



# Air Quality Related Values (AQRVs) for Heartland Network (HTLN) Parks

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

Natural Resource Report NPS/HTLN/NRR—2016/1159



#### 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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# **Air Quality Related Values (AQRVs) for Heartland Network (HTLN) Parks**

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Natural Resource Report NPS/HTLN/NRR—2016/1159

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## Summary

This report describes the Air Quality Related Values (AQRVs) of the Heartland Network (HTLN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The HTLN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Arkansas Post National Memorial (ARPO), Buffalo National River (BUFF), Cuyahoga Valley National Park (CUVA), Effigy Mounds National Monument (EFMO), George Washington Carver National Park (GWCA), Herbert Hoover National Historic Site (HEHO), Homestead National Monument (HOME), Hopewell Culture National Historical Park (HOCU), Hot Springs National Park (HOSP), Lincoln Boyhood National Memorial (LIBO), Ozark National Scenic Riverways (OZAR), Pea Ridge National Military Park (PERI), Pipestone National Monument (PIPE), Tallgrass Prairie National Preserve (TAPR), and Wilson's Creek National Battlefield (WICR).

Sullivan et al. (2011a, 2011b) and Kohut (2007a) conducted risk assessments for acidification, eutrophication, and ozone ( $O_3$ ) for the HTLN parks; their results are described in this report. This report also describes air pollutant emissions and air quality, and their effects on AQRVs. 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).

The 15 park units in the HTLN are located across a broad geographic region from Ohio to Kansas and Minnesota to Arkansas. There are many air pollution sources in the region, including large power plants, industrial facilities, urban areas, agricultural activities, and motor vehicles.

Emissions and deposition of both S and N are relatively high in this network. Several counties within the network region had  $SO_2$  emissions levels higher than 100 tons per square mile per year in 2002. These were located in the eastern part of the network region, predominately in Ohio and Indiana. There are numerous S point sources of considerable magnitude near the HTLN. Most of the largest are coal-fired power plants in Ohio and Indiana. There are also many relatively large (larger than about 4,000 tons per year) point sources of oxidized N ( $NO_x$  – from burning fuel) in and around the eastern portion of the network. In contrast, the  $NH_3$  point sources (associated with agriculture) are primarily located in the western part of the network, in Kansas and Minnesota.

Total S deposition within the network region in 2002 ranged from relatively low values in the west ( $< 5$  kg S/ha/yr) to high levels of deposition ( $> 20$  kg S/ha/yr) in the east. Throughout most of the network region, total N deposition was fairly high, between about 10 and 15 kg N/ha/yr. During the period 2001-2011, S deposition decreased at most parks in the network, in some cases by more than 20%. In contrast, total N deposition increased at many of the network parks and decreased at others.

Atmospheric S and N pollutants can cause acidification of streams, lakes, and soils. Some of the parks in the HTLN were ranked as sensitive to acidification, based on coarse screening analyses

conducted by Sullivan et al. (2011b). Surface water survey data corroborate that finding, but only in the Ozark/Ouschitas region of the U.S. EPA's National Stream Survey (NSS), where nearly two-thirds of the surveyed streams had acid neutralizing capacity (ANC)  $\leq 200 \mu\text{eq/L}$ . There are no data suggesting that soils or surface waters in the HTLN parks have acidified in response to atmospheric S or N deposition to date.

Nitrogen deposition can also cause undesirable enrichment of natural ecosystems, leading to changes in plant species diversity and soil nutrient cycling. Most of the smaller parks in the network were estimated to be Low or Very Low in ecosystem sensitivity to nutrient N enrichment. Exceptions included HOME and PIPE national monuments, both of which were ranked High, and TAPR, which was ranked Very High. These presumed high sensitivities to eutrophication were mainly attributable to the prevalence of grassland vegetation, which has been found to be especially sensitive to nutrient enrichment impacts from atmospheric N deposition.

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. Estimated  $\text{O}_3$  exposures across the parks in this network are highly variable. Sensitive vegetation in some of the parks is considered to be at high risk from  $\text{O}_3$  injury because of relatively high seasonal  $\text{O}_3$  exposures.

Particulate pollution can cause haze, reducing visibility. Haze is monitored at TAPR as part of the national visibility monitoring program, IMPROVE (Interagency Monitoring of Protected Visual Environments), and there are additional monitors in the region that can be used to characterize visibility conditions at several other parks. Haze levels are high at times, with most haze caused by  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , and organic particles.

Airborne toxics, including mercury (Hg) and other heavy metals, can accumulate in food webs, reaching toxic levels in top predators. Some research has been conducted in the HTLN region on the effects on wildlife of mercury (Hg) contamination, much of which is presumed to be of atmospheric origin. Rutkiewicz et al. (2011) evaluated Hg exposure to bald eagles collected in Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Results suggested that bald eagles in this region are exposed to Hg at levels high enough to cause subclinical neurological damage.

## Background

There are 15 parks in the Heartland Network (HTLN). Only two (Buffalo National River [BUFF] and Ozark National Scenic Riverways [OZAR]) are larger than 100 square miles. Larger parks generally have more available data with which to evaluate air pollution sensitivities and effects. In addition, the larger parks generally contain more extensive resources in need of protection against the adverse impacts of air pollution. The smaller parks include Arkansas Post National Memorial (ARPO), Cuyahoga Valley National Park (CUVA), Effigy Mounds National Monument (EFMO), George Washington Carver National Park (GWCA), Herbert Hoover National Historic Site (HEHO), Homestead National Monument (HOME), Hopewell Culture National Historical Park (HOCU), Hot Springs National Park (HOSP), Lincoln Boyhood National Memorial (LIBO), Pea Ridge National Military Park (PERI), Pipestone National Monument (PIPE), Tallgrass Prairie National Preserve (TAPR), and Wilson's Creek National Battlefield (WICR).

The largest population centers in the region are Indianapolis and Columbus. There are numerous other large urban centers within a 300-mile radius of the network, including Philadelphia, Houston, Dallas, and Chicago. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people. The predominant cover types within the HTLN are generally row crops and pasture/hay. There are also forested and developed areas scattered throughout the network, and wetlands are widespread in the southern portion.

## Atmospheric Emissions and Deposition

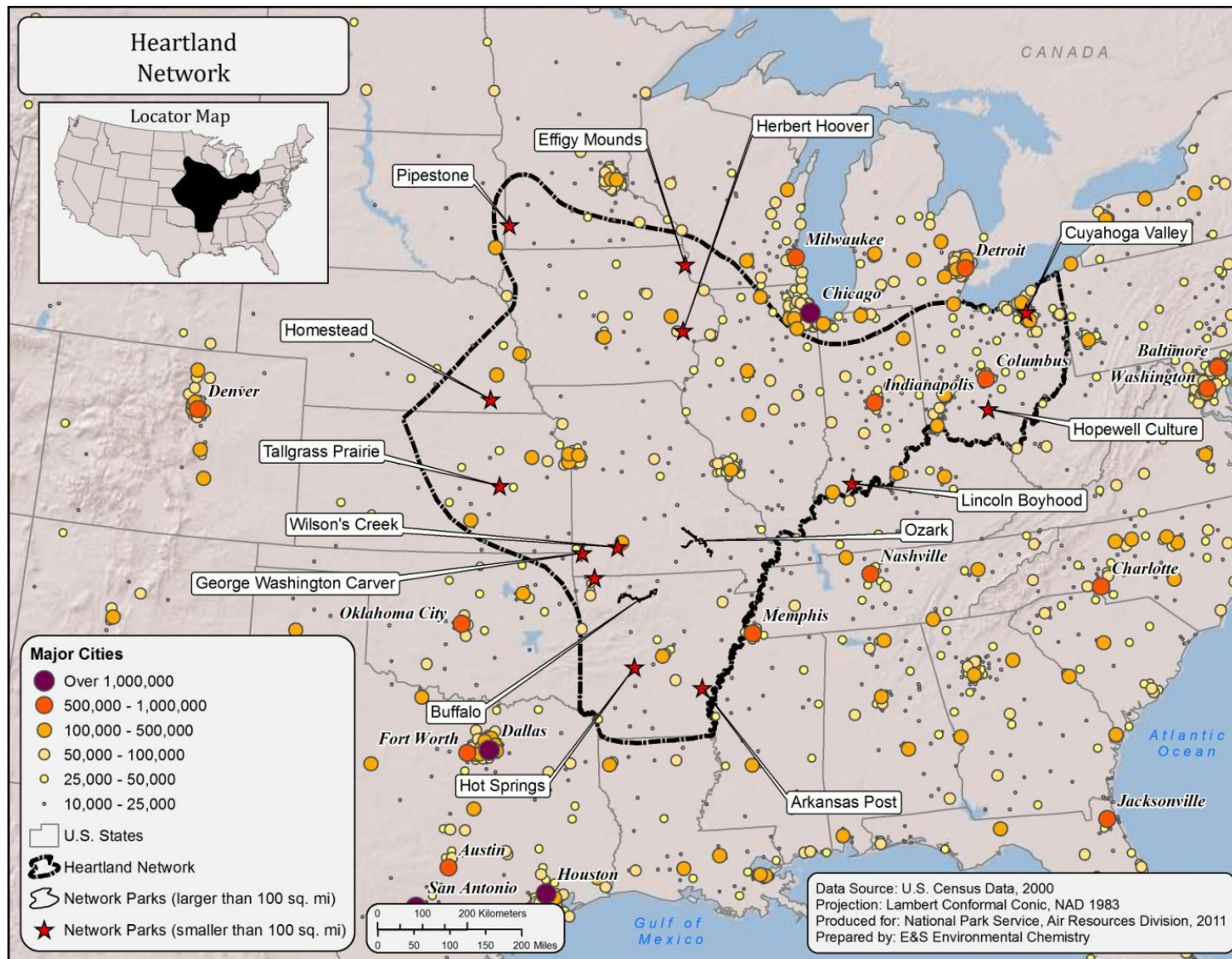
County-level sulfur (S) emissions within the HTLN generally ranged from less than 1 to more than 50 tons per square mile per year (tons/mi<sup>2</sup>/yr; Sullivan et al. 2011b) in 2002. There were several counties that had SO<sub>2</sub> emissions levels that were higher than 100 tons/mi<sup>2</sup>/yr. These high SO<sub>2</sub> emissions counties were located in the eastern part of the network, predominately in Ohio and Indiana.

There are numerous S point sources of considerable magnitude in the HTLN region, many of which are coal-fired power plants. Many emitted more than 20,000 tons per year in 2002 (Sullivan et al. 2011b). The 90<sup>th</sup> percentile summer atmospheric SO<sub>4</sub><sup>2-</sup> concentrations throughout the United States were highest in the Ohio River Valley and in central Tennessee, where power plant emissions of SO<sub>2</sub> have been especially high (Malm et al. 2002).

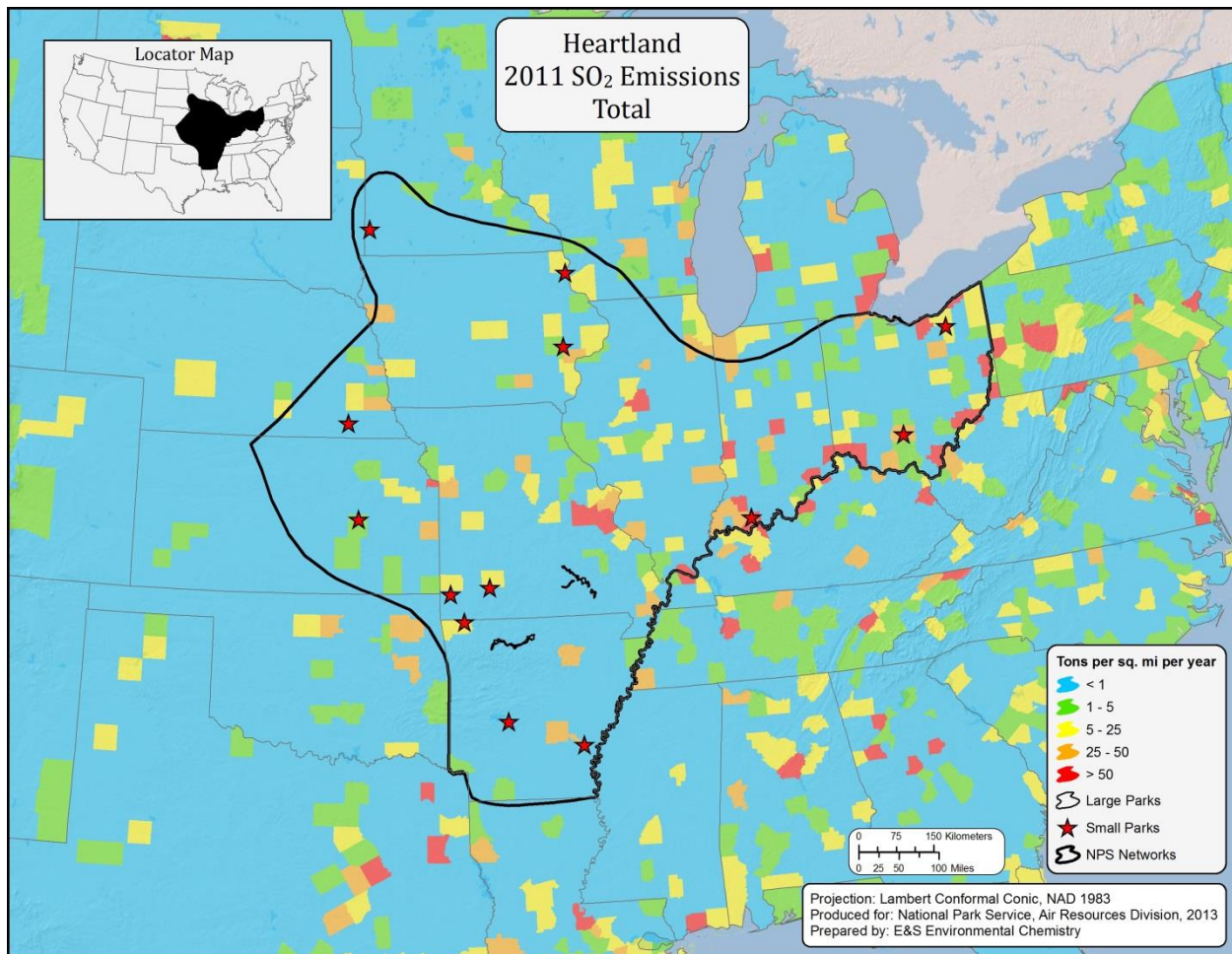
Annual county-level nitrogen (N) emissions within the network region generally ranged from less than 1 ton per square mile to more than 20 tons per square mile in 2002. There was one county, located in eastern Missouri, that had N emissions values higher than 100 tons/mi<sup>2</sup>/yr. In general, however, annual county N emissions within the network region were between 1 and 20 tons/mi<sup>2</sup>/yr. There were many relatively large (larger than about 4,000 tons per year) point sources of oxidized N (NO<sub>x</sub>) around the eastern portion of the network. There were also many smaller point sources of both NO<sub>x</sub> and reduced (ammonia; NH<sub>3</sub>) N. The NH<sub>3</sub> point sources were primarily in the western part of the network, in Kansas and Minnesota. Most were agricultural sources.

County-level emissions near the HTLN, 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 sulfur dioxide (SO<sub>2</sub>), NO<sub>x</sub>, and NH<sub>3</sub>, respectively. Many counties, especially to the east of HTLN parks, had relatively high SO<sub>2</sub> emissions (> 50 tons/mi<sup>2</sup>/yr; Map 2). Spatial patterns in NO<sub>x</sub> emissions showed most counties near the parks having values below 25 tons/mi<sup>2</sup>/yr (Map 3). Emissions of NH<sub>3</sub> near HTLN parks were somewhat lower, with most counties showing emissions levels below 8 tons/mi<sup>2</sup>/yr (Map 4).

