan et al. 1990), but MSSCS data are not available within the NCRN parks.

The Maryland Critical Loads Study applied the PROFILE model to simulate the chemical behavior of soils and stream water and to estimate the steady-state critical load (CL) of S and N deposition to protect stream acid-base chemistry throughout Maryland (Janicki et al. 1995). About one-fourth of the stream reaches in Maryland had estimated levels of S deposition in their watersheds that were higher at the time of the stream survey than the simulated steady-state CL of acidity and were expected to be at risk of episodic acidification. The Appalachian Plateau and Coastal Plain had steady-state CLs estimated to generally be below 8 kg S/ha/yr. All of the NCRN parks received S deposition near that level in 2011 (Table 1).

Steady-state S CL estimates were developed for watersheds in four parks in NCRN as part of the USDA Forest Service and U.S. EPA Ecosystem Management Decision Support (EMDS) project (McDonnell et al. 2014, Reynolds et al. 2012). Modeling was conducted for multiple watersheds in three of the NCRN parks; only one watershed was modeled within CATO. Estimated CLs were generally high, indicating a lack of acid sensitivity in most watersheds evaluated (Table 3).

Table 3. Distribution of steady-state critical loads of sulfur (in kg/ha/yr) to protect stream ANC = 50 µeq/L for parks modeled in the EMDS project within NCRN (McDonnell et al. 2014).

Park Name	Park Code	# of CLs[1]	Minimum	25th Percentile	Median	25th Percentile	Maximum
Antietam	ANTI	32	High	High	High	High	High
Catoctin Mountain	CATO	1	15	15	15	15	15
Chesapeake and Ohio Canal	CHOH	421	5	High	High	High	High
Harpers Ferry	HAFE	51	High	High	High	High	High

[1] Number of small watersheds (generally approximately 1 km^2), for which CL were calculated by Reynolds et al.(2013), that are wholly or partly within the park

"High" signifies that the CL is significantly higher than ambient deposition

CLs of S in units of kg/ha/yr can be converted to $meq/m^2/yr$ by multiplying by 6.25

Nutrient Nitrogen Enrichment

The dominant nonpoint sources of N to watersheds vary across the continental United States (USGS 1999). In most areas, animal manure and fertilizer application account for the vast majority of nonpoint N sources to large watersheds. In a few of the USGS sampling sites that are included within the National Water Quality Assessment (NAWQA) Program, however, atmospheric sources accounted for an estimated one-fourth or more of nonpoint N inputs. These included study watersheds throughout the Northeast, including some around the NCRN (USGS 1999).

All parks in the NCRN were ranked by Sullivan et al. (2011a) in a coarse screening assessment as being in the top quintile for nutrient N Pollutant Exposure. However, none were ranked higher than the second lowest quintile for Ecosystem Sensitivity to nutrient N enrichment (Table 4). Although rankings provide an indication of risk, park-specific data, particularly regarding nutrient-enrichment sensitivity, are needed to fully evaluate risk from nutrient N addition.

Pardo et al. (2011) compiled data on empirical CL for protecting sensitive resources in Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. Available data on empirical CL of nutrient-N compiled by Pardo et al. (2011) suggest that the lower end of the reported empirical CL range was about 4-8 kg N/ha/yr for the protection of mycorrhizal fungi, lichens, and forest vegetation and for the prevention of NO_3^- leaching in drainage waters (Table 5). Ambient N deposition reported by Pardo et al. (2011) at each of the parks in the NCRN was higher than that, suggesting exceedance of the empirical nutrient N CL at all parks in this network.

Table 4. Estimated park rankings[1] according to risk of Nitrogen enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011b)

Park Name	Park Code	Estimated Nutrient N Pollutant Exposure[1]	Estimated Ecosystem Sensitivity to Nutrient N Enrichment[1]
Antietam	ANTI	Very High	Very Low
Catoctin Mountain	CATO	Very High	Very Low
Chesapeake and Ohio Canal	CHOH	Very High	Very Low
George Washington Mem Pkwy	GWMP	Very High	Low
Harpers Ferry	HAFE	Very High	Very Low
Manassas	MANA	Very High	Low
Monocacy	MONO	Very High	Low
National Capital Parks - East	NACE	Very High	Very Low
Prince William Forest	PRWI	Very High	Very Low
Rock Creek Park	ROCR	Very High	Low
Wolf Trap National Park for the Performing Arts	WOTR	Very High	Low

[1] Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk)..

Ozone Injury to Vegetation

The ozone (O_3)-sensitive plant species that are known or thought to occur within the I&M parks found in the NCRN are listed in Table 6. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O_3 (e.g., dark stipple), are designated by an asterisk. Each park within the network contains at least 14 O_3-sensitive and/or bioindicator species.

