



# Air Quality Related Values (AQRVs) for Southern Plains Network (SOPN) Parks

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

Natural Resource Report NPS/SOPN/NRR—2016/1203



#### 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 Southern Plains Network (SOPN) Parks**

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Natural Resource Report NPS/SOPN/NRR—2016/1203

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April 2016

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

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Please cite this publication as:

Sullivan, T. J. 2016. Air quality related values (AQRVs) for Southern Plains Network (SOPN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/SOPN/NRR—2016/1203. National Park Service, Fort Collins, Colorado.

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## Summary

This report describes the Air Quality Related Values (AQRVs) of the Southern Plains Network (SOPN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The SOPN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Alibates Flint Quarries National Monument (ALFL), Bent's Old Fort National Historic Site (BEOL), Capulin Volcano National Monument (CAVO), Chickasaw National Recreation Area (CHIC), Fort Larned National Historic Site (FOLS), Fort Union National Monument (FOUN), Lake Meredith National Recreation Area (LAMR), Lyndon B. Johnson National Historical Park (LYJO), Pecos National Historical Park (PECO), Sand Creek Massacre National Historic Site (SAND) and Washita Battlefield National Historic Site (WABA).

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

Emissions from urban, industrial, and agricultural sources affect air quality in SOPN parks. There are several large population centers near the SOPN region, including Dallas, San Antonio (just outside the network boundary), and Oklahoma City.

Atmospheric deposition of both S and N are moderately high in the SOPN. These pollutants can contribute to acidification of streams, lakes, and soils. Total S deposition in and around the SOPN for the period 2010-2012 was generally highest (2 to 5 kg S/ha/yr) in the southeastern and lowest ( $< 2$  kg S/ha/yr) in the northwestern portion of the network area. Oxidized inorganic N deposition for the period 2010-2012 was variable throughout the park lands within the SCPN, ranging from generally less than 2 kg N/ha/yr in the western portions of the network to more than 5 kg/ha/yr to the east. Most areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period. Total N deposition was less than 10 kg N/ha/yr at most park locations. Despite moderately high levels of S and N deposition, there is no information suggesting that aquatic or terrestrial ecosystems in the SOPN are affected by acid deposition. Streams and soils are likely to be well-buffered and resistant to acidification.

Nitrogen pollutants can also cause undesirable enrichment of natural ecosystems, leading to changes in plant species diversity and soil nutrient cycling. Plant communities in the SOPN are likely vulnerable to enrichment, or eutrophication, by N. Grasslands, including short and mixed grass prairie, and arid ecosystem plant communities are mainly N-limited or co-limited by N, phosphorus (P) and/or water. Increasing N inputs can favor invasive grasses and forbs, reducing native diversity.

Such effects are confounded by interactions with periodic disturbance from fire, drought, and herbivory (Knapp et al. 1998, Seastedt and Knapp 1993).

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. Risk of injury to plants was rated as low to moderate in all SOPN parks except for CHIC, where risk was judged to be high.

Particulate pollution can cause haze, reducing visibility. Haze is not measured at any of the SOPN parks, but monitors considered representative of two of the parks suggest that haze levels due to anthropogenic sources of particulate air pollution are high.