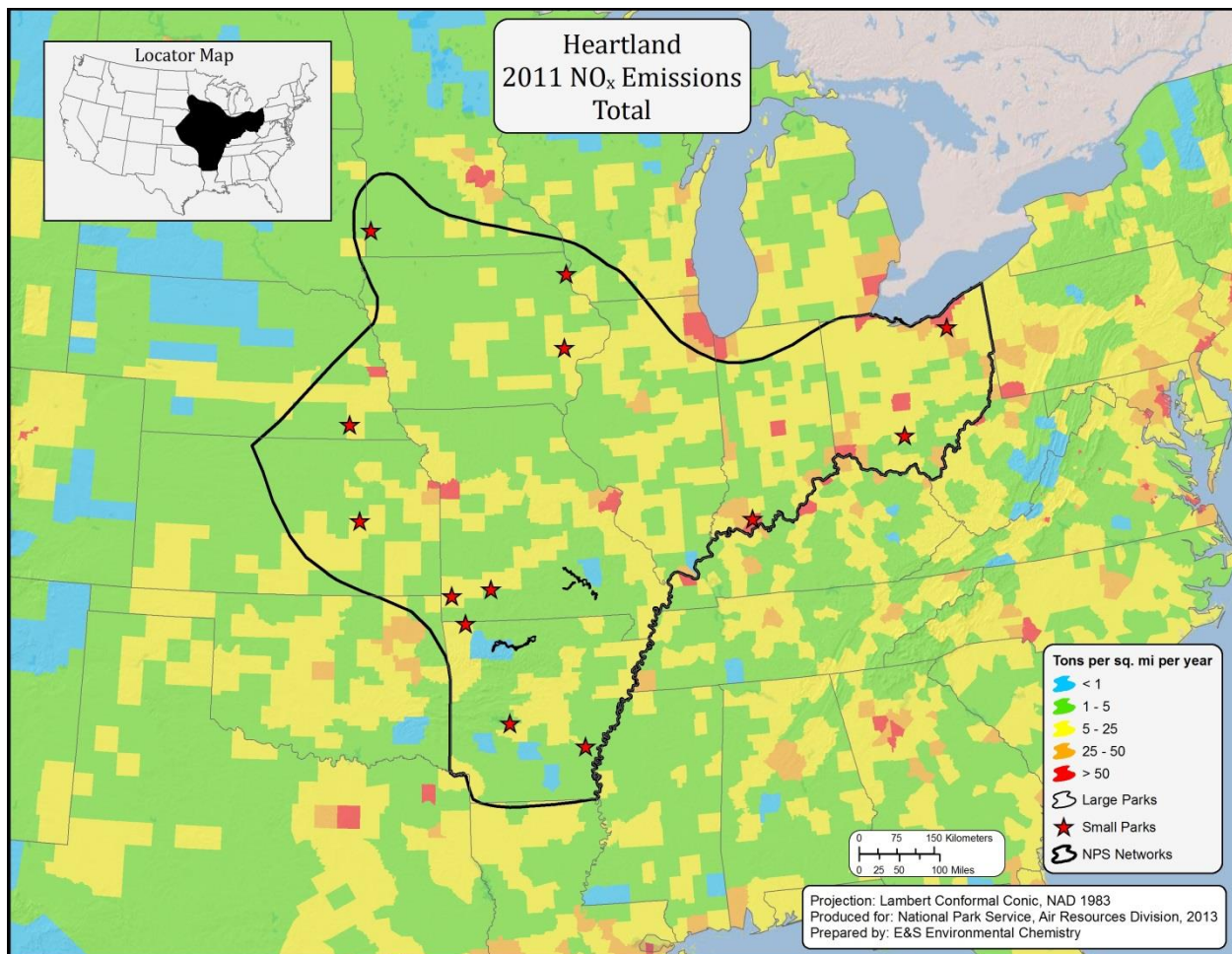
Total S deposition within the network region in 2002 generally ranged from 2 to 5 kg S/ha/yr to greater than 20 kg S/ha/yr (Sullivan et al. 2011b). Total S deposition increased from relatively low values in the west to high levels of deposition in the east. Total N deposition within the network region ranged from as low as 5 to 10 kg N/ha/yr to above 15 kg N/ha/yr at some locations. Throughout most of the network region, total N deposition was between about 10 and 15 kg N/ha/yr in 2002 (Sullivan et al. 2011b).



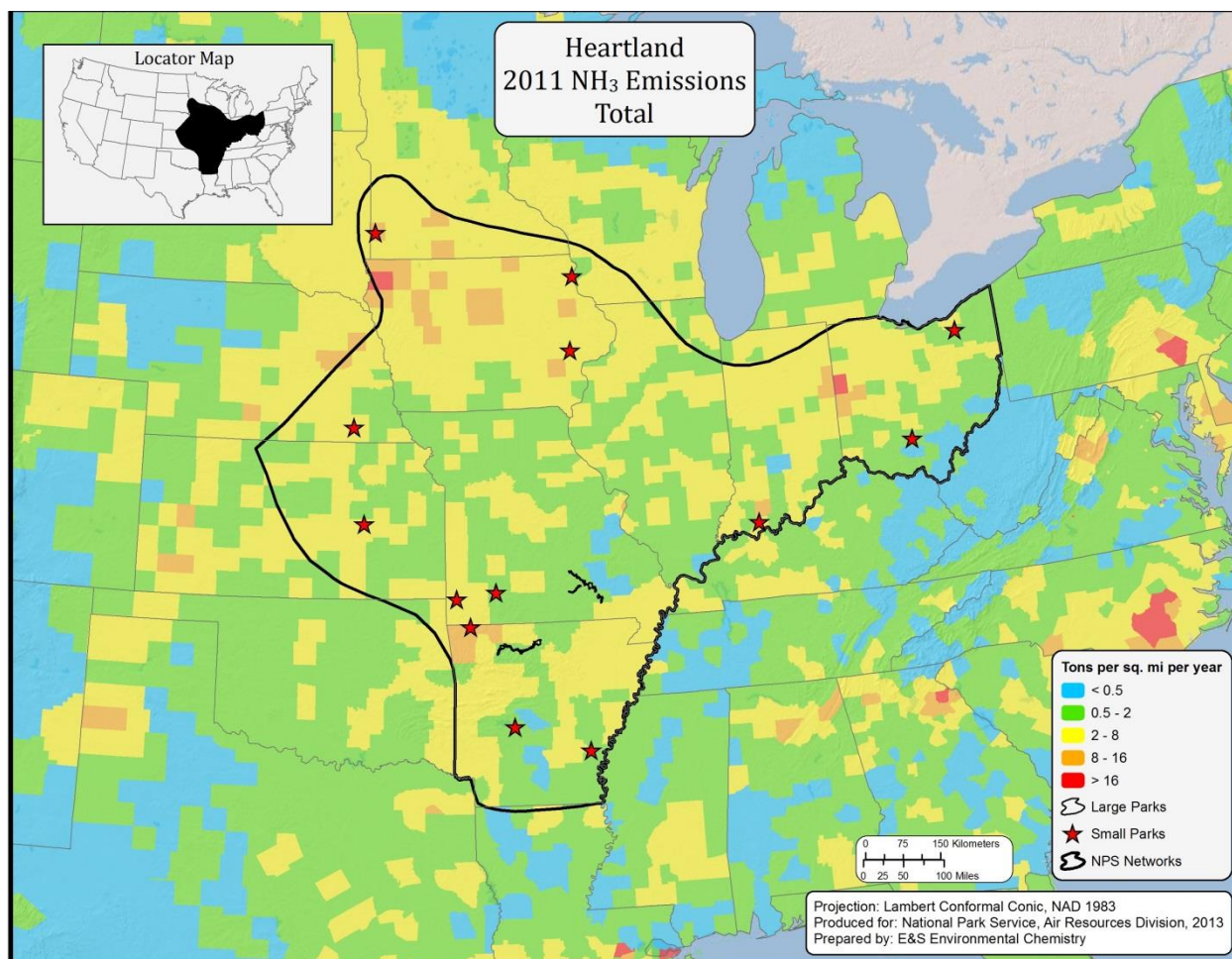
**Map 1.** Network boundary and locations of parks and population centers greater than 10,000 people within the HTLN region.



**Map 2.** Total SO<sub>2</sub> emissions, by county, near the HTLN for the year 2011. Data from EPA's National Emissions Inventory.



**Map 3.** Total NO<sub>x</sub> emissions, by county, near the HTLN for the year 2011. Data from EPA's National Emissions Inventory.



**Map 4.** Total NH<sub>3</sub> emissions, by county, near the HTLN for the year 2011. Data from EPA's National Emissions Inventory.

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 (PAN), N<sub>2</sub>O<sub>5</sub>, NO, NO<sub>2</sub>, HONO, and organic NO<sub>3</sub>. 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.

**Table 1.** Average changes in S and N deposition between 2001 and 2011 across park grid cells at HTLN 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) |
|-----------|--------------------------|------------|-------------------------|-------------------------|----------------------------|----------------|-------------------------|-------------------------|-----------------------|
| ARPO      | Arkansas Post            | Total S    | 6.38                    | 3.81                    | -2.56                      | -40.2%         | 3.80                    | 3.83                    | 0.03                  |
|           |                          | Total N    | 11.01                   | 8.84                    | -2.18                      | -19.7%         | 8.72                    | 8.98                    | 0.26                  |
|           |                          | Oxidized N | 5.70                    | 3.68                    | -2.02                      | -35.4%         | 3.67                    | 3.68                    | 0.01                  |
|           |                          | Reduced N  | 5.32                    | 5.16                    | -0.16                      | -3.0%          | 5.03                    | 5.31                    | 0.28                  |
| BUFF      | Buffalo                  | Total S    | 4.97                    | 4.66                    | -0.31                      | -6.3%          | 4.17                    | 5.48                    | 1.31                  |
|           |                          | Total N    | 9.14                    | 9.74                    | 0.61                       | 6.6%           | 8.54                    | 11.49                   | 2.95                  |
|           |                          | Oxidized N | 5.56                    | 4.73                    | -0.84                      | -15.1%         | 3.97                    | 5.55                    | 1.58                  |
|           |                          | Reduced N  | 3.57                    | 5.02                    | 1.45                       | 40.3%          | 4.25                    | 6.14                    | 1.89                  |
| CUVA      | Cuyahoga Valley          | Total S    | 23.19                   | 17.87                   | -5.31                      | -22.8%         | 15.63                   | 18.60                   | 2.97                  |
|           |                          | Total N    | 19.73                   | 18.90                   | -0.82                      | -4.7%          | 13.23                   | 32.29                   | 19.06                 |
|           |                          | Oxidized N | 10.71                   | 7.56                    | -3.15                      | -29.3%         | 6.92                    | 7.74                    | 0.82                  |
|           |                          | Reduced N  | 9.01                    | 11.34                   | 2.33                       | 24.7%          | 6.16                    | 24.58                   | 18.43                 |
| EFMO      | Effigy Mounds            | Total S    | 6.64                    | 5.26                    | -1.38                      | -20.7%         | 5.01                    | 5.47                    | 0.46                  |
|           |                          | Total N    | 14.00                   | 14.30                   | 0.30                       | 2.1%           | 14.18                   | 15.66                   | 1.49                  |
|           |                          | Oxidized N | 5.93                    | 5.02                    | -0.91                      | -15.3%         | 4.56                    | 5.04                    | 0.48                  |
|           |                          | Reduced N  | 8.07                    | 9.28                    | 1.20                       | 14.9%          | 9.14                    | 10.86                   | 1.72                  |
| GWCA      | George Washington Carver | Total S    | 5.00                    | 5.34                    | 0.34                       | 6.8%           | 5.17                    | 5.37                    | 0.20                  |
|           |                          | Total N    | 11.83                   | 14.36                   | 2.53                       | 21.4%          | 14.12                   | 15.57                   | 1.45                  |
|           |                          | Oxidized N | 5.73                    | 5.07                    | -0.66                      | -11.5%         | 4.99                    | 5.09                    | 0.10                  |
|           |                          | Reduced N  | 6.10                    | 9.29                    | 3.19                       | 52.3%          | 9.03                    | 10.58                   | 1.55                  |
| HEHO      | Herbert Hoover           | Total S    | 7.49                    | 5.85                    | -1.64                      | -21.8%         | 5.85                    | 5.85                    | 0.00                  |
|           |                          | Total N    | 13.71                   | 15.70                   | 1.99                       | 14.5%          | 15.70                   | 15.70                   | 0.00                  |
|           |                          | Oxidized N | 6.68                    | 4.74                    | -1.94                      | -29.0%         | 4.74                    | 4.74                    | 0.00                  |
|           |                          | Reduced N  | 7.03                    | 10.96                   | 3.93                       | 55.9%          | 10.96                   | 10.96                   | 0.00                  |

**Table 1** (continued). Average changes in S and N deposition between 2001 and 2011 across park grid cells at HTLN 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               | 2011               | Absolute          | Percent Change | 2011               | 2011               | 2011             |
|-----------|------------------|------------|--------------------|--------------------|-------------------|----------------|--------------------|--------------------|------------------|
|           |                  |            | Average (kg/ha/yr) | Average (kg/ha/yr) | Change (kg/ha/yr) |                | Minimum (kg/ha/yr) | Maximum (kg/ha/yr) | Range (kg/ha/yr) |
| HOCU      | Hopewell Culture | Total S    | 20.82              | 11.74              | -9.08             | -43.5%         | 10.71              | 14.09              | 3.38             |
|           |                  | Total N    | 14.34              | 10.86              | -3.49             | -24.3%         | 10.42              | 11.65              | 1.23             |
|           |                  | Oxidized N | 10.20              | 5.86               | -4.34             | -42.5%         | 5.57               | 6.36               | 0.79             |
|           |                  | Reduced N  | 4.15               | 5.00               | 0.85              | 20.6%          | 4.85               | 5.29               | 0.44             |
| HOME      | Homestead        | Total S    | 4.01               | 3.54               | -0.47             | -11.7%         | 3.54               | 3.54               | 0.00             |
|           |                  | Total N    | 11.22              | 15.25              | 4.03              | 35.9%          | 15.25              | 15.25              | 0.00             |
|           |                  | Oxidized N | 4.94               | 4.46               | -0.48             | -9.8%          | 4.46               | 4.46               | 0.00             |
|           |                  | Reduced N  | 6.28               | 10.79              | 4.51              | 71.9%          | 10.79              | 10.79              | 0.00             |
| HOSP      | Hot Springs      | Total S    | 6.05               | 5.37               | -0.68             | -11.2%         | 5.34               | 5.43               | 0.08             |
|           |                  | Total N    | 9.01               | 9.91               | 0.90              | 10.0%          | 9.79               | 10.02              | 0.23             |
|           |                  | Oxidized N | 5.88               | 5.02               | -0.86             | -14.6%         | 4.91               | 5.08               | 0.17             |
|           |                  | Reduced N  | 3.13               | 4.89               | 1.76              | 56.1%          | 4.87               | 4.94               | 0.07             |
| LIBO      | Lincoln Boyhood  | Total S    | 20.74              | 12.75              | -7.99             | -38.5%         | 12.75              | 12.75              | 0.00             |
|           |                  | Total N    | 14.62              | 13.75              | -0.87             | -6.0%          | 13.75              | 13.75              | 0.00             |
|           |                  | Oxidized N | 9.29               | 6.27               | -3.02             | -32.5%         | 6.27               | 6.27               | 0.00             |
|           |                  | Reduced N  | 5.33               | 7.48               | 2.15              | 40.3%          | 7.48               | 7.48               | 0.00             |
| OZAR      | Ozark            | Total S    | 7.22               | 6.29               | -0.93             | -12.6%         | 5.60               | 6.75               | 1.14             |
|           |                  | Total N    | 10.00              | 10.00              | -0.01             | 0.0%           | 9.62               | 10.60              | 0.99             |
|           |                  | Oxidized N | 6.43               | 5.42               | -1.01             | -15.6%         | 4.97               | 5.77               | 0.80             |
|           |                  | Reduced N  | 3.57               | 4.57               | 1.00              | 28.3%          | 4.36               | 4.99               | 0.64             |
| PERI      | Pea Ridge        | Total S    | 5.09               | 4.75               | -0.34             | -6.7%          | 4.74               | 4.91               | 0.17             |
|           |                  | Total N    | 13.07              | 15.20              | 2.13              | 16.3%          | 14.94              | 15.23              | 0.29             |
|           |                  | Oxidized N | 4.93               | 4.65               | -0.28             | -5.6%          | 4.59               | 4.87               | 0.28             |
|           |                  | Reduced N  | 8.14               | 10.55              | 2.41              | 29.6%          | 10.07              | 10.58              | 0.51             |