The W126 (a measure of cumulative O_3 exposure that preferentially weights higher concentrations) and SUM06 (a measure of cumulative exposure that includes only hourly concentrations over 60 ppb O_3) exposure indices calculated by NPS staff for the years 2005-2009 are given in Table 7, along with Kohut's (2007) O_3 risk ranking. The NPS and Kohut ranking systems differ. The NPS (2010) ranking system is a quick assessment of O_3 condition that ranks O_3 exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of either the W126 or SUM06 index. Both metrics are calculated over a 3-month period. The W126 was calculated as Moderate exposure at values between 7 and 13 ppm-hr, as defined by NPS (2010). Values higher than 13 ppm-hr were classified as High exposure, and values lower than 7 ppm-hr were classified as Low exposure. The SUM06 was classified as Moderate at values between 8 and 15 ppm-hr. Higher and lower values were classified as High and Low, respectively, as defined by NPS (2010).

Table 5. Empirical critical loads for nitrogen in the NCRN, by ecoregion and receptor from Pardo et al. (2011). Ambient N deposition reported by Pardo et al. (2011) is compared to the lowest critical load for a receptor to identify potential exceedance, indicated by graying. A critical load exceedance suggests that the receptor is at increased risk for harmful effects.

NPS Unit	Ecoregion	Ambient N Deposition (kg N/ha/yr)	Critical Load (kg N/ha/yr)				
			Mycorrhizal Fungi	Lichen	Herbaceous Plant	Forest	Nitrate Leaching
Antietam NB	Eastern Temperate Forests	14.2	5 - 12	4 - 8	17.5	3 - 8	8
Catoctin Mountain Park	Eastern Temperate Forests	14.2	5 - 12	4 - 8	17.5	3 - 8	8
Chesapeake and Ohio Canal NHP	Eastern Temperate Forests	15.7	5 - 12	4 - 8	17.5	3 - 8	8
George Washington Mem PKWY	Eastern Temperate Forests	16.4	5 - 12	4 - 8	17.5	3 - 8	8
Harpers Ferry NHP	Eastern Temperate Forests	13.2	5 - 12	4 - 8	17.5	3 - 8	8
Manassas NBP	Eastern Temperate Forests	14.7	5 - 12	4 - 8	17.5	3 - 8	8
Monocacy NB	Eastern Temperate Forests	15.2	5 - 12	4 - 8	17.5	3 - 8	8
Prince William Forest Park	Eastern Temperate Forests	13.4	5 - 12	4 - 8	17.5	3 - 8	8
Wolf Trap Farm Park	Eastern Temperate Forests	14.7	5 - 12	4 - 8	17.5	3 - 8	8

Kohut's approach constitutes a more rigorous assessment of potential risk to plants. It considers both O_3 exposure and environmental conditions (soil moisture). Kohut also used injury thresholds from the literature, but evaluated a different O_3 metric (after Lefohn et al. 1997), the W126 over a 5-month period in conjunction with the N100 (number of hours over 100 ppb O_3). The rationale for the N100 statistic is that higher O_3 concentrations are most likely to cause plant injury. Kohut examined five individual years of O_3 exposure and soil moisture data and considered the effects of low soil moisture on O_3 uptake each year when assigning risk. Soil moisture is important because dry conditions induce stomatal closure in plants, which has the effect of limiting O_3 uptake and injury.

The results of both ranking systems should be considered when evaluating the potential for O_3 injury to park vegetation. The Kohut approach considered environmental conditions that significantly affect plant response to O_3, but exposures have likely changed since the time of the assessment in the period 1995-1999. The NPS approach considers more recent O_3 conditions (2005-2009), but not environmental conditions.

Ozone condition, as rated by NPS, was Moderate or High in the NCRN parks. Kohut's evaluation of risk to plants was High for all parks in this network. These data suggest that exposure to O_3 constitutes an important threat to vegetation resources in this network. Nevertheless, park-specific data regarding the impacts of O_3 on vegetation in these parks is generally lacking.

Table 6. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the NCRN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at https://irma.nps.gov/NPSpecies/Report).

Species	**Common Name**	**ANTI**	**CATO**	**CHOH**	**GWMP**	**HAFE**	**MANA**	**MONO**	**NACE**	**PRWI**	**ROCR**	**WOTR**
Aesculus flava	Yellow buckeye		x									
Aesculus octandra	Yellow buckeye				x							
*Ageratina altissima**	White snakeroot					x						
*Ailanthus altissima**	Tree-of-heaven	x	x	x	x	x	x	x	x	x	x	x
*Apios americana**	Groundnut		x	x	x	x			x	x		
*Apocynum androsaemifolium**	Spreading dogbane		x			x	x		x			
Apocynum cannabinum	Dogbane, Indian hemp	x	x	x	x	x	x	x	x	x	x	x
*Asclepias exaltata**	Tall milkweed		x									
Asclepias incarnata	Swamp milkweed			x	x	x	x	x	x	x		
*Asclepias syriaca**	Common milkweed	x	x	x	x	x	x	x	x	x	x	
*Aster macrophyllus**	Big-leaf aster					x						
*Cercis canadensis**	Redbud	x	x	x	x	x	x	x	x	x	x	
Clematis virginiana	Virgin's bower	x	x	x	x	x		x	x	x		
*Corylus americana**	American hazelnut	x	x			x	x		x	x	x	
*Eupatorium rugosum**	White snakeroot	x	x	x	x					x		
*Fraxinus americana**	White ash	x	x	x	x	x	x	x	x	x	x	x

* Bioindicator species

Table 6 (continued). Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the NCRN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at https://irma.nps.gov/NPSpecies/Report).