## Background

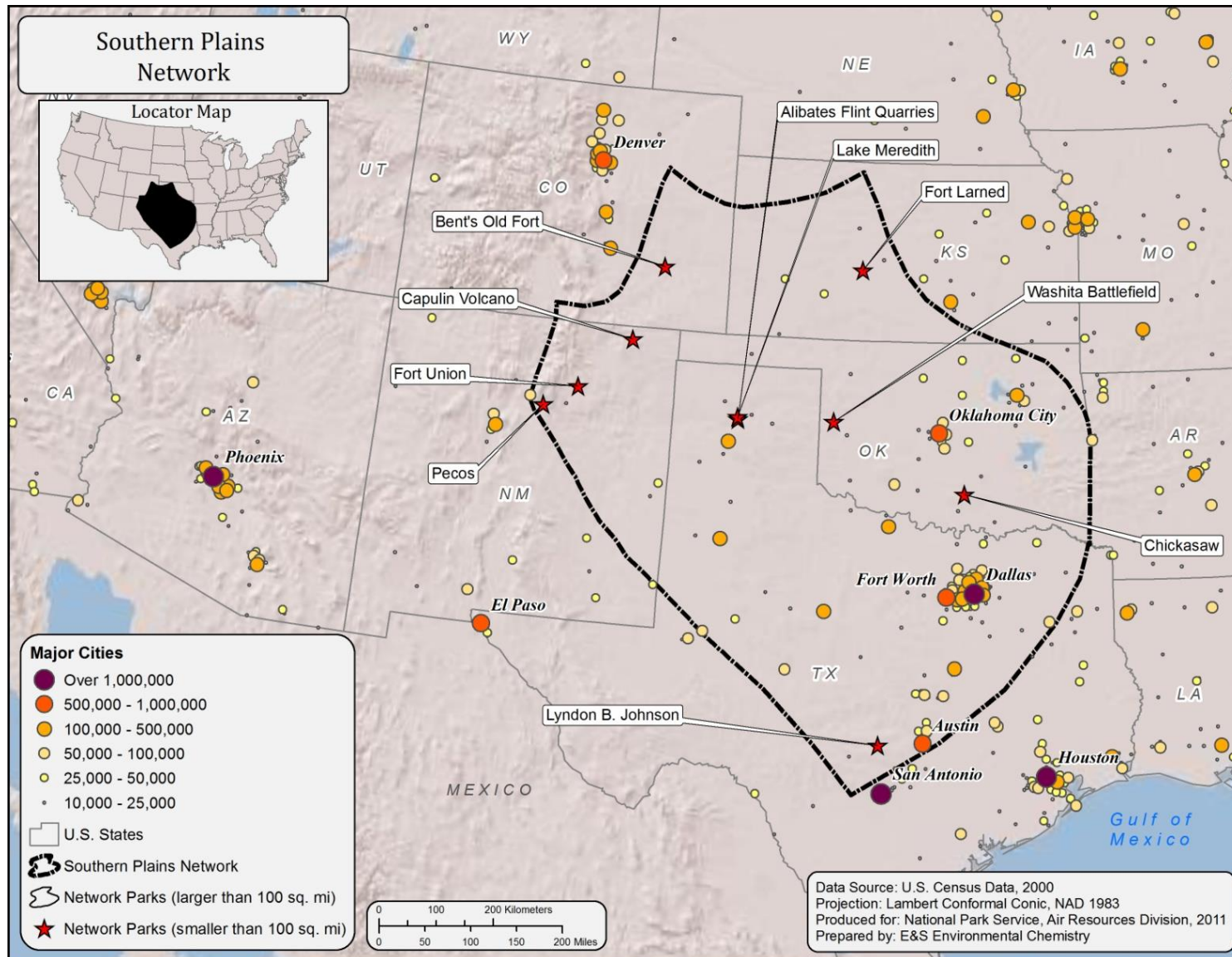
There are 11 parks in the Southern Plains Network (SOPN): Alibates Flint Quarries National Monument (ALFL), Bent's Old Fort National Historic Site (BEOL), Capulin Volcano National Monument (CAVO), Chickasaw National Recreation Area (CHIC), Fort Larned National Historic Site (FOLS), Fort Union National Monument (FOUN), Lake Meredith National Recreation Area (LAMR), Lyndon B. Johnson National Historical Park (LYJO), Pecos National Historical Park (PECO), Sand Creek Massacre National Historic Site (SAND) and Washita Battlefield National Historic Site (WABA). The network area includes a number of large urban centers to the southeast and less developed land to the northwest. There are several large population centers in and near the network region. The largest include Dallas, San Antonio, and Oklahoma City. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people around the network.