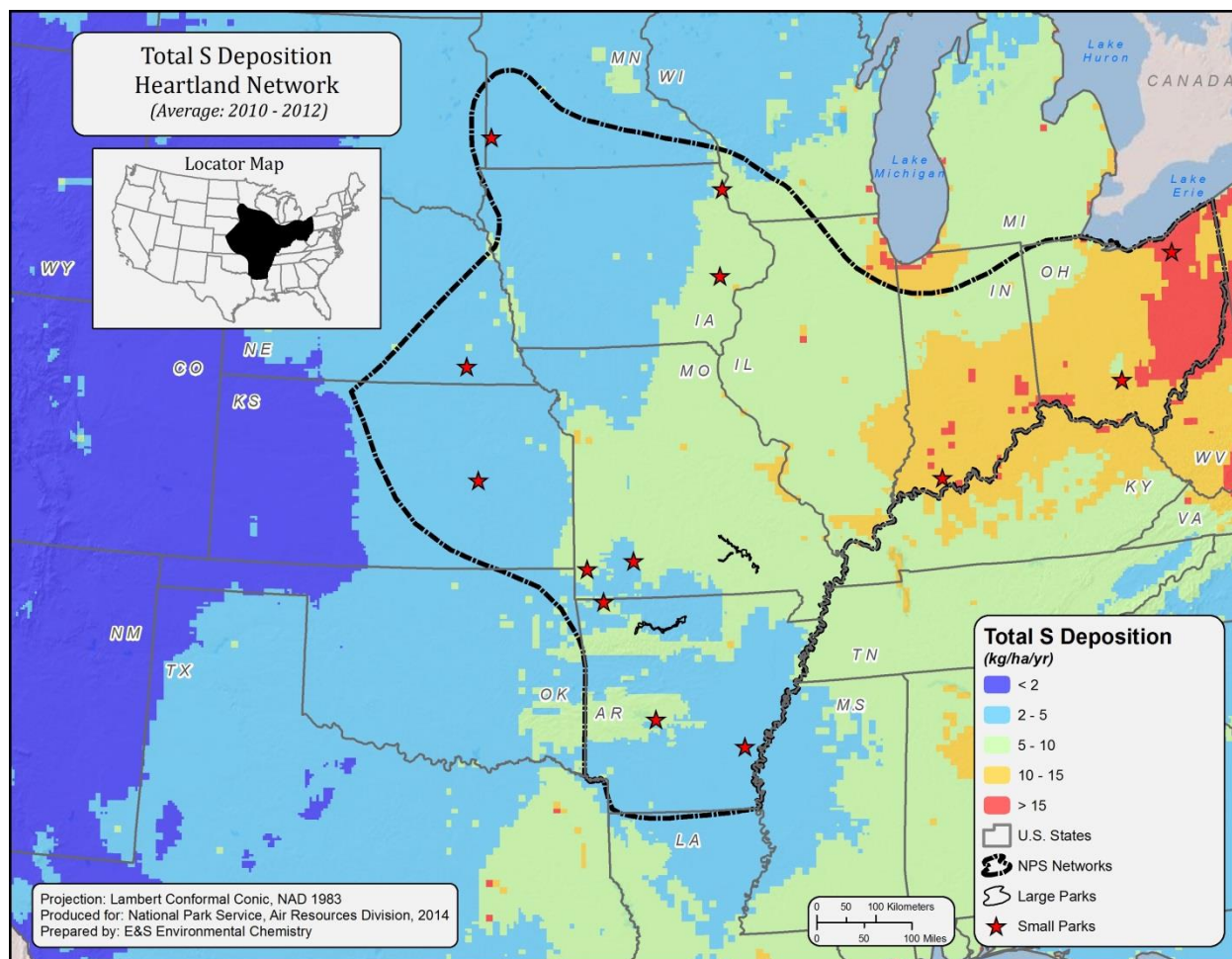
**Table 1** (continued). Average changes in S and N deposition between 2001 and 2011 across park grid cells at HTLN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, 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) |
|-----------|-------------------|------------|-------------------------|-------------------------|----------------------------|----------------|-------------------------|-------------------------|-----------------------|
| PIPE      | Pipestone         | Total S    | 3.08                    | 3.25                    | 0.17                       | 5.5%           | 3.24                    | 3.27                    | 0.03                  |
|           |                   | Total N    | 13.72                   | 18.67                   | 4.95                       | 36.1%          | 18.64                   | 18.73                   | 0.09                  |
|           |                   | Oxidized N | 3.89                    | 3.38                    | -0.51                      | -13.2%         | 3.37                    | 3.39                    | 0.02                  |
|           |                   | Reduced N  | 9.83                    | 15.30                   | 5.47                       | 55.6%          | 15.27                   | 15.34                   | 0.07                  |
| TAPR      | Tallgrass Prairie | Total S    | 4.10                    | 3.37                    | -0.73                      | -17.7%         | 3.36                    | 3.38                    | 0.02                  |
|           |                   | Total N    | 9.97                    | 9.40                    | -0.58                      | -5.8%          | 9.32                    | 9.43                    | 0.11                  |
|           |                   | Oxidized N | 5.15                    | 4.02                    | -1.13                      | -22.0%         | 4.01                    | 4.03                    | 0.02                  |
|           |                   | Reduced N  | 4.82                    | 5.38                    | 0.56                       | 11.6%          | 5.32                    | 5.41                    | 0.09                  |
| WICR      | Wilson's Creek    | Total S    | 4.68                    | 5.01                    | 0.33                       | 7.1%           | 4.93                    | 6.38                    | 1.44                  |
|           |                   | Total N    | 10.11                   | 10.72                   | 0.61                       | 6.0%           | 10.70                   | 11.01                   | 0.32                  |
|           |                   | Oxidized N | 5.25                    | 4.59                    | -0.66                      | -12.6%         | 4.56                    | 5.11                    | 0.55                  |
|           |                   | Reduced N  | 4.86                    | 6.13                    | 1.27                       | 26.2%          | 5.90                    | 6.18                    | 0.28                  |

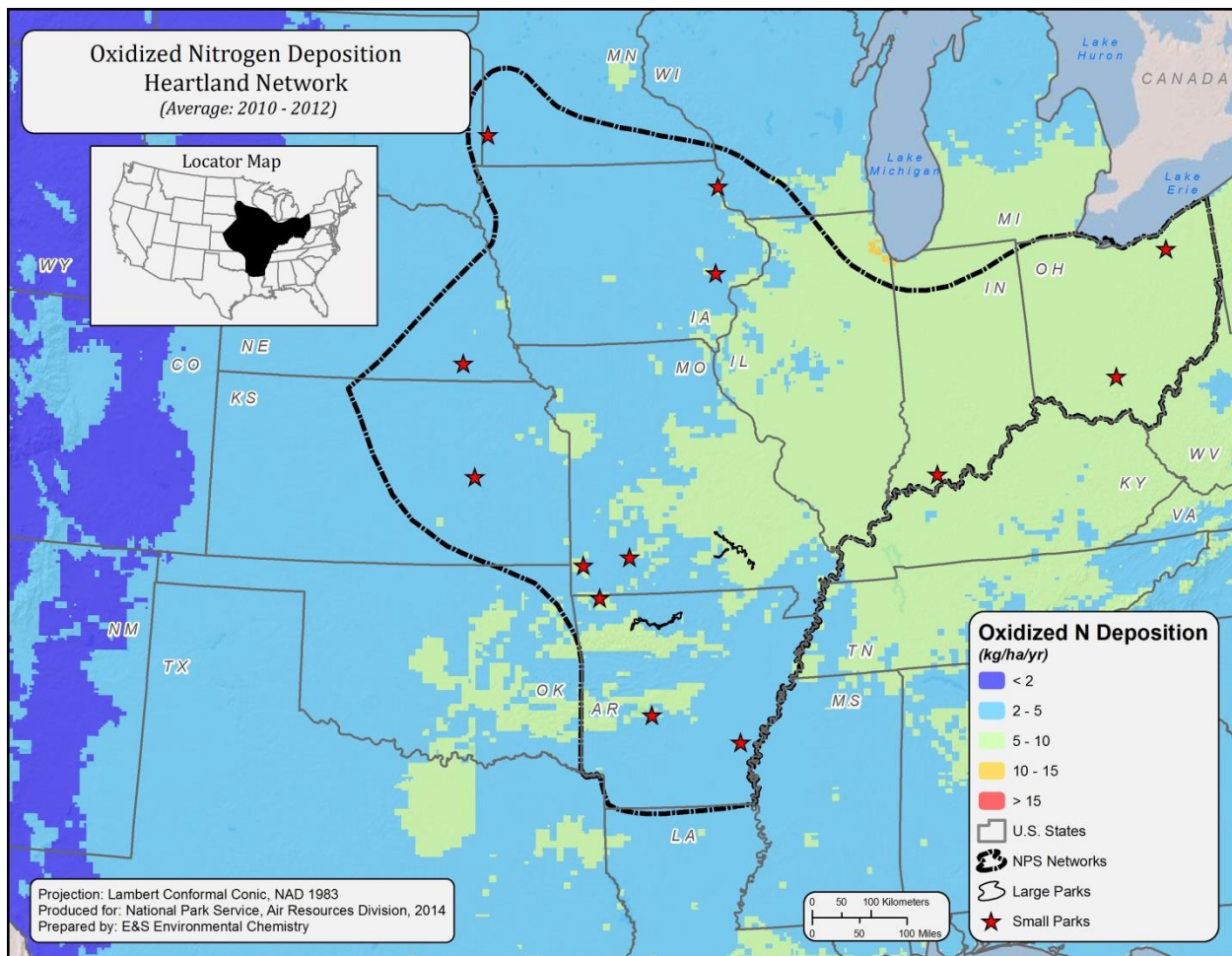
Atmospheric S deposition levels have declined at most HTLN parks since 2001, based on TDEP estimates (Table 1). Decreases in total S deposition over the previous decade for the parks in this network were as large as -43.5% at HOCU and -40.2% at ARPO. Estimated total N deposition over that same time period decreased at some parks and increased at others. In most parks, reduced N deposition increased by more than 20%, whereas oxidized N deposition consistently decreased, in some cases by more than 30%.

Total S deposition in and around the HTLN for the period 2010-2012 was generally highest ( $> 10$  kg S/ha/yr) to the east and lowest ( $< 5$  kg S/ha/yr) to the west within the network area (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was in the range of 2-10 kg N/ha/yr throughout the park lands within the HTLN (Map 6). Highest estimates were in the eastern portion of the network. Most park areas received high levels of reduced inorganic N from atmospheric deposition during this same period, with estimates ranging from 2-5 kg N/ha/yr to more than 15 kg N/ha/yr (Map 7). Total N deposition was higher than 10 kg N/ha/yr at many park locations (Map 8).

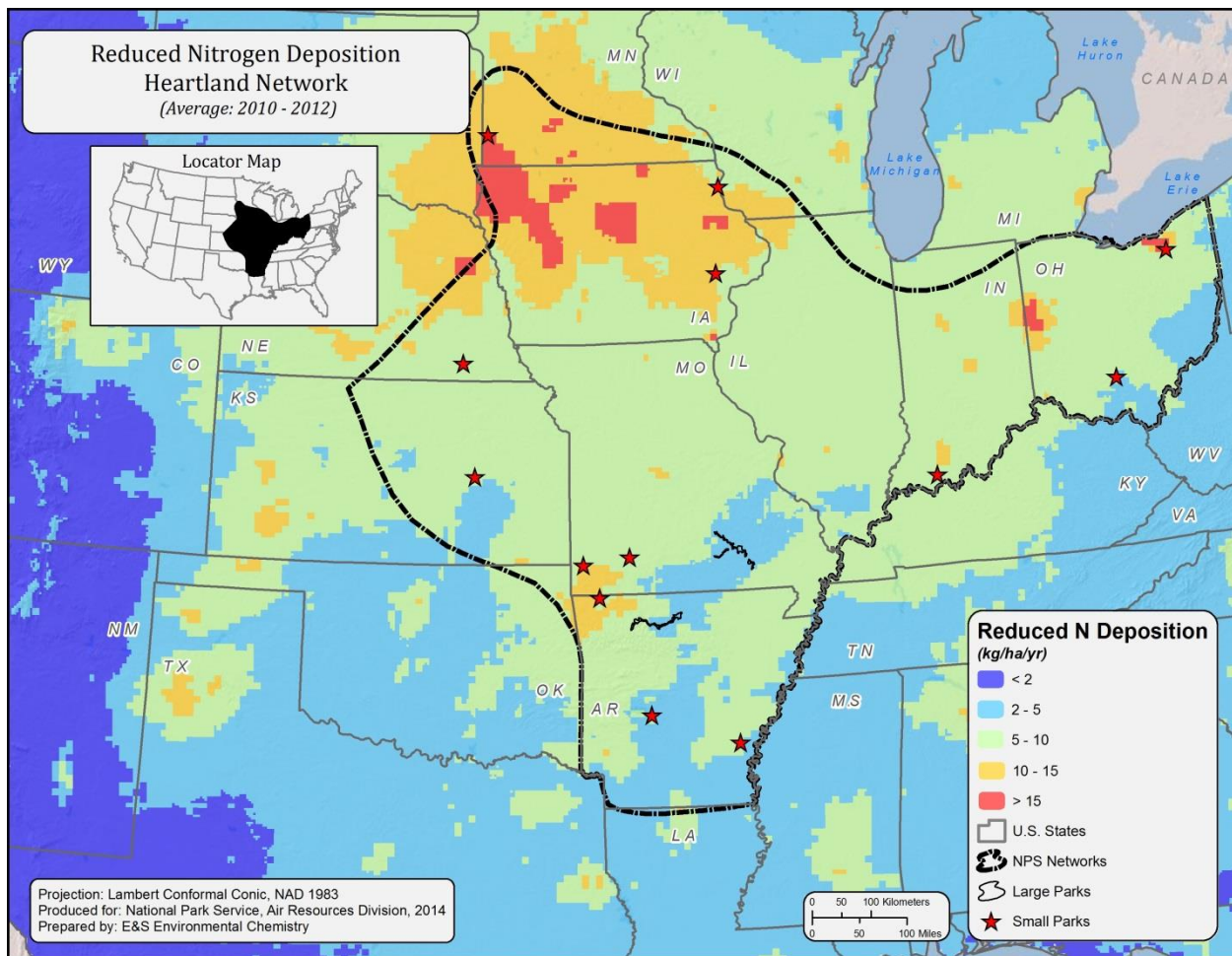
Risch et al. (2012) reported wet Hg deposition throughout the Great Lakes region during the period 2002-2008, based on data from three Hg and precipitation monitoring networks. Areas in southern Indiana and Illinois, eastern Pennsylvania, and central Michigan had highest estimated wet Hg deposition, ranging from about 10 to 14  $\mu\text{g}/\text{m}^2$ . Such high wet deposition levels were caused by high Hg concentration in precipitation ( $> 12$  ng/L) and/or high precipitation amount (120-140 cm/yr). No change in deposition was observed over the course of the monitoring period; any small decrease that may have occurred in atmospheric Hg concentration was apparently offset by increased precipitation (Risch et al. 2012).



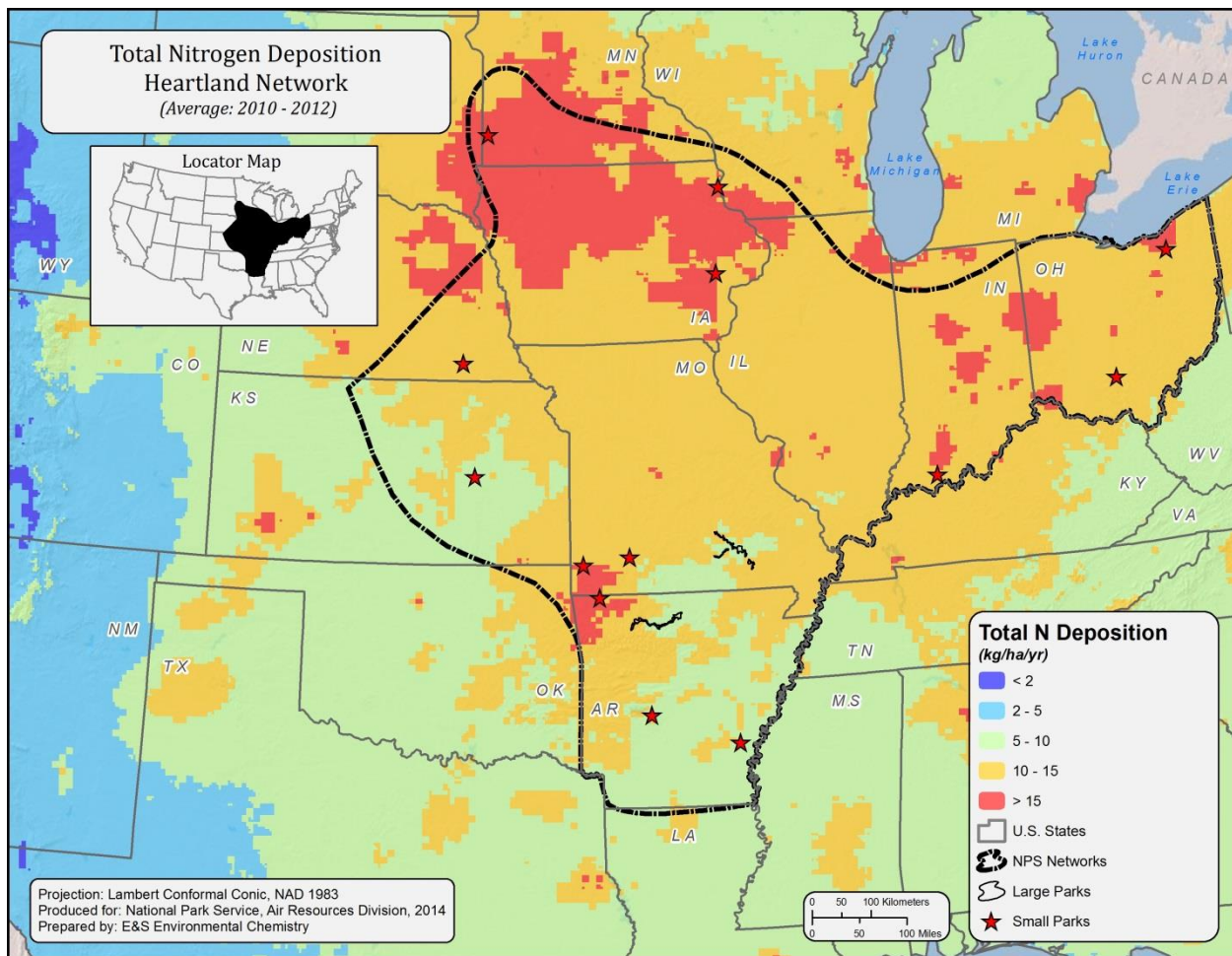
**Map 5.** Total S deposition for the three-year period centered on 2011 in and around the HTLN. (Source: Schwede and Lear 2014)



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



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



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

## Acidification

The network rankings developed by Sullivan et al. (2011b) in a coarse screening assessment for S and N acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking for the HTLN that was Moderate among networks. The largest I&M parks in this network (BUFF and OZAR) were ranked by Sullivan et al. (2011b) as Moderate and High, respectively, in acid Pollutant Exposure (Table 2). Smaller parks in the network were ranked Moderate (four parks), High (six parks), and Very High (three parks) for this theme. BUFF was ranked Very High in Ecosystem Sensitivity to acidification, and OZAR was ranked Moderate. The smaller parks in the network varied, and were ranked from Very Low to High in Ecosystem Sensitivity to acidification (Sullivan et al. 2011b; Table 2). Ecosystem sensitivity to acidification rankings take into account elevation and land slope, which often influence the degree of acid neutralization provided by soils and bedrock within a watershed.