Species	Common Name	ANTI	CATO	CHOH	GWMP	HAFE	MANA	MONO	NACE	PRWI	ROCR	WOTR
Fraxinus pennsylvanica	Green ash	x	x	x	x	x	x	x	x	x	x	x
*Gaylussacia baccata**	Black huckleberry		x		x	x	x	x	x	x	x	x
Liquidambar styraciflua	Sweetgum	x			x				x	x	x	
*Liriodendron tulipifera**	Yellow-poplar	x	x	x	x	x	x	x	x	x	x	x
*Lyonia ligustrina**	Maleberry									x		
Parthenocissus quinquefolia	Virginia creeper	x	x	x	x	x	x	x	x	x	x	x
Philadelphus coronarius	Sweet mock orange		x		x	x						
Pinus pungens	Table-mountain pine		x		x	x				x	x	
Pinus rigida	Pitch pine	x	x			x		x		x	x	
Pinus taeda	Loblolly pine								x		x	
Pinus virginiana	Virginia pine	x	x	x	x	x	x	x		x	x	x
*Platanus occidentalis**	American sycamore	x	x	x	x	x	x	x	x	x	x	x
*Populus tremuloides**	Quaking aspen			x		x				x		
*Prunus serotina**	Black cherry	x	x	x	x	x	x	x	x	x	x	x
Prunus virginiana	Choke cherry	x	x			x	x	x		x	x	
Rhus copallinum	Winged sumac					x				x	x	
Robinia pseudoacacia	Black locust	x	x	x	x	x	x	x	x	x	x	
*Rubus allegheniensis**	Allegheny blackberry	x	x			x	x	x	x	x	x	x
Rubus cuneifolius	Sand blackberry						x					
*Rudbeckia laciniata**	Cutleaf coneflower	x	x	x	x	x	x	x	x	x	x	
*Sambucus nigra spp. canadensis**	American elder		x	x	x	x	x	x	x	x	x	
Sassafras albidum	Sassafras	x	x	x	x	x	x	x	x	x	x	x
Solidago altissima	Goldenrod										x	
Solidago canadensis var. scabra	Goldenrod									x		
*Symphoricarpos albus**	Common snowberry			x								
*Verbesina occidentalis**	Crownbeard				x	x	x		x			
*Vitis labrusca**	Northern fox grape	x	x		x	x			x	x		x

* Bioindicator species

Table 7. Ozone assessment results for I&M parks in the NCRN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007) ozone risk ranking for the period 1995-1999[1].

Park Name	Park Code	W126		SUM06		Kohut O_3 Risk Ranking[1]
		Value (ppm-hr)	Ranking[1]	Value (ppm-hr)	Ranking[1]	
Antietam	ANTI	12.22	Moderate	16.29	High	High
Catoctin Mountain	CATO	12.58	Moderate	16.79	High	High
Chesapeake and Ohio Canal	CHOH	12.01	Moderate	15.86	High	High
George Washington	GWMP	14.78	High	19.59	High	High
Harpers Ferry	HAFE	12.50	Moderate	16.65	High	High
Manassas	MANA	12.88	Moderate	16.95	High	High
Monocacy	MONO	13.67	High	18.17	High	High
National Capital Parks - East	NACE	15.40	High	20.30	High	High
Prince William Forest	PRWI	13.13	High	17.18	High	High
Rock Creek Park	ROCR	15.17	High	20.06	High	High
Wolf Trap National Park for the Performing Arts	WOTR	14.40	High	19.06	High	High

[1] Parks are classified into one of three ranks (Low, Moderate, High), based on comparison with other I&M parks.

Visibility Degradation

Natural Background and Ambient Visibility Conditions

The Clean Air Act set a specific goal for visibility protection in Class I areas: "the prevention of any future, and the remedying of any existing, impairment of visibility[1] in mandatory Class I federal areas which impairment results from manmade air pollution" (42 U.S.C. 7491). In 1999, EPA passed the Regional Haze Rule (RHR), which requires each state to develop a plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions in 2064. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity, and biogenic emissions. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Network and typically reported using the haze index deciview[2] (dv). Although all the parks in the NCRN are designated as Class II under the Clean Air Act, the RHR is expected to benefit all areas, not just those designated Class I.

An IMPROVE monitor (WASH1) is located in Washington, DC and is considered representative of several of the NCRN park units; an IMPROVE monitor in Arendtsville, Pennsylvania, (AREN1) is considered representative of other NCRN park units (Table 8). A monitoring site is considered by IMPROVE to be representative of an area if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area.

Current visibility estimates reflect current pollution levels and were used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and air pollution. Rankings range from very low haze (very good visibility) to very high haze (very poor visibility). Only parks with on-site or representative IMPROVE monitors were used in generating the baseline visibility ranking. Table 8 gives the relative park haze rankings on the 20% clearest, 20% haziest, and average days.

The parks in the NCRN had relatively high natural (in the absence of human-caused pollution) haze in comparison with other I&M parks for the 20% clearest natural haze conditions, 20% haziest natural haze conditions, and for the average of all natural haze conditions (Table 8). Nevertheless, measured ambient haze for the period 2004 through 2008 was considerably (about 9 to 18 dv) higher than the estimated natural condition (Table 8). Measured ambient haze in all parks in this network was ranked Very High for the 20% clearest, 20% haziest, and average days.

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[1] Visibility impairment means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

[2] The *deciview* visibility metric expresses uniform changes in haziness in terms of common increments across the entire range of visibility conditions, from pristine to extremely hazy conditions. Because each unit change in deciview represents a common change in perception, the deciview scale is like the decibel scale for sound. A one deciview change in haziness is a small but noticeable change in haziness under most circumstances when viewing scenes in Class I areas.

Composition of Haze

Various pollutants make up the haze that causes visibility degradation. IMPROVE measures these pollutants and reports them as ammonium sulfate, ammonium nitrate, elemental carbon, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO_2 emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, power plants, industry, and fires. Organic compounds are emitted from a variety of both natural (biogenic) and anthropogenic sources, including agriculture, industry, and fires. Atmospheric sea salt concentrations are higher in coastal areas. Soil can enter the atmosphere through both natural processes and human disturbance.

Figure 1 shows estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze and its composition for the parks in the NCRN. The figure illustrates that sulfates are the primary components of ambient haze at all of the parks on the 20% clearest, annual average, and 20% haziest visibility days. Organics and nitrates also contribute to haze at these parks and carbon is important on the clearest days at some of the parks.

IMPROVE data allow estimation of visual range (VR). Data indicate that at AREN1 (representative of ANTI, CATO, and HAFE), pollution has reduced average VR from 110 to 20 miles (177 to 32 km). On the haziest days, VR has been reduced from 70 to 10 miles (113 to 16 km). Severe haze episodes occasionally reduce visibility to 5 miles (8 km). At WASH1 (representative of CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR), pollution has reduced average VR from 100 to 20 miles (161 to 32 km). On the haziest days, VR has been reduced from 75 to 10 miles (121 to 16 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km).

Table 8. Estimated natural background visibility (top panel) and ambient visibility conditions in NCRN parks averaged over the period 2004 through 2008 (bottom panel)[1]. WASH1 is in Washington, DC; AREN1 is in Arendtsville, PA.

Park Name	Park Code	Site ID	Estimated Natural Background Visibility (dv)		
			20% Clearest Days	20% Haziest Days	Average Days
Antietam[2]	ANTI	AREN1	4.24	11.77	7.68
Catoctin Mountain[2]	CATO	AREN1	4.24	11.77	7.68
Chesapeake and Ohio Canal[2]	CHOH	WASH1	5.51	11.86	8.26
George Washington[2]	GWMP	WASH1	5.51	11.86	8.26
Harpers Ferry[2]	HAFE	AREN1	4.24	11.77	7.68
Manassas[2]	MANA	WASH1	5.51	11.86	8.26
Monocacy[2]	MONO	WASH1	5.51	11.86	8.26
National Capital Parks - East	NACE	WASH1	5.51	8.26	11.86
Prince William Forest[2]	PRWI	WASH1	5.51	11.86	8.26
Rock Creek Park[2]	ROCR	WASH1	5.51	11.86	8.26
Wolf Trap National Park for the Performing Arts[2]	WOTR	WASH1	5.51	11.86	8.26

Park Name	Park Code	Site ID	Baseline Visibility (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking[1]	dv	Ranking[1]	dv	Ranking[1]
Antietam[2]	ANTI	AREN1	13.48	Very High	29.46	Very High	21.41	Very High
Catoctin Mountain[2]	CATO	AREN1	13.48	Very High	29.46	Very High	21.41	Very High
Chesapeake and Ohio Canal[2]	CHOH	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
George Washington[2]	GWMP	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
Harpers Ferry[2]	HAFE	AREN1	13.48	Very High	29.46	Very High	21.41	Very High
Manassas[2]	MANA	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
Monocacy[2]	MONO	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
National Capital Parks - East	NACE	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
Prince William Forest[2]	PRWI	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
Rock Creek Park[2]	ROCR	WASH1	16.86	Very High	29.70	Very High	23.11	Very High
Wolf Trap National Park for the Performing Arts[2]	WOTR	WASH1	16.86	Very High	29.70	Very High	23.11	Very High

[1] Parks are classified into one of five haze ranks (Very Low, Low, Moderate, High, or Very High haze).

[2] Data are borrowed from nearby IMPROVE sites. A monitoring site is considered by IMPROVE to be representative of an area if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area.