Park lands within the HTLN generally have low relief, with slopes less than 20° across most of the parks. Two parks, HOSP and BUFF have average slope in the range of 20° to 30°, however, contributing to higher ecosystem sensitivity to acidification. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

**Table 2.** Estimated I&M park rankings<sup>1</sup> according to risk of acidification impacts on sensitive receptors. (Source: Sullivan et al. 2011b)

| Park Name <sup>2</sup>   | Park Code | Estimated Acid Pollutant Exposure | Estimated Ecosystem Sensitivity to Acidification |
|--------------------------|-----------|-----------------------------------|--------------------------------------------------|
| Arkansas Post            | ARPO      | Moderate                          | Very Low                                         |
| <b>Buffalo</b>           | BUFF      | Moderate                          | Very High                                        |
| Cuyahoga Valley          | CUVA      | Very High                         | High                                             |
| Effigy Mounds            | EFMO      | High                              | High                                             |
| George Washington Carver | GWCA      | High                              | Very Low                                         |
| Herbert Hoover           | HEHO      | High                              | Very Low                                         |
| Homestead                | HOME      | High                              | Low                                              |
| Hopewell Culture         | HOCU      | Very High                         | Low                                              |
| Hot Springs              | HOSP      | Moderate                          | Moderate                                         |
| Lincoln Boyhood          | LIBO      | Very High                         | Low                                              |
| <b>Ozark</b>             | OZAR      | High                              | Moderate                                         |
| Pea Ridge                | PERI      | High                              | Moderate                                         |
| Pipestone                | PIPE      | Moderate                          | Low                                              |
| Tallgrass Prairie        | TAPR      | High                              | High                                             |
| Wilson's Creek           | WICR      | Moderate                          | Low                                              |

<sup>1</sup> 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).

<sup>2</sup> Park names are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

Portions of the HTLN region were included in EPA's National Stream Survey (NSS; Kaufmann et al. 1988). Results indicated that there were no acidic (acid neutralizing capacity [ANC]  $\leq 0$   $\mu\text{eq/L}$ ) streams in Arkansas or Oklahoma and few upper node stream sites were estimated to have had ANC below 50  $\mu\text{eq/L}$ . However, nearly two-thirds of the streams in this subregion were estimated to have had ANC  $\leq 200$   $\mu\text{eq/L}$ . Thus, acid sensitivity of streams in the Ozark/Ouschitas region that were included in the NSS was estimated to be moderate. There are no data suggesting pronounced acid sensitivity of surface waters or soils in any of the HTLN parks, however.

## Nutrient Nitrogen Enrichment

The Great Plains were formerly characterized by grasslands maintained by interactions among climate, fire, and grazing by large herbivores. Rainfall is lowest in the short-grass prairie to the west, intermediate in the mixed-grass prairie, and highest in the tallgrass prairie to the east. These prairie environments now roughly correspond with the western rangelands, wheat belt, and corn/soybean region of the Midwest, respectively.

Nearly 96% of the historical tallgrass prairie has been lost to human development (Clark 2011, Samson and Knopf 1994). Many plant species that occur in tallgrass prairie are listed as federally protected. These grasslands are mainly N-limited or co-limited by N, P and/or water. Many species respond rapidly to changing environmental conditions (Clark 2011, Hooper and Johnson 1999, Knapp and Smith 2001, Vitousek and Howarth 1991) and would be expected to respond to changes in N input. It is difficult to ascertain the likely effects of N addition to these ecosystems, however, without also considering the effects of periodic disturbance (especially fire and drought) and herbivory (Knapp et al. 1998, Seastedt and Knapp 1993). Most studies of the effects of N enrichment on grasslands of the Great Plains have involved experimental addition of very high amounts of N (> 30 kg N/ha/yr; Clark 2011). Most of the relatively few experiments that included lower levels of N addition have been conducted in Minnesota (Cedar Creek Ecosystem Science Reserve) or Oklahoma (Center for Subsurface and Ecological Assessment Research). Tilman (1987) added N to four sites in Minnesota at levels ranging from 10 to 270 kg N/ha/yr. At the lower rates of experimental N addition (10 to 20 kg N/ha/yr) to two old fields, much of the added N was retained in the soil after 22 years of treatment (Wedin and Tilman 1996). Nevertheless, the N retention efficiency decreased, soil extractable  $\text{NO}_3^-$  increased, and plant species composition shifted over time in response to N addition (Clark and Tilman 2008, Clark et al. 2009).

Experimental N addition for five years at a rate of 16.3 kg N/ha/yr to a mixed-grass prairie in Oklahoma caused an increase in soil  $\text{NO}_3^-$ ; leaching of N increased about 12-fold (Clark 2011, Jorgensen et al. 2005). Total plant biomass increased, and the cover of tall fescue (*Schedonorus phoenix*) increased 2-fold (Clark et al. 2003, Jorgensen et al. 2005).

The population of voles decreased after nine years of high N addition (336 kg N/ha/yr) to an oldfield in Ohio (Hall et al. 1991). The researchers interpreted the small mammal response to a change from mainly edible plants such as Canada goldenrod (*Solidago canadensis*) and clover (*Trifolium* spp.) to mainly non-edible species such as annual ragweed (*Ambrosia artemisiifolia*) and great ragweed (*A. trifida*).

Lichens have been heavily impacted by air pollution throughout the eastern hardwood forests. High levels of both S and N have also played important roles in lichen distribution in Ohio (Showman 1975, Wetmore 1989) and Indiana (McCune 1988, Wetmore 1988). Epiphytic lichen diversity and cover has increased in response to decreases in S and N emissions during recent decades in the Upper Ohio Valley (Showman 1981, 1990, Showman and Long 1992, Showman 1998). Returning lichen species in Ohio and Pennsylvania have mainly been S-sensitive, but they have also been somewhat

N-tolerant (Geiser et al. 2010), likely because N deposition was still relatively high at the study locations (about 6.2 to 7.0 kg N/ha/yr; Gilliam et al. 2011).

The network rankings developed in a coarse screening assessment by Sullivan et al. (2011a) for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection yielded an overall network nutrient N enrichment Summary Risk ranking for the HTLN that was in the second lowest quintile among networks. Both of the I&M parks in the HTLN that are larger than 100 square miles (BUFF and OZAR) were ranked by Sullivan et al. (2011a) in the middle quintile in nutrient N Pollutant Exposure (Table 3). For the smaller parks in the network, three were ranked Moderate, five were ranked High, and five were ranked Very High for this theme. The two larger parks were in the middle (BUFF) or second lowest (OZAR) quintile in Ecosystem Sensitivity to nutrient enrichment (Sullivan et al. 2011a; Table 3). Most of the smaller parks in the network were ranked Low or Very Low in Ecosystem Sensitivity to nutrient enrichment. Exceptions included HOME and PIPE, both of which were ranked High, and TAPR which was ranked Very High (Table 3). The cause of the High ranking of these three parks for this theme was the prevalence of grassland vegetation, which is especially sensitive to nutrient enrichment impacts from atmospheric N deposition. 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. (2011b) compiled data on empirical critical load (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 at parks in the HTLN for resource protection suggest that the lower end of the CL range for a variety of resources (especially for protection of mycorrhizal fungi, lichens, and forests and for prevention of  $\text{NO}_3^-$  leaching in drainage water) is about 4-8 kg N/ha/yr (Table 4). Ambient N deposition values reported by Pardo et al. (2011b) for parks in the HTLN were consistently above 9 kg N/ha/yr. Thus, there appears to be widespread exceedance of the nutrient-N empirical CL at parklands throughout the HTLN. Although not in the Great Plains ecoregion, EFMO, GWCA, and WICR all actively manage prairie restorations as part of their cultural landscape (M. DeBacker, NPS, personal communication, August 2014).

Ellis et al. (2013) estimated the CL for nutrient-N deposition to protect the most sensitive ecosystem receptors in 45 national parks. The lowest terrestrial CL of N is generally estimated for protection of lichens (Geiser et al. 2010). Changes to lichen communities may signal the beginning of other changes to the ecosystem that might affect structure and function (Pardo et al. 2011a). Ellis et al. (2013) estimated the N CL for CUVA and HOSP in the range of 3-8 kg N/ha/yr for protection of hardwood forests.

**Table 3.** Estimated park rankings<sup>1</sup> according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a).

| Park Name <sup>2</sup>   | Park Code | Estimated Nutrient N<br>Pollutant Exposure | Estimated Ecosystem<br>Sensitivity to Nutrient N<br>Enrichment |
|--------------------------|-----------|--------------------------------------------|----------------------------------------------------------------|
| Arkansas Post            | ARPO      | Moderate                                   | Very Low                                                       |
| <b>Buffalo</b>           | BUFF      | Moderate                                   | Moderate                                                       |
| Cuyahoga Valley          | CUVA      | Very High                                  | Very Low                                                       |
| Effigy Mounds            | EFMO      | High                                       | Low                                                            |
| George Washington Carver | GWCA      | High                                       | Very Low                                                       |
| Herbert Hoover           | HEHO      | High                                       | Low                                                            |
| Homestead                | HOME      | High                                       | High                                                           |
| Hopewell Culture         | HOCU      | Very High                                  | Very Low                                                       |
| Hot Springs              | HOSP      | Moderate                                   | Very Low                                                       |
| Lincoln Boyhood          | LIBO      | Very High                                  | Very Low                                                       |
| <b>Ozark</b>             | OZAR      | Moderate                                   | Low                                                            |
| Pea Ridge                | PERI      | Very High                                  | Very Low                                                       |
| Pipestone                | PIPE      | Very High                                  | High                                                           |
| Tallgrass Prairie        | TAPR      | High                                       | Very High                                                      |
| Wilson's Creek           | WICR      | Moderate                                   | Low                                                            |

<sup>1</sup> 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).

<sup>2</sup> Park names are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

**Table 4.** Empirical critical loads for nitrogen in the HTLN, by ecoregion and receptor from Pardo et al. (2011b). Ambient N deposition reported by Pardo et al. (2011b) 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                 | N<br>Deposition<br>(kg N/ha/yr) | Critical Load (kg N/ha/yr) |        |                     |        |                     |
|-----------------------------|---------------------------|---------------------------------|----------------------------|--------|---------------------|--------|---------------------|
|                             |                           |                                 | Mycorrhizal<br>Fungi       | Lichen | Herbaceous<br>Plant | Forest | Nitrate<br>Leaching |
| Arkansas Post NMem          | Eastern Temperate Forests | 11.0                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Buffalo NR                  | Eastern Temperate Forests | 10.9                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Cuyahoga Valley NP          | Eastern Temperate Forests | 22.5                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Effigy Mounds NM            | Eastern Temperate Forests | 12.6                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| George Washington Carver NM | Eastern Temperate Forests | 12.0                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Herbert Hoover NHS          | Great Plains              | 12.6                            | 12                         | NA     | 5 - 25              | NA     | 10 - 25             |
| Hopewell Culture NHP        | Eastern Temperate Forests | 13.1                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Homestead NM of America     | Great Plains              | 10.6                            | 12                         | NA     | 5 - 25              | NA     | 10 - 25             |
| Hot Springs NP              | Eastern Temperate Forests | 9.4                             | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Lincoln Boyhood NMem        | Eastern Temperate Forests | 14.3                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Ozark NSR                   | Eastern Temperate Forests | 12.3                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Pea Ridge NMP               | Eastern Temperate Forests | 12.0                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |
| Pipestone NM                | Great Plains              | 12.2                            | 12                         | NA     | 5 - 25              | NA     | 10 - 25             |
| Tallgrass Prairie NPRES     | Great Plains              | 11.0                            | 12                         | NA     | 5 - 25              | NA     | 10 - 25             |
| Wilsons Creek NB            | Eastern Temperate Forests | 10.8                            | 5 - 12                     | 4 - 8  | 17.5                | 3 - 8  | 8                   |

## Ozone Injury to Vegetation

The ozone (O<sub>3</sub>)-sensitive plant species that are known or thought to occur within the I&M parks found in the HTLN are listed in Table 5. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O<sub>3</sub> (e.g., dark stipple), are designated by an asterisk. Each park within the network contains at least eight O<sub>3</sub>-sensitive and bioindicator species.

The W126 and SUM06 exposure indices calculated by NPS staff are given in Table 6, along with Kohut's (2007a) O<sub>3</sub> risk ranking. The NPS and Kohut ranking systems differ in significant ways. The NPS ranking system (NPS 2010) is a quick assessment of O<sub>3</sub> condition that ranks O<sub>3</sub> 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. The former is a measure of cumulative O<sub>3</sub> exposure that preferentially weights higher concentrations; the latter is a measure of cumulative O<sub>3</sub> exposure that includes only hourly concentrations over 60 ppb. Both metrics are calculated over a 3-month period. The W126 was classified 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). Using these criteria, O<sub>3</sub> at the HTLN parks is rated High at several parks, especially HOCU, LIBO, and OZAR.

Kohut's approach constitutes a more rigorous assessment of potential risk to plants. It considers both O<sub>3</sub> exposure and environmental conditions (soil moisture). Kohut also used injury thresholds from the literature, but evaluated a different O<sub>3</sub> 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<sub>3</sub>). The rationale for the N100 statistic is that higher O<sub>3</sub> concentrations are most likely to cause plant injury). Kohut examined five individual years of O<sub>3</sub> exposure and soil moisture data and considered the effects of low soil moisture on O<sub>3</sub> 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<sub>3</sub> uptake and injury. In areas where low soil moisture levels correspond with high O<sub>3</sub> exposure, uptake and injury are limited by stomatal closure even when exposures are relatively high.

The results of both ranking systems should be considered when evaluating the potential for O<sub>3</sub> injury to park vegetation. The Kohut approach considered environmental conditions that significantly affect plant response to O<sub>3</sub>, but exposures have likely changed since the time of the assessment (1995-1999). The NPS approach considers more recent O<sub>3</sub> conditions (2005-2009), but not environmental conditions.

**Table 5.** Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the HTLN. (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          | Park <sup>1</sup> |      |      |     |      |      |      |      |      |      |      |      |      |      |      |
|----------------------------------------------------|----------------------|-------------------|------|------|-----|------|------|------|------|------|------|------|------|------|------|------|
|                                                    |                      | ARPO              | BUFF | CUVA | FMO | GWCA | HEHO | HOCU | HOME | HOSP | LIBO | OZAR | PERI | PIPE | TAPR | WICR |
| <i>Ailanthus altissima</i> *                       | Tree-of-heaven       |                   | x    | x    |     |      |      | x    |      | x    |      |      | x    |      |      |      |
| <i>Alnus rugosa</i> *                              | Speckled alder       |                   |      | x    |     |      |      |      |      |      |      |      |      |      |      |      |
| <i>Apios americana</i> *                           | Groundnut            |                   | x    | x    | x   |      |      |      |      | x    |      | x    |      |      |      |      |
| <i>Apocynum androsaemifolium</i> *                 | Spreading dogbane    |                   |      | x    | x   |      |      |      |      |      |      |      |      |      |      |      |
| <i>Apocynum cannabinum</i>                         | Dogbane, Indian hemp |                   | x    | x    | x   | x    |      | x    | x    |      | x    | x    | x    | x    | x    | x    |
| <i>Artemisia ludoviciana</i> *                     | Silver wormwood      |                   |      |      |     | x    |      |      | x    |      | x    |      |      | x    | x    |      |
| <i>Asclepias exaltata</i> *                        | Tall milkweed        |                   |      | x    | x   |      |      |      |      |      |      |      |      |      |      |      |
| <i>Asclepias incarnata</i>                         | Swamp milkweed       |                   |      | x    | x   | x    |      | x    |      |      |      | x    |      | x    |      | x    |
| <i>Asclepias syriaca</i> *                         | Common milkweed      |                   |      | x    | x   | x    | x    | x    | x    |      | x    |      |      | x    | x    | x    |
| <i>Aster macrophyllus</i> *                        | Big-leaf aster       |                   |      | x    |     |      |      |      |      |      |      |      |      |      |      |      |
| <i>Cercis canadensis</i> var. <i>canadensis</i> *  | Redbud               | x                 | x    |      |     |      |      |      |      | x    |      |      |      |      |      |      |
| <i>Cercis canadensis</i> *                         | Redbud               |                   |      | x    |     | x    | x    | x    |      |      | x    | x    |      |      | x    | x    |
| <i>Clematis virginiana</i>                         | Virgin's bower       |                   | x    | x    | x   |      |      | x    |      |      | x    | x    |      |      |      |      |
| <i>Corylus americana</i> *                         | American hazelnut    |                   | x    | x    | x   | x    |      |      |      | x    | x    | x    | x    |      |      | x    |
| <i>Eupatorium rugosum</i> *                        | White snakeroot      |                   |      | x    |     | x    |      | x    |      |      | x    | x    |      |      | x    |      |
| <i>Fraxinus americana</i> *                        | White ash            |                   | x    | x    | x   | x    | x    | x    |      | x    | x    | x    | x    |      |      | x    |
| <i>Fraxinus pennsylvanica</i>                      | Green ash            | x                 | x    | x    | x   | x    | x    | x    | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Gaylussacia baccata</i> *                       | Black huckleberry    |                   |      | x    |     |      |      |      |      | x    |      |      |      |      |      |      |
| <i>Liquidambar styraciflua</i>                     | Sweetgum             | x                 | x    | x    |     | x    |      | x    |      | x    | x    |      | x    |      |      |      |
| <i>Liriodendron tulipifera</i> *                   | Yellow-poplar        |                   |      | x    |     |      |      | x    |      | x    | x    |      |      |      |      |      |
| <i>Lyonia ligustrina</i> *                         | Maleberry            |                   |      |      |     |      |      |      |      | x    |      |      |      |      |      |      |
| <i>Parthenocissus quinquefolia</i>                 | Virginia creeper     | x                 | x    | x    | x   | x    | x    | x    | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Philadelphus coronarius</i>                     | Sweet mock orange    |                   |      | x    |     | x    |      |      |      |      | x    |      |      | x    |      |      |
| <i>Pinus rigida</i>                                | Pitch pine           |                   |      |      |     |      |      |      |      |      | x    |      |      |      |      |      |
| <i>Pinus taeda</i>                                 | Loblolly pine        | x                 |      |      |     |      |      |      |      |      |      |      |      |      |      |      |
| <i>Pinus virginiana</i>                            | Virginia pine        |                   |      | x    |     |      |      |      |      |      |      |      |      |      |      |      |
| <i>Platanus occidentalis</i> *                     | American sycamore    | x                 | x    | x    |     | x    |      | x    |      | x    | x    | x    | x    |      | x    | x    |
| <i>Populus tremuloides</i> *                       | Quaking aspen        |                   |      | x    | x   |      |      |      |      |      |      |      |      |      |      |      |
| <i>Prunus serotina</i> *                           | Black cherry         | x                 | x    | x    | x   | x    | x    | x    |      | x    | x    | x    | x    |      |      | x    |
| <i>Prunus virginiana</i>                           | Choke cherry         |                   |      | x    | x   |      | x    |      | x    |      | x    |      |      | x    | x    |      |
| <i>Rhus copallina</i>                              | Winged sumac         | x                 | x    |      |     | x    |      |      |      | x    |      |      | x    |      |      |      |
| <i>Rhus trilobata</i> *                            | Skunkbush            |                   |      |      |     |      |      |      | x    |      |      |      |      |      |      |      |
| <i>Robinia pseudoacacia</i>                        | Black locust         | x                 | x    | x    |     | x    | x    | x    |      | x    | x    | x    | x    |      | x    | x    |
| <i>Rubus allegheniensis</i> *                      | Allegheny blackberry |                   | x    | x    | x   |      |      | x    |      |      |      |      | x    |      |      |      |
| <i>Rudbeckia laciniata</i> var. <i>laciniata</i> * | Cutleaf coneflower   |                   | x    |      |     |      |      |      |      | x    |      |      |      |      |      |      |
| <i>Rudbeckia laciniata</i> *                       | Cutleaf coneflower   |                   |      | x    | x   |      | x    |      |      |      |      | x    |      |      |      |      |

<sup>1</sup> Park acronyms are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

\* Bioindicator species

**Table 5** (continued). Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the HTLN. (Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at <https://irma.nps.gov/NPSpecies/Report>.

|                                                |                    |   |   |   |  |   |   |   |   |   |   |   |   |   |   |   |
|------------------------------------------------|--------------------|---|---|---|--|---|---|---|---|---|---|---|---|---|---|---|
| <i>Sambucus canadensis</i> *                   | American elder     |   |   | x |  | x | x | x | x |   | x | x |   | x | x |   |
| <i>Sambucus nigra</i> spp. <i>canadensis</i> * | American elder     |   | x |   |  |   |   |   |   | x |   |   | x |   |   |   |
| <i>Sambucus racemosa</i> *                     | Red elderberry     |   |   | x |  |   |   |   |   |   |   |   |   |   |   |   |
| <i>Sassafras albidum</i>                       | Sassafras          | x | x | x |  | x |   | x |   | x | x | x | x |   |   | x |
| <i>Solidago altissima</i>                      | Goldenrod          |   |   | x |  | x |   |   |   |   |   | x |   |   |   |   |
| <i>Solidago canadensis</i> var. <i>scabra</i>  | Goldenrod          |   |   |   |  |   |   |   |   |   | x |   |   |   |   |   |
| <i>Vitis labrusca</i> *                        | Northern fox grape |   |   | x |  |   |   |   |   |   |   |   |   |   |   | x |

<sup>1</sup> Park acronyms are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

\* Bioindicator species

**Table 6.** Ozone assessment results for I&M parks in the HTLN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007a) ozone risk ranking for the period 1995-1999<sup>1</sup>.

| Park Name <sup>2</sup>   | Park Code | W126           |          | SUM06          |          | Kohut O <sub>3</sub> Risk Ranking |
|--------------------------|-----------|----------------|----------|----------------|----------|-----------------------------------|
|                          |           | Value (ppm-hr) | Ranking  | Value (ppm-hr) | Ranking  |                                   |
| Arkansas Post            | ARPO      | 11.56          | Moderate | 15.82          | High     | Moderate                          |
| <b>Buffalo</b>           | BUFF      | 8.56           | Moderate | 10.49          | Moderate | Low                               |
| Cuyahoga Valley          | CUVA      | 12.03          | Moderate | 16.17          | High     | High                              |
| Effigy Mounds            | EFMO      | 7.25           | Moderate | 8.12           | Moderate | Low                               |
| George Washington Carver | GWCA      | 10.06          | Moderate | 13.10          | Moderate | Moderate                          |
| Herbert Hoover           | HEHO      | 6.52           | Low      | 7.25           | Low      | Low                               |
| Homestead                | HOME      | 6.21           | Low      | 7.21           | Low      | Low                               |
| Hopewell Culture         | HOCU      | 13.67          | High     | 18.62          | High     | High                              |
| Hot Springs              | HOSP      | 8.69           | Moderate | 11.28          | Moderate | Low                               |
| Lincoln Boyhood          | LIBO      | 13.20          | High     | 17.96          | High     | High                              |
| <b>Ozark</b>             | OZAR      | 14.26          | High     | 19.03          | High     | High                              |
| Pea Ridge                | PERI      | 8.44           | Moderate | 10.14          | Moderate | Low                               |
| Pipestone                | PIPE      | 5.63           | Low      | 6.31           | Low      | Low                               |
| Tallgrass Prairie        | TAPR      | 9.46           | Moderate | 11.95          | Moderate | Moderate                          |
| Wilson's Creek           | WICR      | 10.22          | Moderate | 13.42          | Moderate | Low                               |

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

<sup>2</sup> Park names are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

Four of the parks were classified by Kohut (2007b) as having High risk of foliar injury due to O<sub>3</sub> exposure (CUVA, HOCU, LIBO, OZAR). However, at CUVA, HOCU, and OZAR, the observed inverse relationship between O<sub>3</sub> exposure and soil moisture during 1995-1999 reduced the likelihood of injury despite the high O<sub>3</sub> exposures observed. Soil conditions at LIBO generally favored O<sub>3</sub> uptake, although drought might reduce uptake in a given month or year. Only at HOME and PIPE were both the NPS and Kohut index values consistently below levels considered necessary for injury to vegetation.

Atmospheric O<sub>3</sub> concentrations at 568 monitoring sites nationwide were generally stable throughout the 1990s, but declined between 2002 and 2007, due largely to NO<sub>x</sub> emissions reductions (U.S. EPA 2008). One of the sites that showed the greatest improvement since the 1990s was Cleveland, Ohio, near CUVA.

# Visibility Degradation

## Natural Background and Ambient Visibility Conditions

The Clean Air Act (CAA) 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<sup>1</sup> 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. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments Network (IMPROVE) and typically reported using the haze index deciview<sup>2</sup> (dv).

The NPS manages 48 Class I air quality areas, a designation under the CAA. No HTLN parks are designated Class I; they are Class II parks under the CAA, still receiving many protections under the Act, but not to the extent of Class I areas. Although none of the HTLN parks are Class I, there is an IMPROVE sampling site (TALL1) located in TAPR, in order to characterize particulate haze in the region. Data are also available that are considered to be representative of visibility conditions in several other parks (BUFF, EFMO, GWCA, PIPE, and WICR), based on measured values taken from alternative IMPROVE sites located within 60 mi (100 km) and 425 ft (130 m) elevation of the parks (see Table 7).

Natural background and ambient visibility conditions have been estimated by IMPROVE for these parks for the 20% clearest visibility days, the 20% haziest visibility days, and average days. Natural background visibility, the goal of the Clean Air Act, assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic (vegetative) emissions.

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 7 gives the relative park haze rankings on the 20% clearest, 20% haziest, and average days. Measured ambient haze for the period 2004 through 2008 was substantially higher than the estimated natural condition. Ambient haze was considered High to Very High for all parks having data in this network (Table 7).

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

<sup>2</sup> 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.

IMPROVE data allow estimation of visual range (VR). Data indicate that at the UPBU1 site (representative of BUFF), air pollution has reduced average VR from 110 to 30 miles (177 to 48 km). On the haziest days, VR has been reduced from 75 to 15 miles (121 to 24 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km). At the GRRI1 site (representative of EFMO), air pollution has reduced average VR from 110 to 35 miles (177 to 56 km). On the haziest days, VR has been reduced from 75 to 15 miles (121 to 24 km). Severe haze episodes occasionally reduce visibility to 4 miles (6 km). At the ELDO1 site (representative of GWCA), air pollution has reduced average VR from 110 to 30 miles (177 to 48 km). On the haziest days, VR has been reduced from 75 to 15 miles (121 to 24 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km). At the BLMO1 site (representative of PIPE), air pollution has reduced average VR from 110 to 35 miles (177 to 56 km). On the haziest days, VR has been reduced from 75 to 15 miles (121 to 24 km). Severe haze episodes occasionally reduce visibility to 7 miles (11 km). At the TALL1 site (in TAPR), air pollution has reduced average VR from 110 to 30 miles (177 to 48 km). On the haziest days, VR has been reduced from 65 to 15 miles (104 to 24 km). Severe haze episodes occasionally reduce visibility to 4 miles (6 km). At the HEGL1 site (representative of WICR), air pollution has reduced average VR from 110 to 30 miles (177 to 48 km). On the haziest days, VR has been reduced from 75 to 15 miles (121 to 24 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km).

### **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<sub>2</sub> emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO<sub>x</sub> 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. 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 six parks in this network with on-site or representative IMPROVE data. The RHR requires at least three years of valid data out of a five-year period to calculate the five-year average for the baseline period (2000-2004). Sites having fewer than three years of valid data required use of the RHR\_VS substitution algorithm to calculate the baseline. This process entailed using substituted valid data for incomplete years. However, there were no substitute data available for the parks in this network, and therefore the charts shown in Figure 1 are based on fewer years of data. For more information on this process, see

[http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm).

**Table 7.** Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008<sup>1</sup>. UPBU1 is at Upper Buffalo Wilderness (AR); GRR11 is at Great River Bluffs (MN); ELDO1 is at Eldorado Springs (MO); BLMO1 is at Blue Mounds (MN); TALL1 is at TAPR; HEGL1 is at Hercules-Glades (MO). More site information is available at <http://views.cira.colostate.edu/web/SiteBrowser/>.

| Park Name <sup>2</sup>                | Park Code | Site ID | Estimated Natural Haze |                  |              |
|---------------------------------------|-----------|---------|------------------------|------------------|--------------|
|                                       |           |         | 20% Clearest Days      | 20% Haziest Days | Average Days |
|                                       |           |         | dv                     | dv               | dv           |
| Arkansas Post                         | ARPO      | No Site |                        |                  |              |
| <b>Buffalo</b> <sup>3</sup>           | BUFF      | UPBU1   | 4.18                   | 11.57            | 7.53         |
| Cuyahoga Valley                       | CUVA      | No Site |                        |                  |              |
| Effigy Mounds <sup>3</sup>            | EFMO      | GRR11   | 4.51                   | 11.78            | 7.56         |
| George Washington Carver <sup>3</sup> | GWCA      | ELDO1   | 4.41                   | 11.36            | 7.55         |
| Herbert Hoover                        | HEHO      | No Site |                        |                  |              |
| Homestead                             | HOME      | No Site |                        |                  |              |
| Hopewell Culture                      | HOCU      | No Site |                        |                  |              |
| Hot Springs                           | HOSP      | No Site |                        |                  |              |
| Lincoln Boyhood                       | LIBO      | No Site |                        |                  |              |
| <b>Ozark</b>                          | OZAR      | No Site |                        |                  |              |
| Pea Ridge                             | PERI      | No Site |                        |                  |              |
| Pipestone <sup>3</sup>                | PIPE      | BLMO1   | 4.36                   | 11.53            | 7.56         |
| Tallgrass Prairie                     | TAPR      | TALL1   | 4.02                   | 11.75            | 7.30         |
| Wilson's Creek <sup>3</sup>           | WICR      | HEGL1   | 4.69                   | 11.30            | 7.57         |

| Park Name                             | Park Code | Site ID | Measured Ambient Haze (For Years 2004 through 2008) |           |                  |           |              |           |
|---------------------------------------|-----------|---------|-----------------------------------------------------|-----------|------------------|-----------|--------------|-----------|
|                                       |           |         | 20% Clearest Days                                   |           | 20% Haziest Days |           | Average Days |           |
|                                       |           |         | dv                                                  | Ranking   | dv               | Ranking   | dv           | Ranking   |
| Arkansas Post                         | ARPO      | No Site |                                                     |           |                  |           |              |           |
| <b>Buffalo</b> <sup>3</sup>           | BUFF      | UPBU1   | 12.00                                               | High      | 26.45            | Very High | 19.03        | Very High |
| Cuyahoga Valley                       | CUVA      | No Site |                                                     |           |                  |           |              |           |
| Effigy Mounds <sup>3</sup>            | EFMO      | GRR11   | 10.38                                               | High      | 26.78            | Very High | 18.00        | High      |
| George Washington Carver <sup>3</sup> | GWCA      | ELDO1   | 13.24                                               | Very High | 26.38            | Very High | 19.79        | Very High |
| Herbert Hoover                        | HEHO      | No Site |                                                     |           |                  |           |              |           |
| Homestead                             | HOME      | No Site |                                                     |           |                  |           |              |           |
| Hopewell Culture                      | HOCU      | No Site |                                                     |           |                  |           |              |           |
| Hot Springs                           | HOSP      | No Site |                                                     |           |                  |           |              |           |
| Lincoln Boyhood                       | LIBO      | No Site |                                                     |           |                  |           |              |           |

<sup>1</sup> Parks are classified into one of five ranks (Very Low, Low, Moderate, High, Very High).

<sup>2</sup> Park names are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

<sup>3</sup> Data are borrowed from a nearby site for these parks. 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.

**Table 7** (continued). Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008. UPBU1 is at Upper Buffalo Wilderness (AR); GRR11 is at Great River Bluffs (MN); ELDO1 is at Eldorado Springs (MO); BLMO1 is at Blue Mounds (MN); TALL1 is at TAPR; HEGL1 is at Hercules-Glades (MO). More site information is available at <http://views.cira.colostate.edu/web/SiteBrowser/>.

| Park Name                   | Park Code | Site ID | Measured Ambient Haze (For Years 2004 through 2008) |           |                  |           |              |           |
|-----------------------------|-----------|---------|-----------------------------------------------------|-----------|------------------|-----------|--------------|-----------|
|                             |           |         | 20% Clearest Days                                   |           | 20% Haziest Days |           | Average Days |           |
|                             |           |         | dv                                                  | Ranking   | dv               | Ranking   | dv           | Ranking   |
| <b>Ozark</b>                | OZAR      | No Site |                                                     |           |                  |           |              |           |
| Pea Ridge                   | PERI      | No Site |                                                     |           |                  |           |              |           |
| Pipestone <sup>3</sup>      | PIPE      | BLMO1   | 11.11                                               | High      | 25.58            | High      | 17.83        | High      |
| Tallgrass Prairie           | TAPR      | TALL1   | 10.69                                               | High      | 25.13            | High      | 17.88        | High      |
| Wilson's Creek <sup>3</sup> | WICR      | HEGL1   | 12.86                                               | Very High | 26.63            | Very High | 19.49        | Very High |

<sup>1</sup> Parks are classified into one of five ranks (Very Low, Low, Moderate, High, Very High).

<sup>2</sup> Park names are printed in bold italic for parks larger than 100 mi<sup>2</sup>.

<sup>3</sup> Data are borrowed from a nearby site for these parks. 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.

For the 20% clearest days in all parks, the majority of total particulate light extinction ( $b_{\text{ext}}$ ) was contributed by  $\text{SO}_4^{2-}$ , ranging from 36.8% to 46.1% (Figure 1). Contributions on the 20% haziest days and average days were predominantly from  $\text{SO}_4^{2-}$  in four of the parks (BUFF, GWCA, TAPR and WICR) and from  $\text{NO}_3^-$  in the other two parks (EFMO and PIPE).

### Trends in Visibility

During the 1990s,  $\text{SO}_2$  emissions in Ohio and Indiana decreased by 35% and 44%, respectively (Malm et al. 2002). Thus, although emissions of S have been very high in the HTLN, recent reductions have been substantial in Ohio and Indiana. However, there are no clear trends in haze in any of the monitored parks in this network over the period of available data (Figure 2). At some of the parks, however, (e.g., BUFF, WICR), data from representative sites suggest that small decreases in haze may have occurred within the past few years on the 20% haziest days.

### 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).

Progress to date in meeting the national visibility goal is illustrated in Figure 3 using a uniform rate of progress glideslope. Glideslope analyses to date are inconclusive at some of the parks within the HTLN. Compliance with the RHR requirement to make continued progress towards natural visibility in 2064 appears most strongly for the IMPROVE sites that are representative of BUFF, GWCA, TARR, and WICR.