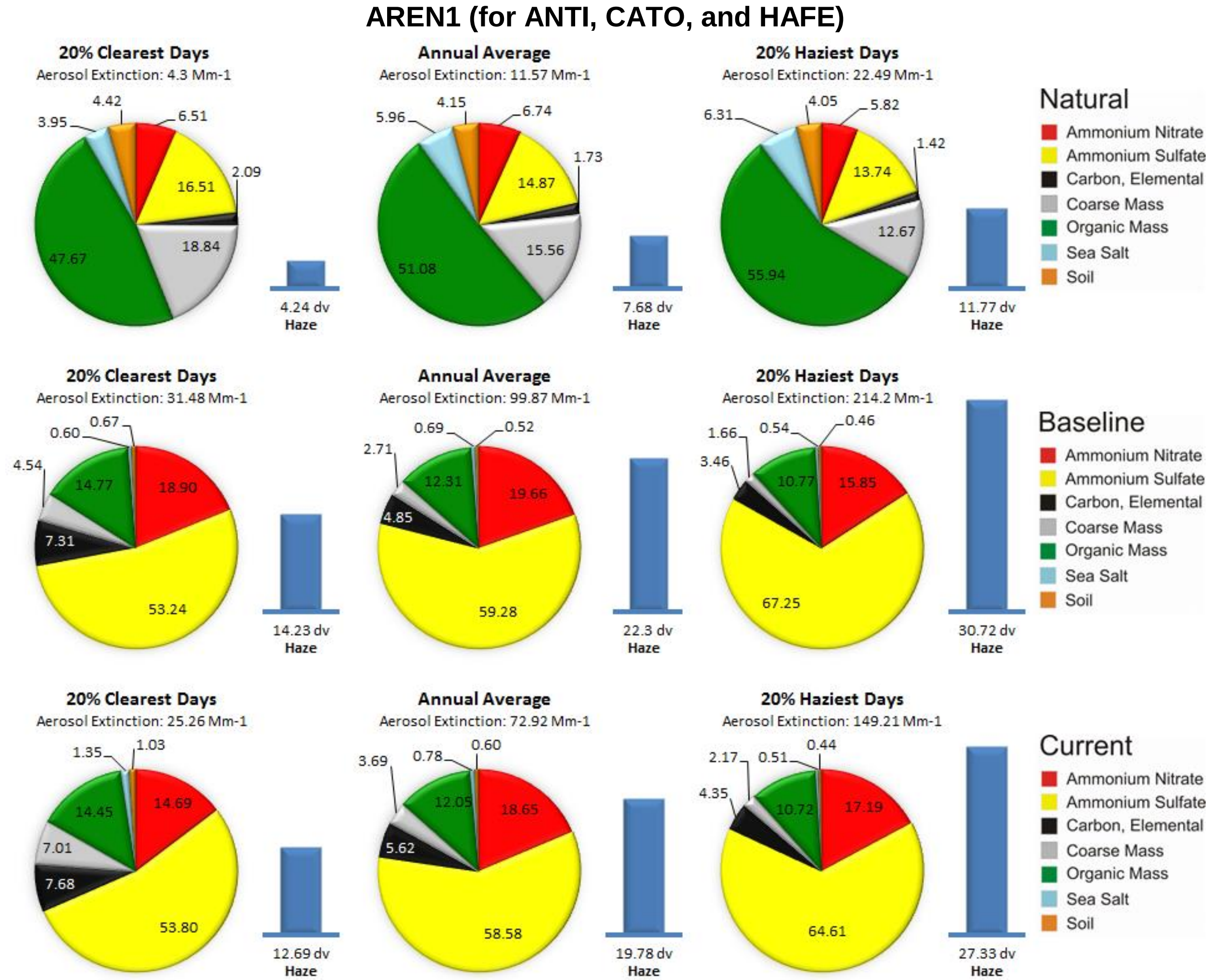

Figure 1a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for NCRN parks. Data were taken from nearby sites (see Table 8). ANTI, CATO, and HAFE have no data for the years 2000 and 2001; and CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR have no data for the year 2010. Data Source: NPS-ARD.

WASH1 (for CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR)