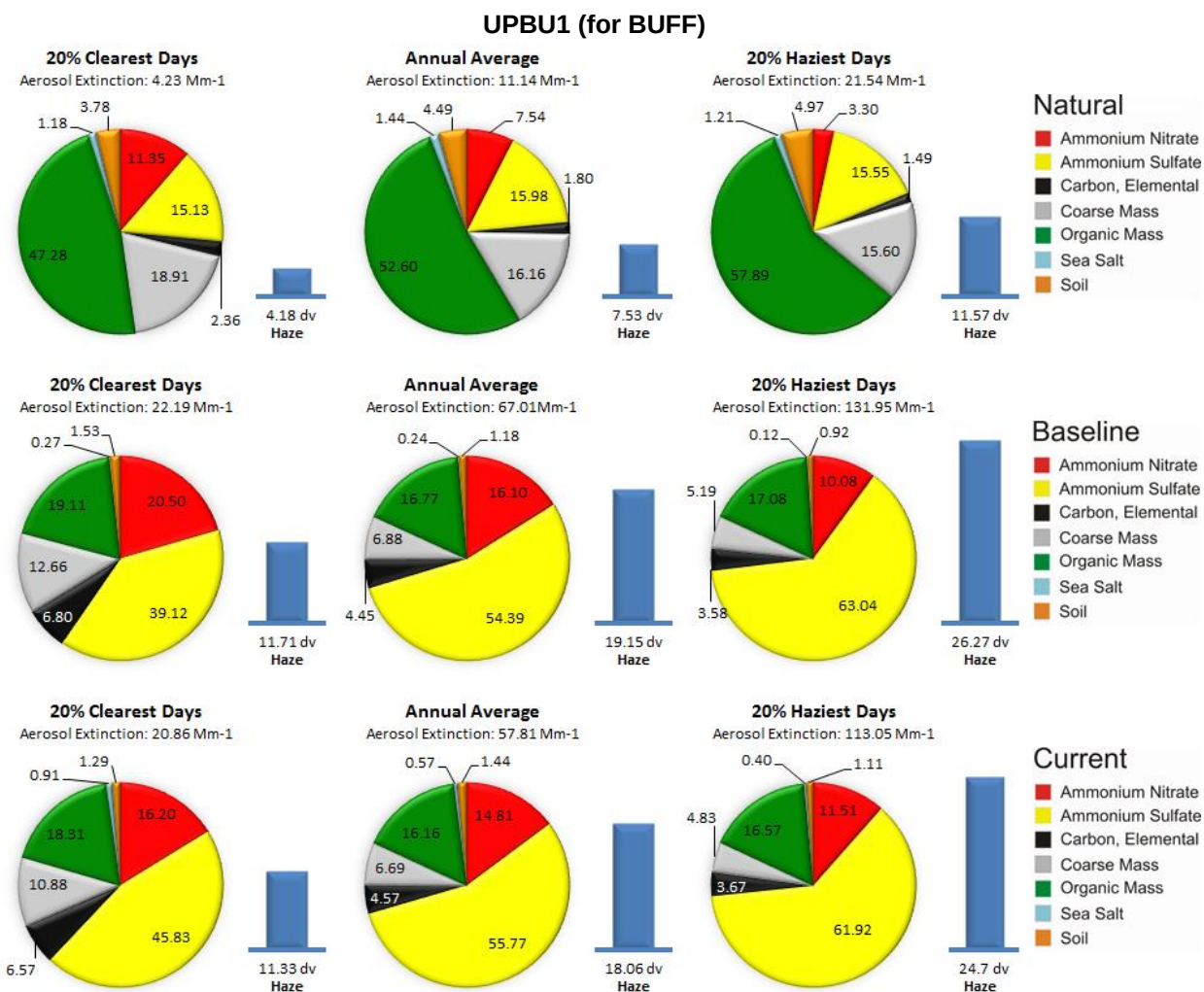


**Figure 1a.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for BUFF. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

### GRR11 (for EFMO)

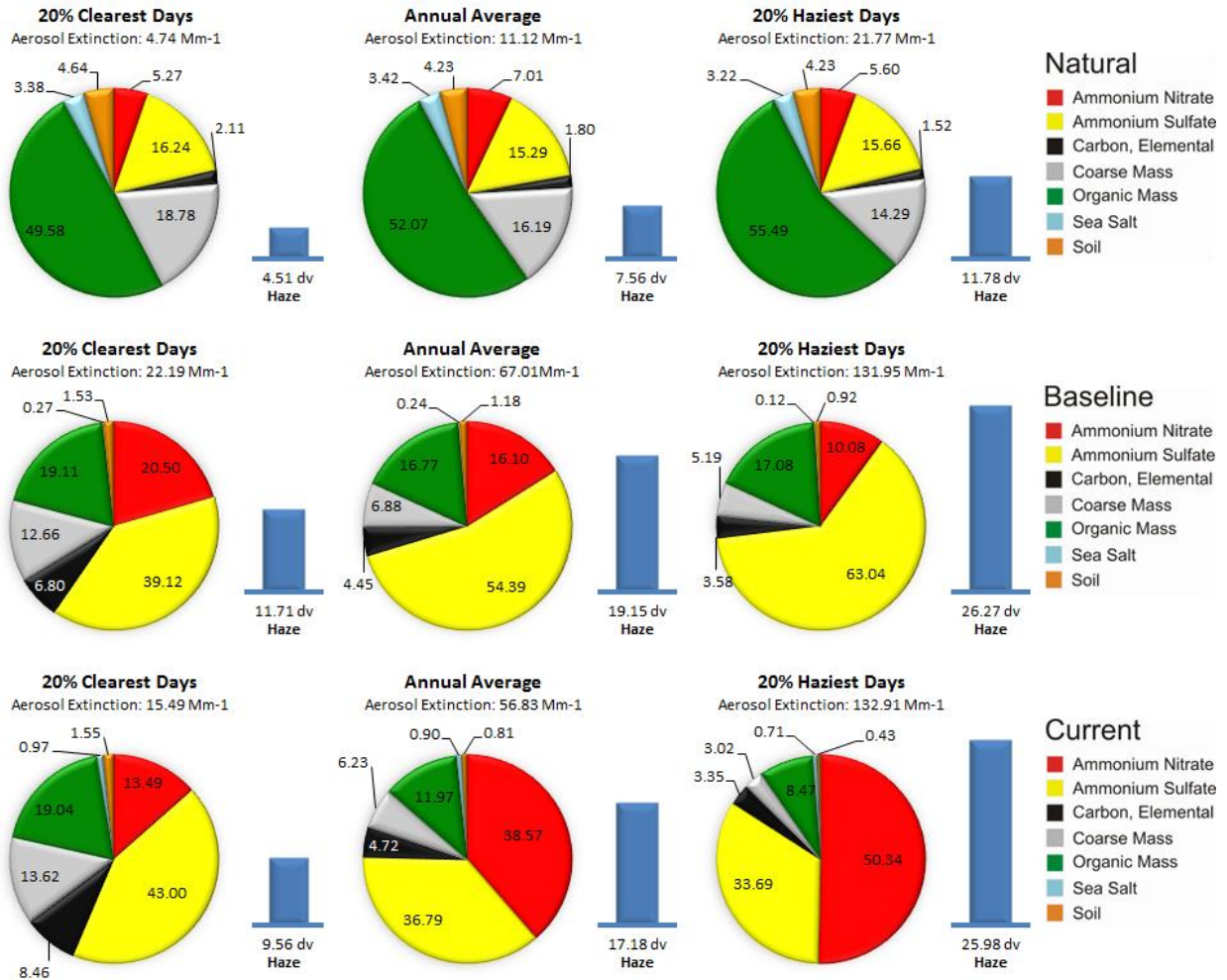


**Figure 1b.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for EFMO. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

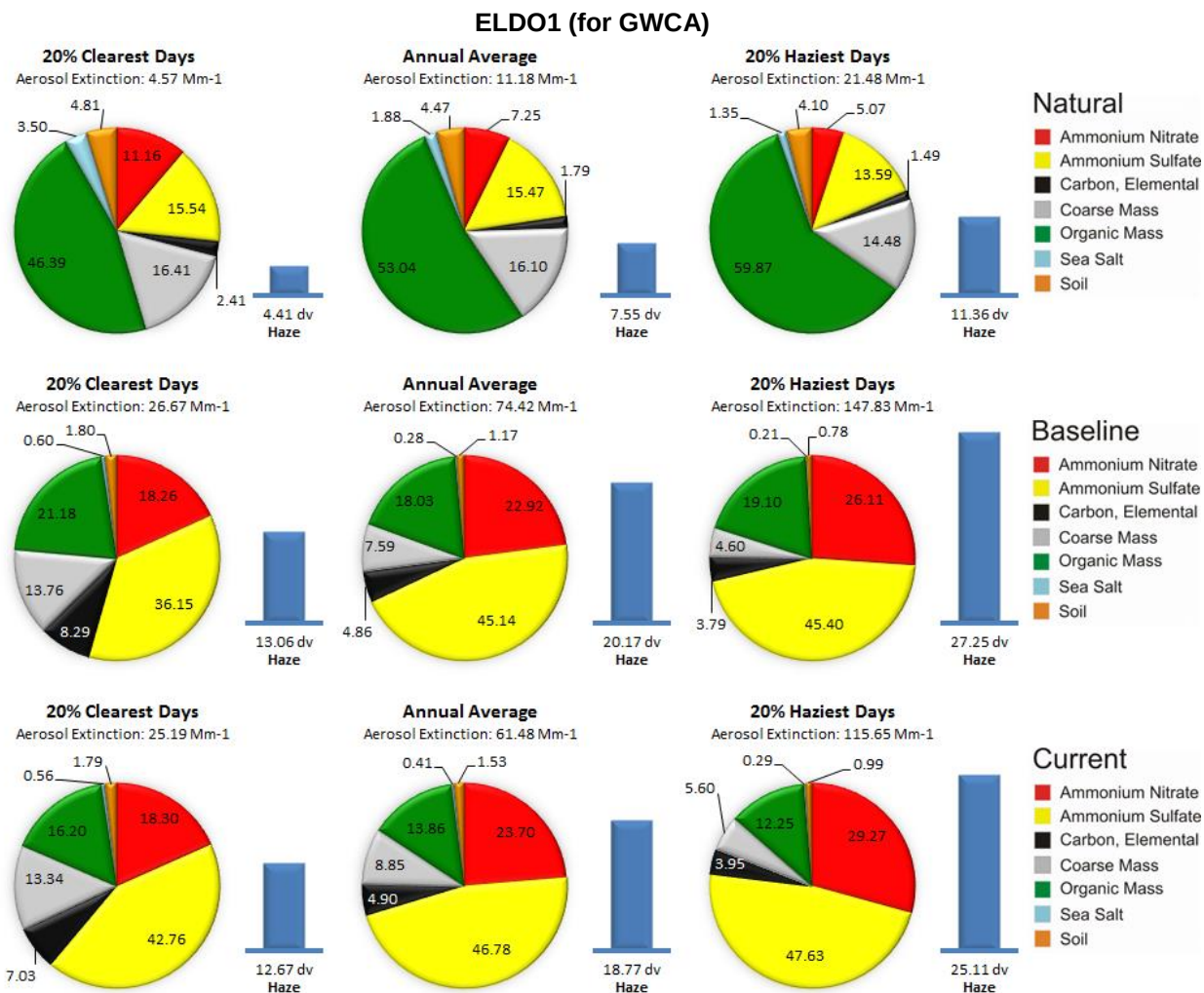


**Figure 1c.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for GWCA. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

### BLMO1 (for PIPE)

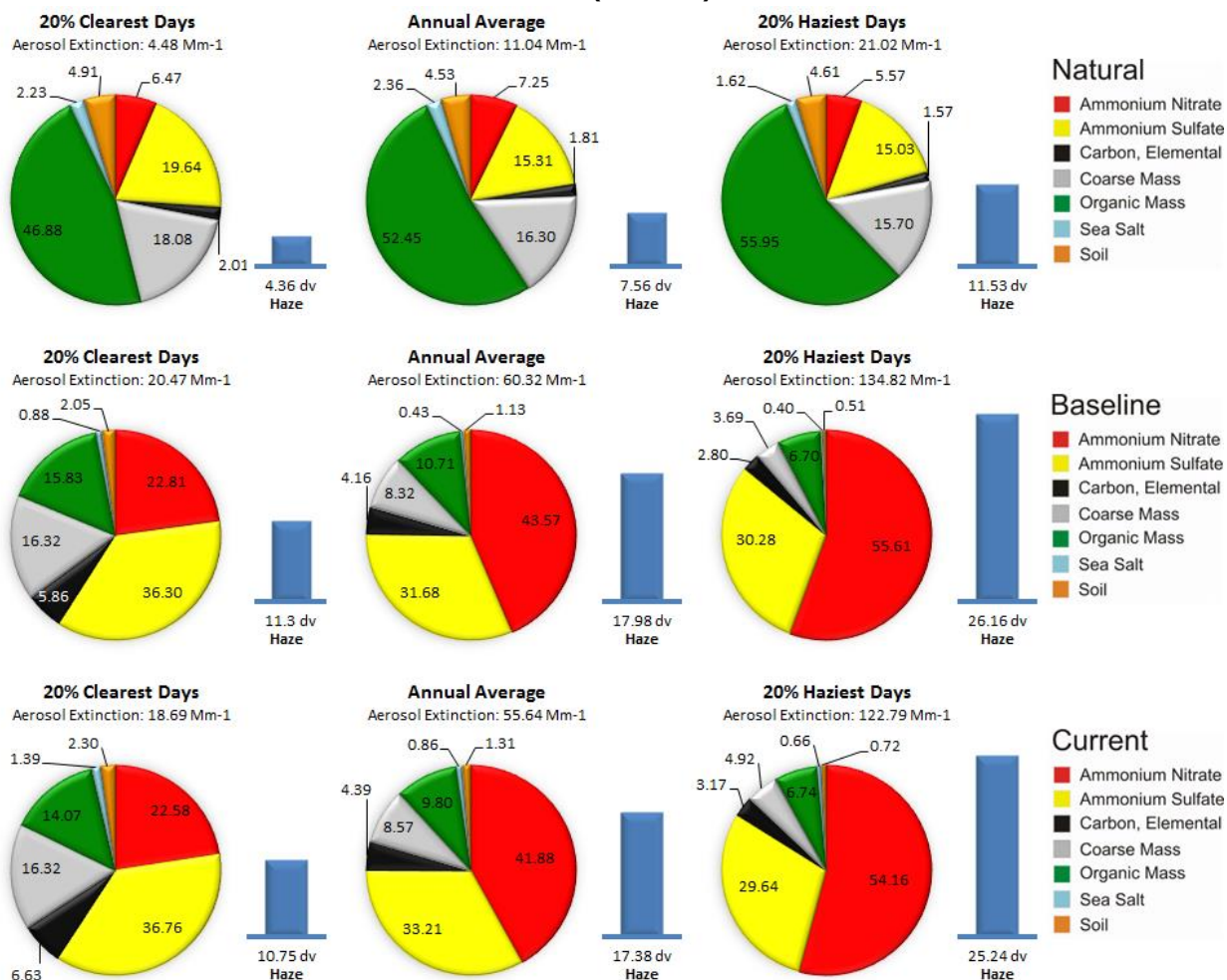


**Figure 1d.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for PIPE. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

## TALL1 (TAPR)

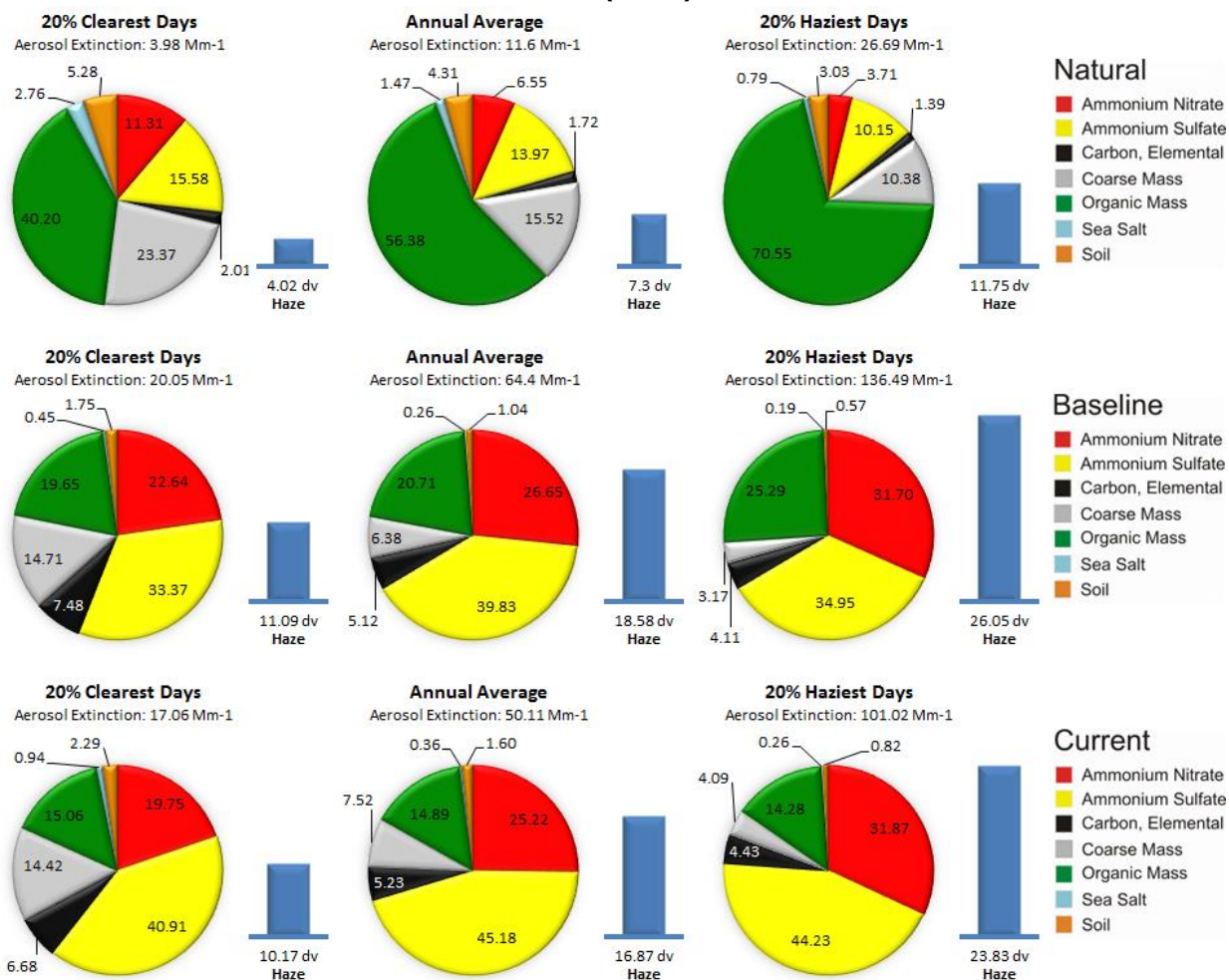


**Figure 1e.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for TAPR. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