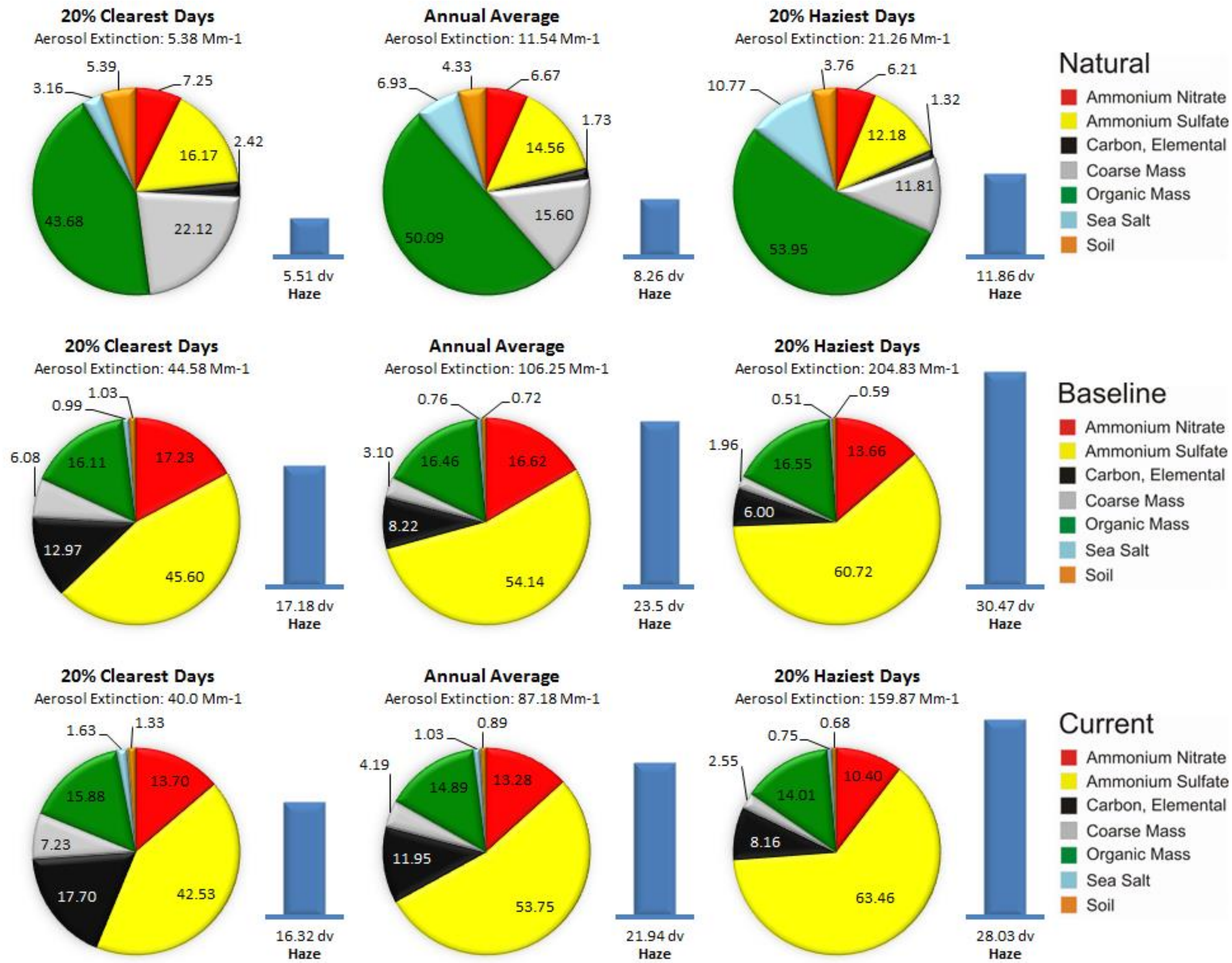

Figure 1b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for NCRN parks. Data were taken from nearby sites (see Table 8). ANTI, CATO, and HAFE have no data for the years 2000 and 2001; and CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR have no data for the year 2010. Data Source: NPS-ARD.

Trends in Visibility

Progress to date in meeting the national visibility goal is illustrated in Figure 2 using a uniform rate of progress glideslope. Although clear progress has been made since the baseline period (2000-2004), substantial additional visibility improvement is needed to eliminate anthropogenic haze by 2064.

NPS (2010) reported long-term trends in annual dv on the clearest and haziest 20% of days at monitoring sites in 29 national parks. Of the 27 parks that showed statistically significant ($p \leq 0.05$) dv trends on the clearest days for the 11-20 year monitoring periods through 2008, all of them exhibited decreases in dv (improved visibility) over time. None of the sites showed increasing haze on the clearest days. The steepest declines in haze (-0.18 to -0.20 dv/yr) on the clearest days were reported for Shenandoah National Park, Acadia National Park, and Washington, DC, with 18-19 years of monitoring data at each of those locations. Available haze monitoring data are shown in Figure 3 for the period of record at each park. In general, haze levels appear to be decreasing at all parks in the network.

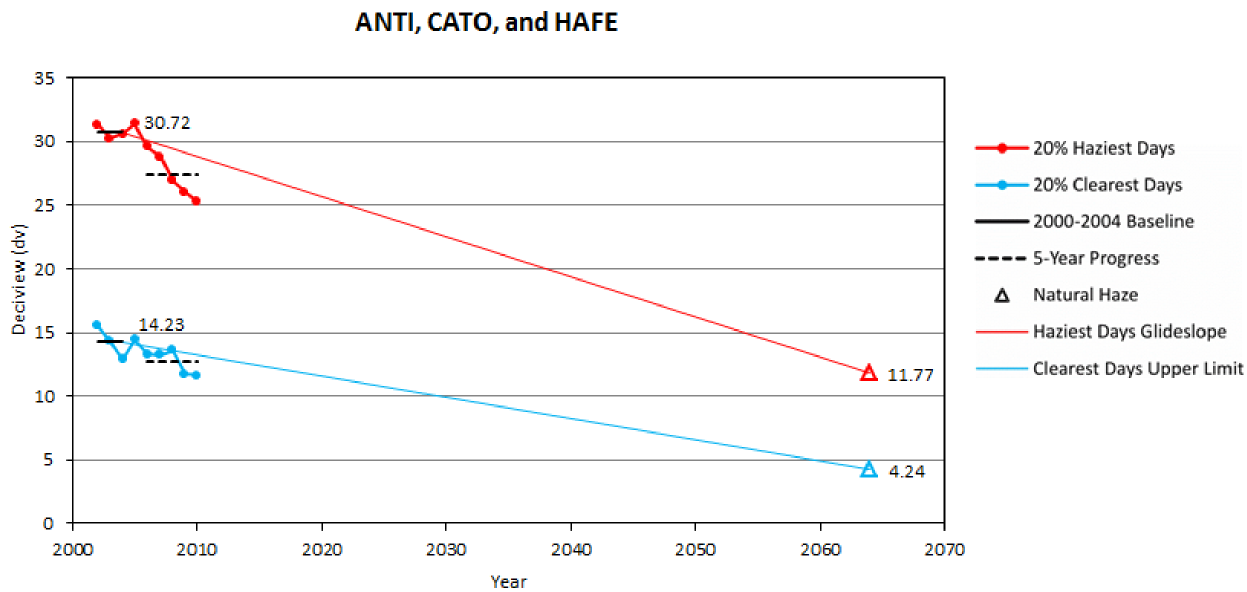

Figure 2a. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in the parks in the NCRN. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for all parks were taken from nearby sites, AREN1 and WASH1. ANTI, CATO, and HAFE have no data for the years 2000 and 2001; and CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR have no data for the year 2010. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

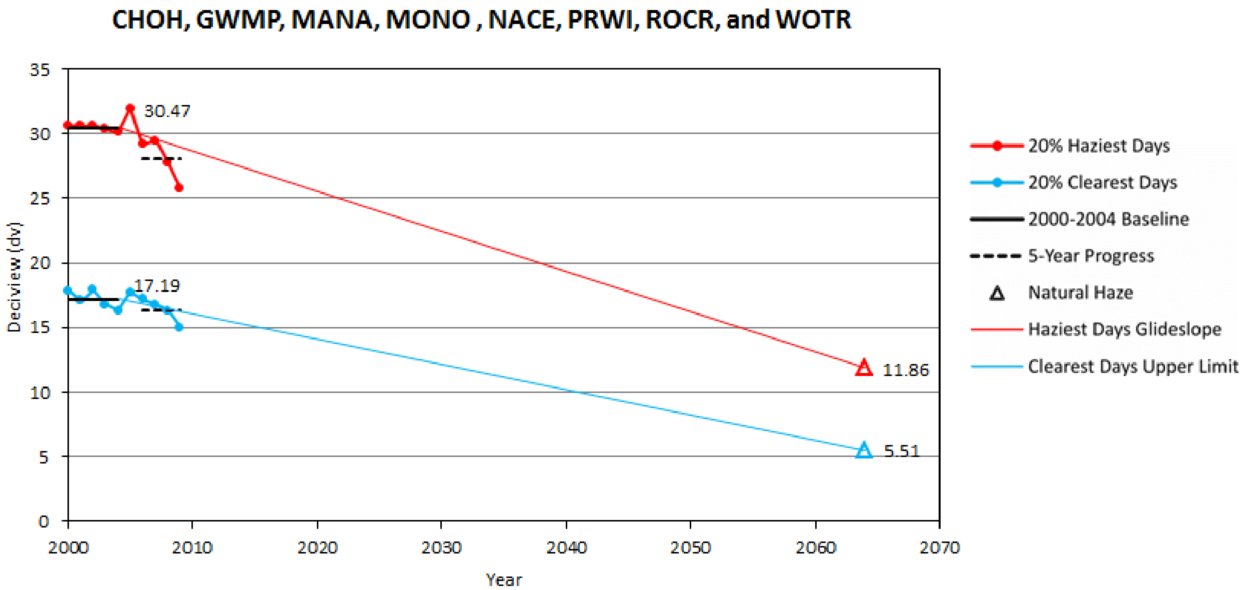

Figure 2b. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in the parks in the NCRN. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for all parks were taken from nearby sites, AREN1 and WASH1. ANTI, CATO, and HAFE have no data for the years 2000 and 2001; and CHOH, GWMP, MANA, MONO, NACE, PRWI, ROCR, and WOTR have no data for the year 2010. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Development of State Implementation Plans

According to the RHR, states and tribes must establish and meet reasonable progress goals for each federal Class I area to improve visibility on the 20% haziest days and to prevent visibility degradation on the 20% clearest days. The national goal is to return visibility in Class I areas to natural background levels in 2064. States must evaluate progress by 2018 (and every 10 years thereafter) based on a baseline period of 2000 to 2004 (Air Resource Specialists 2007).

Toxic Airborne Contaminants

Little information is available regarding possible effects of air toxics deposition on sensitive park resources in the NCRN. Rattner and Ackerson (2006) conducted a study of ecotoxicological threats to 23 I&M park units in the National Capital Region and Mid-Atlantic networks. Information was provided on existing or potential toxic pollution hazards in order to prioritize future contaminant biomonitoring activities. Pesticides used at the park units were judged to be generally of low toxicity, posing little or no threat to terrestrial vertebrates. Atmospheric deposition of toxic material from sources outside the park units was not assessed.