### HEGL1 (for WICR)

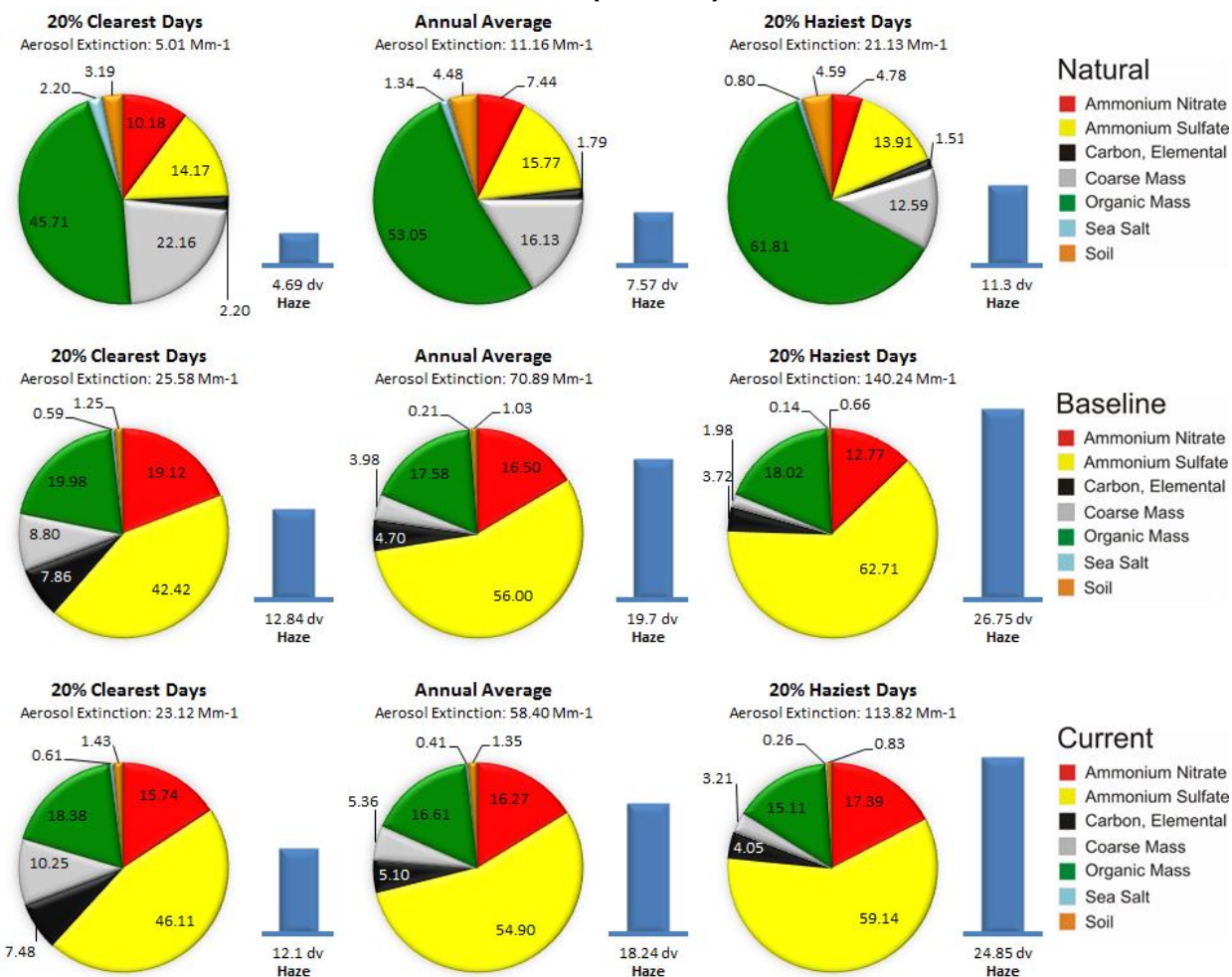


**Figure 1f.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for WICR. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). The charts for PIPE, EFMO, GWCA, and TAPR are based on only two years of data (2003-2004); the chart for WICR is based on data for 2002-2004. BUFF has no measured data for the year 2010. Data Source: NPS-ARD.

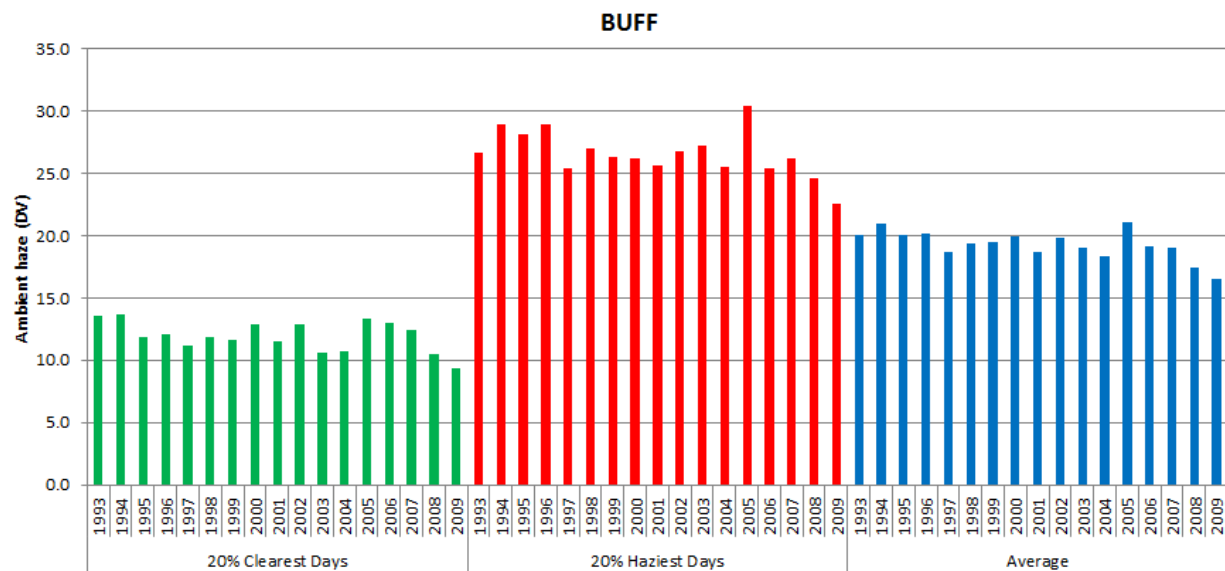


**Figure 2a.** Trends in ambient haze levels at BUFF, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

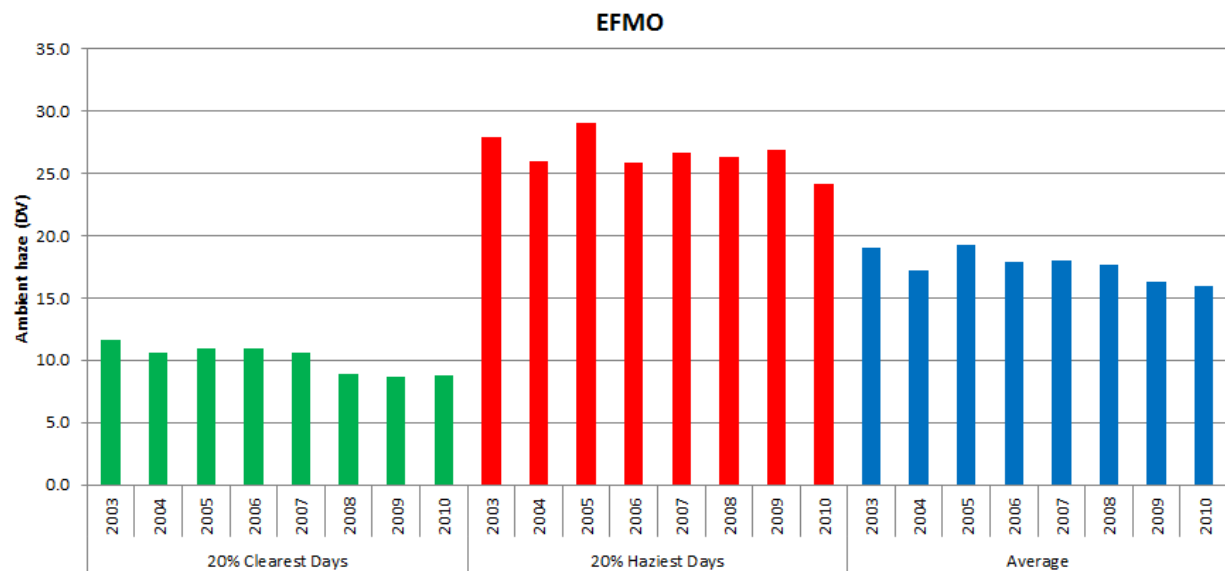


**Figure 2b.** Trends in ambient haze levels at EFMO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

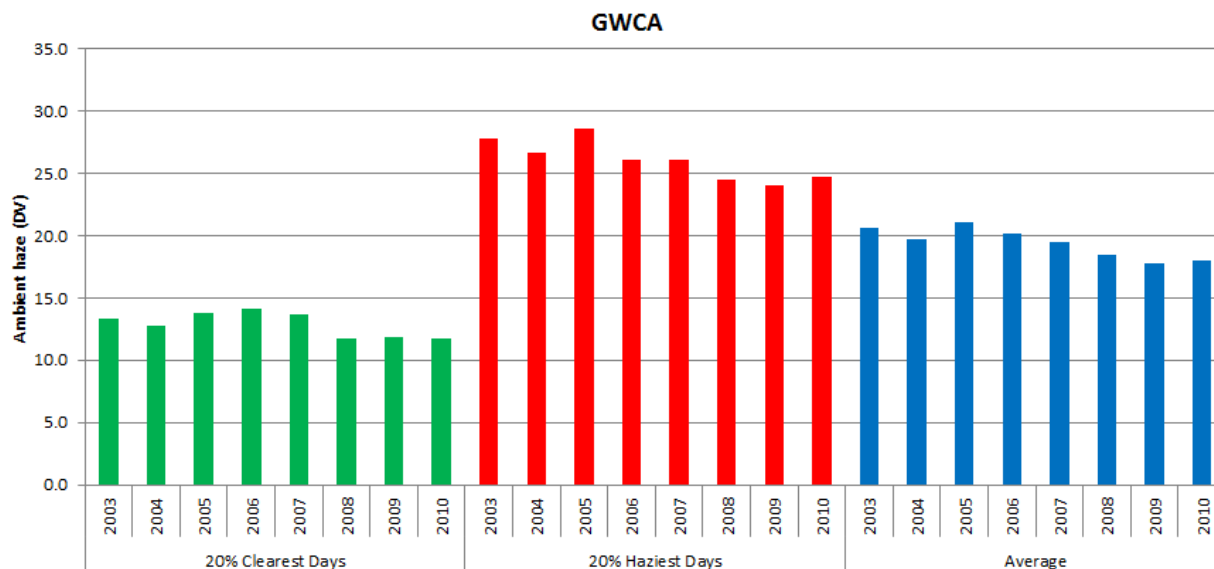


**Figure 2c.** Trends in ambient haze levels at GWCA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

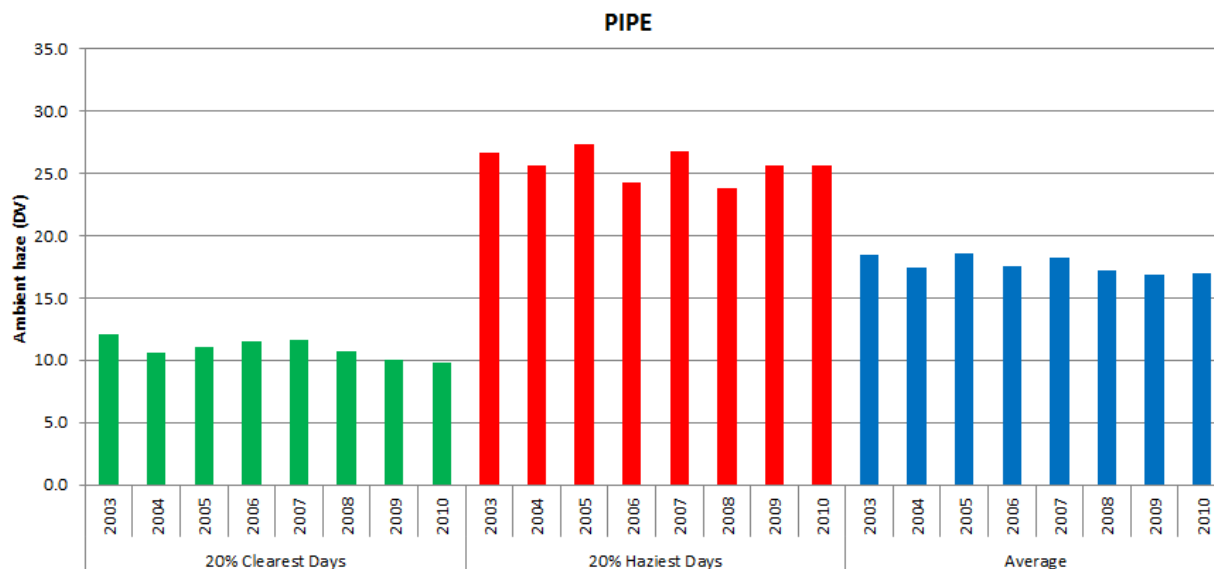


**Figure 2d.** Trends in ambient haze levels at PIPE, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

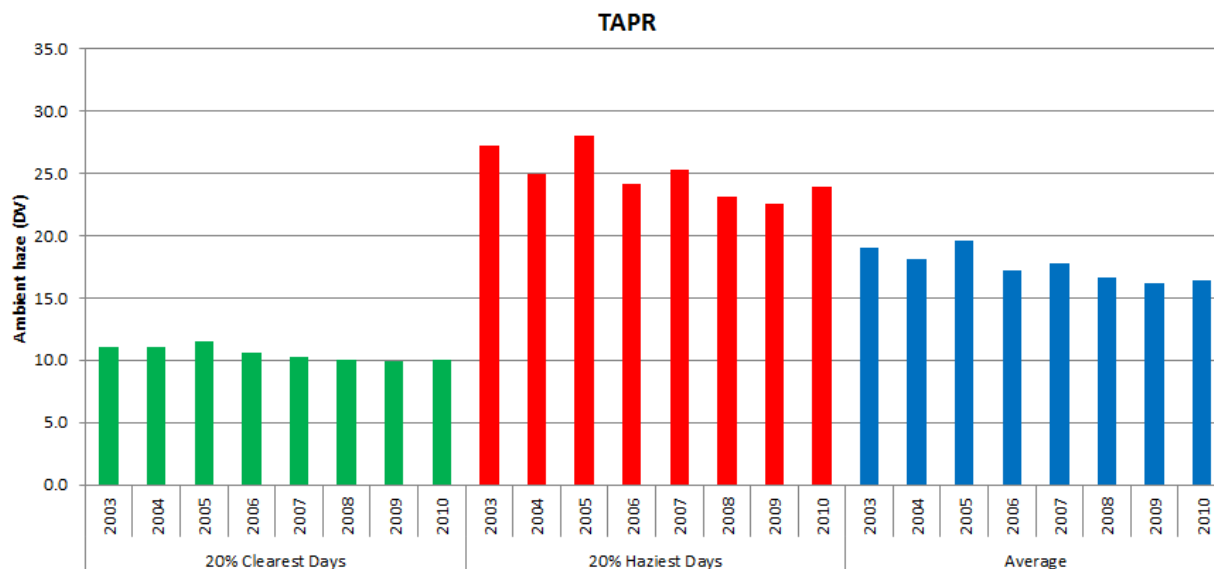


**Figure 2e.** Trends in ambient haze levels at TAPR, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

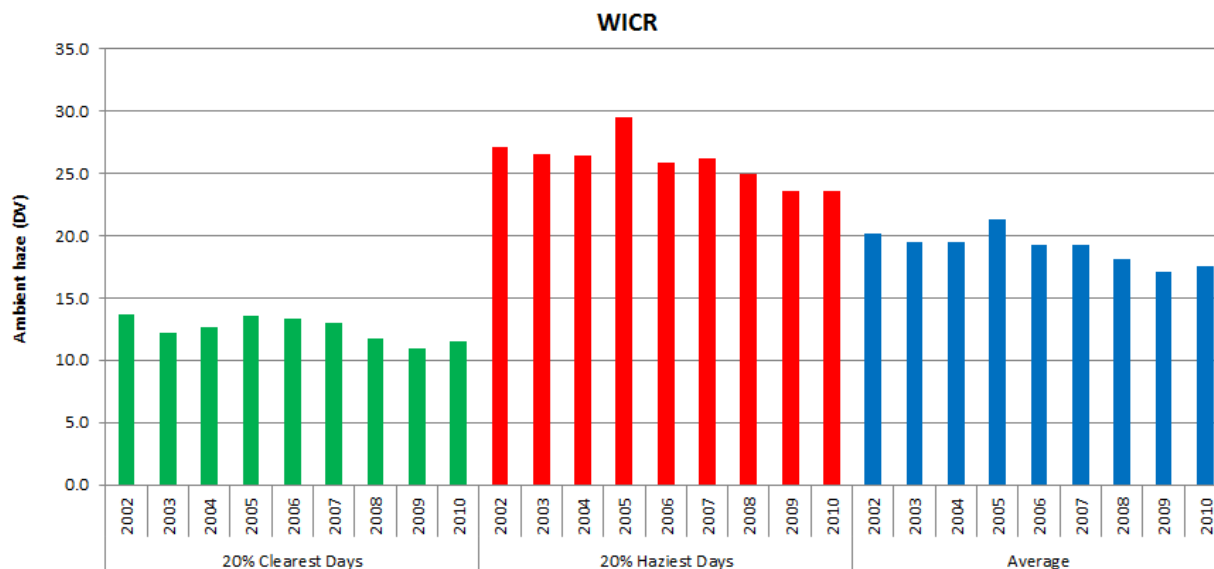


**Figure 2f.** Trends in ambient haze levels at WICR, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

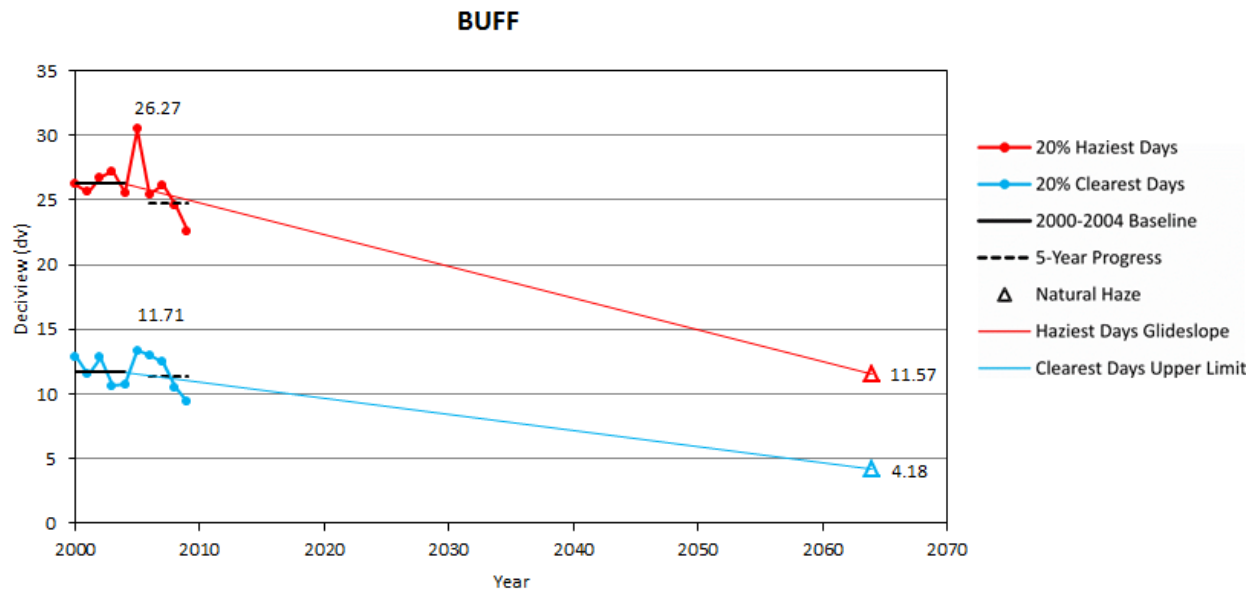


**Figure 3a.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in BUFF. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

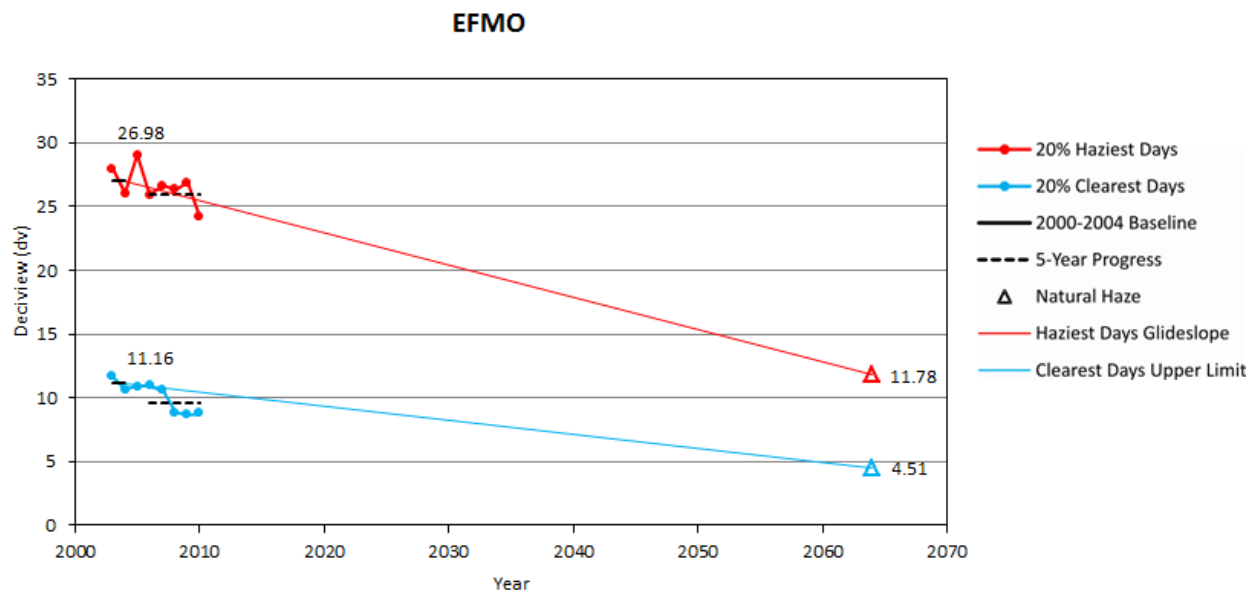


**Figure 3b.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in EFMO. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

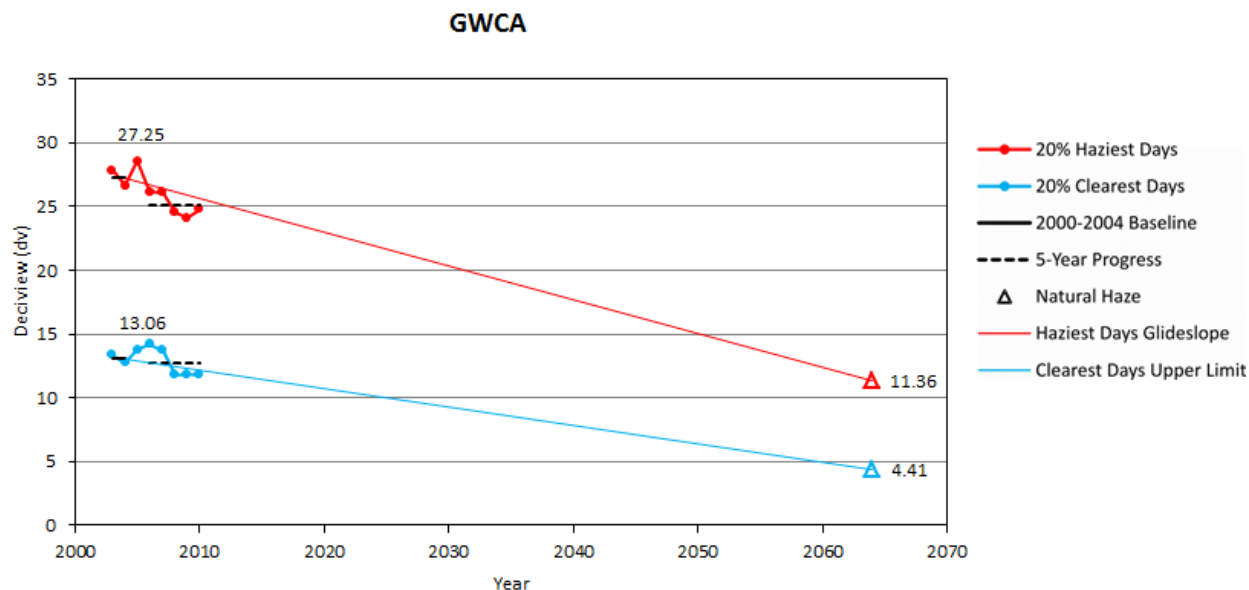


**Figure 3c.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in GWCA. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

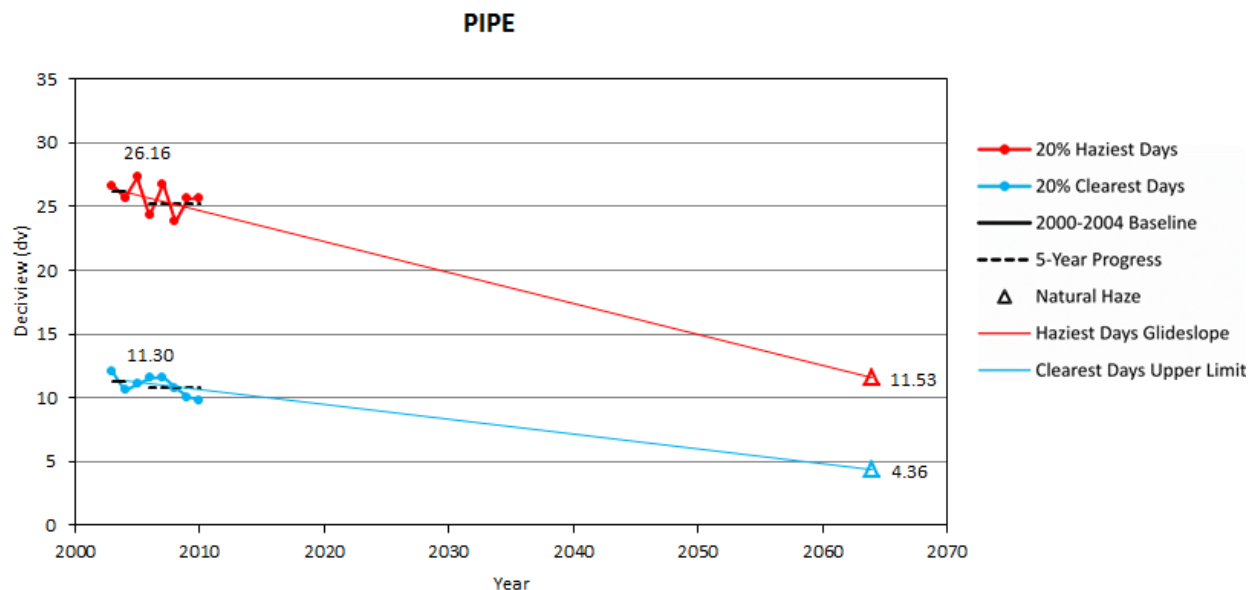


**Figure 3d.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in PIPE. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

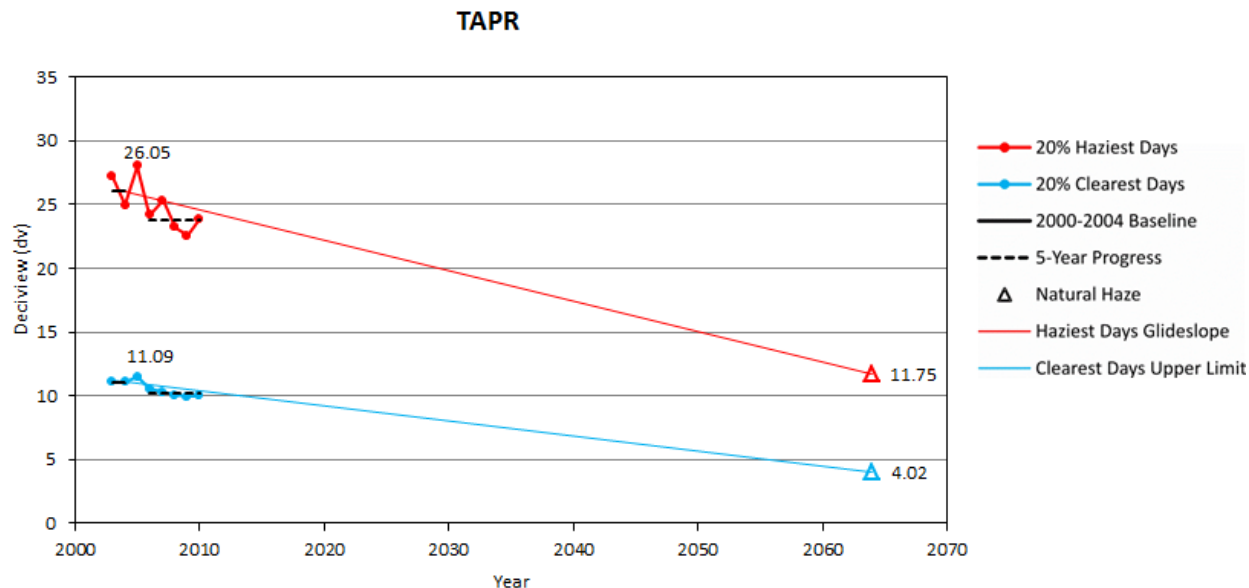


**Figure 3e.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in TAPR. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

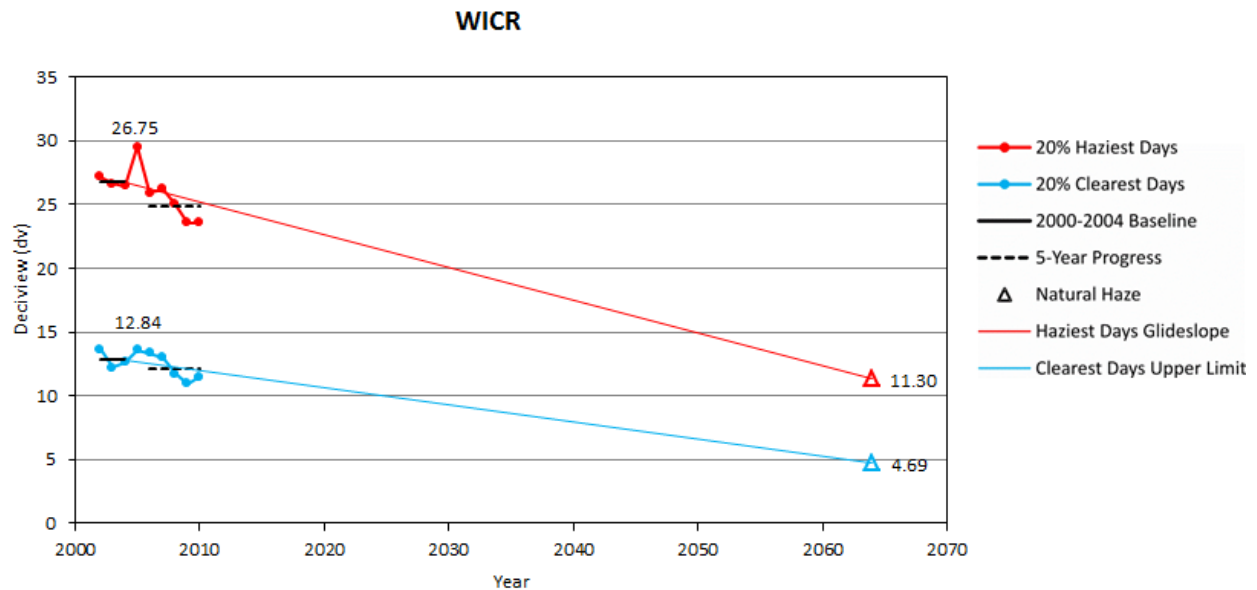


**Figure 3f.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in WICR. Data for all of the parks except TAPR were taken from nearby sites (See Table 7). In the regional haze rule, the clearest days do not have a uniform 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. PIPE, EFMO, GWCA, and TAPR have no valid measured or substituted data for the years 2000-2002; WICR has no measured data for the years 2000 and 2001; and BUFF has no measured data for the year 2010. Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

## Toxic Airborne Contaminants

Limited information is available regarding the effects of atmospherically deposited toxics on resources in the parks of the HTLN. However, some information is available regarding Hg bioaccumulation and biomagnification in Ozark streams. For example, Schmitt et al. (2011) analyzed multiple aquatic species for total Hg and stable isotopes of C, N, and S to discern Hg transfer pathways in Missouri. Concentrations of total Hg were generally lowest in crayfish (*Orconectes* spp.) and highest in smallmouth bass (*Micropterus dolomieu*). The researchers concluded that Hg concentrations in Ozark streams were low compared to many other locations in the United States, but nevertheless might represent a threat to wildlife.

Bald eagles (*Haliaeetus leucocephalus*) in the United States have been found to contain substantial amounts of Hg in feathers, eggs, liver, and brain (cf., Bechard et al. 2007, Scheuhammer et al. 2008, Wood et al. 1996). Impacts of Hg toxicity on eagle reproduction and survival can affect individual and population condition. It is therefore important to identify markers of subclinical effects of Hg on the brain of eagles and other piscivorous bird species as early warning signals. Rutkiewicz et al. (2011) evaluated Hg exposure to bald eagles collected in Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Levels of Hg in eagle brains were associated with neurochemical receptors and enzymes. Results suggested that bald eagles in this region are exposed to Hg at levels high enough to cause subclinical neurological damage (Rutkiewicz et al. 2011). The concentrations of total Hg in bald eagle brain and liver tissues within the study area were lowest in Ohio and Wisconsin, and highest in Michigan, Iowa, and Minnesota.

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