The District Department of the Environment has issued a public health advisory to limit consumption of certain fish species from all DC waters because of contamination from polychlorinated biphenyls (PCBs) and other toxics. Maryland and West Virginia have issued statewide fish consumption advisories for many fish species because of elevated levels of mercury (Hg), PCBs, and other toxics in fish tissues. Virginia has issued fish consumption advisories because of Hg and PCBs. The extent to which such contaminants have been contributed to park waters from atmospheric sources is unclear.

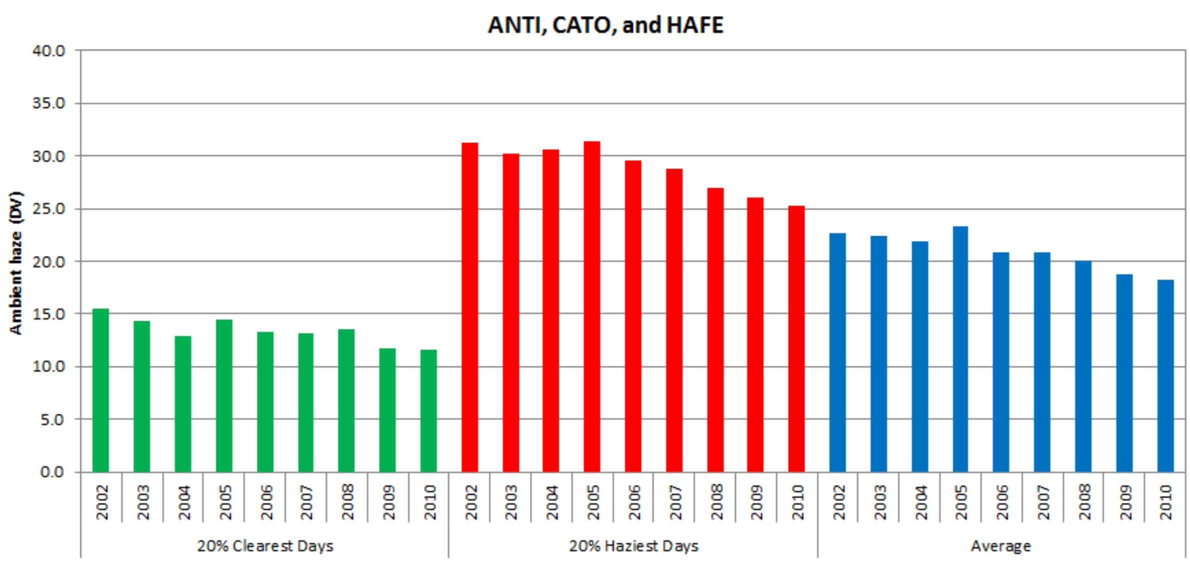

Figure 3a. Trends in ambient haze levels at the parks in the NCRN, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all parks were taken from nearby sites, AREN1 and WASH1. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

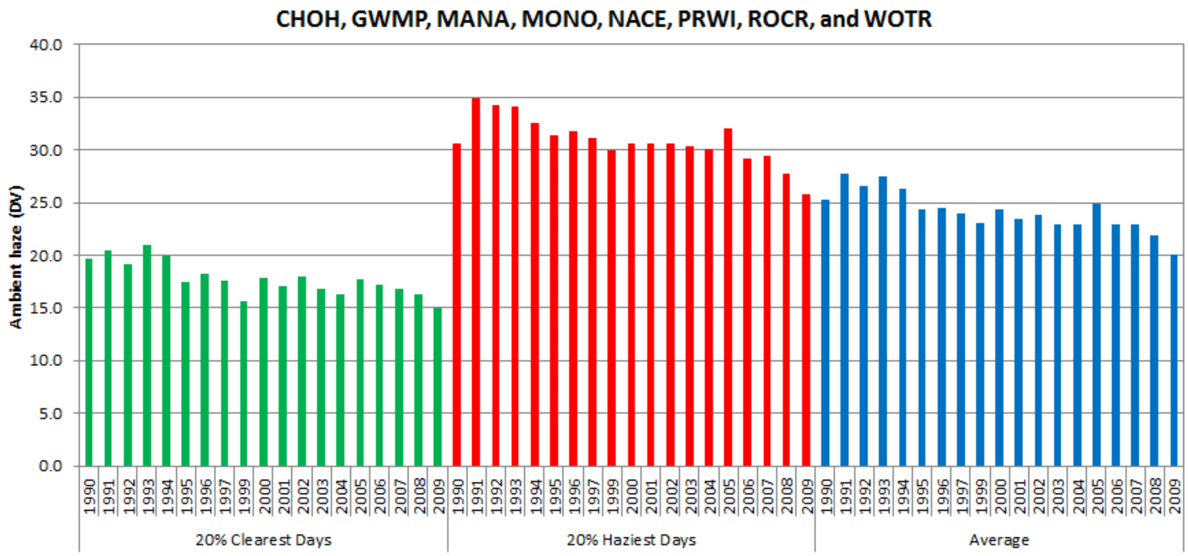

Figure 3b. Trends in ambient haze levels at the parks in the NCRN, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all parks were taken from nearby sites, AREN1 and WASH1. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

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