## Atmospheric Emissions and Deposition

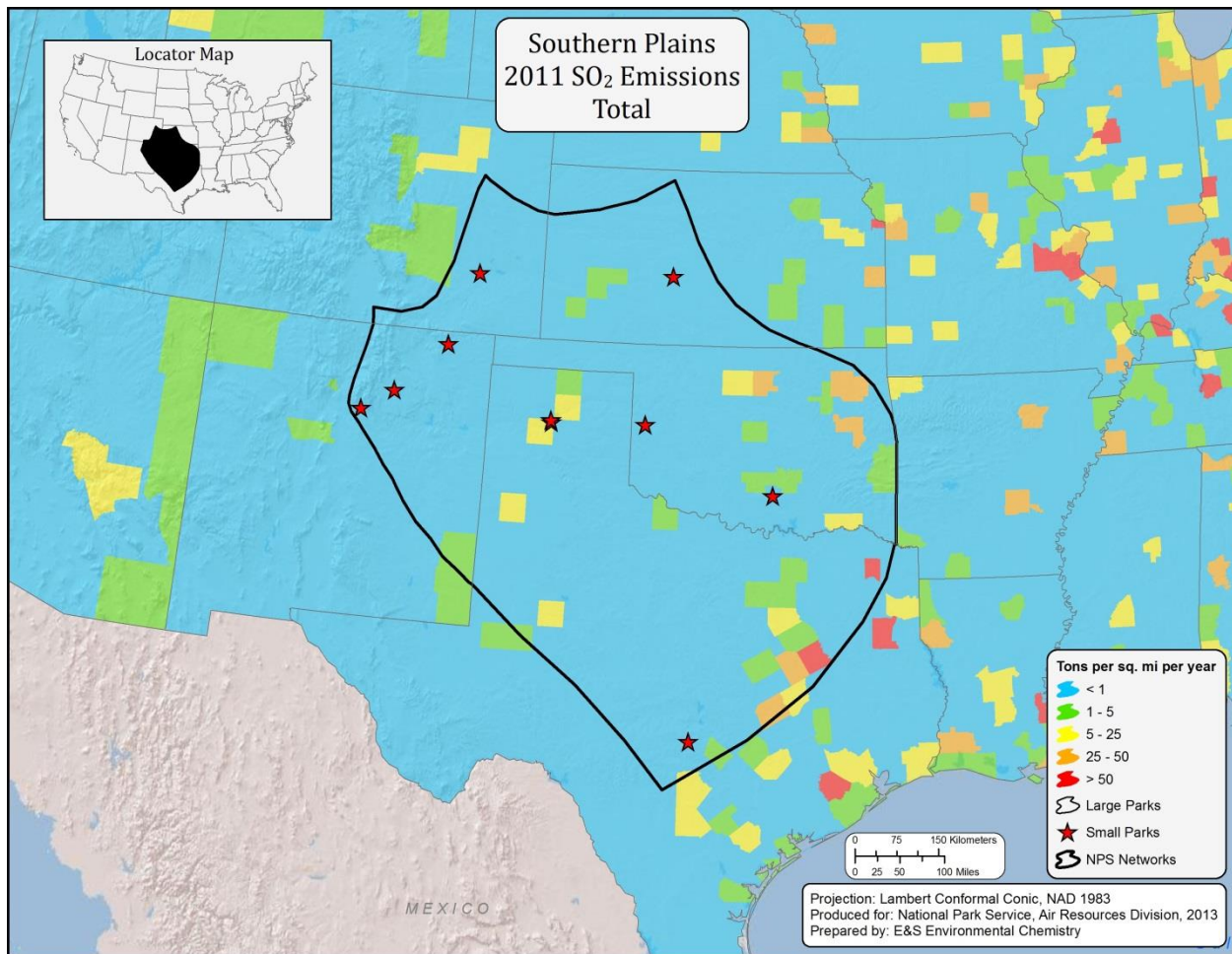
Annual county-level sulfur (S) emissions in 2002 varied within the SOPN region, ranging from less than 1 ton of sulfur dioxide (SO<sub>2</sub>) per square mile throughout most of the region to one small area emitting more than 100 tons per square mile. There were many point sources of SO<sub>2</sub> throughout this network region. Most were relatively small (less than a few hundred tons per year). The larger point sources of SO<sub>2</sub> were in Texas and Oklahoma.

In general, annual county nitrogen (N) emissions were in the range of 1 to 20 tons per square mile throughout much of the network, with substantial areas being lower and some scattered areas being higher than that. Sources of oxidized N (NO<sub>x</sub>) emissions within the network were mainly concentrated in Texas. The larger sources of reduced N (NH<sub>3</sub>) were concentrated primarily in Kansas. Most point sources of N were small. In the central part of the United States from Texas to North Dakota, SO<sub>2</sub> emissions increased during the 1990s, with statistically significant increases in Texas (14%), New Mexico (10%), Colorado (11%), Wyoming (31%), North Dakota (35%), and Minnesota (9%; Malm et al. 2002). Numerous small sources of NO<sub>x</sub> are associated with oil and gas development, which is prevalent throughout the SOPN region.

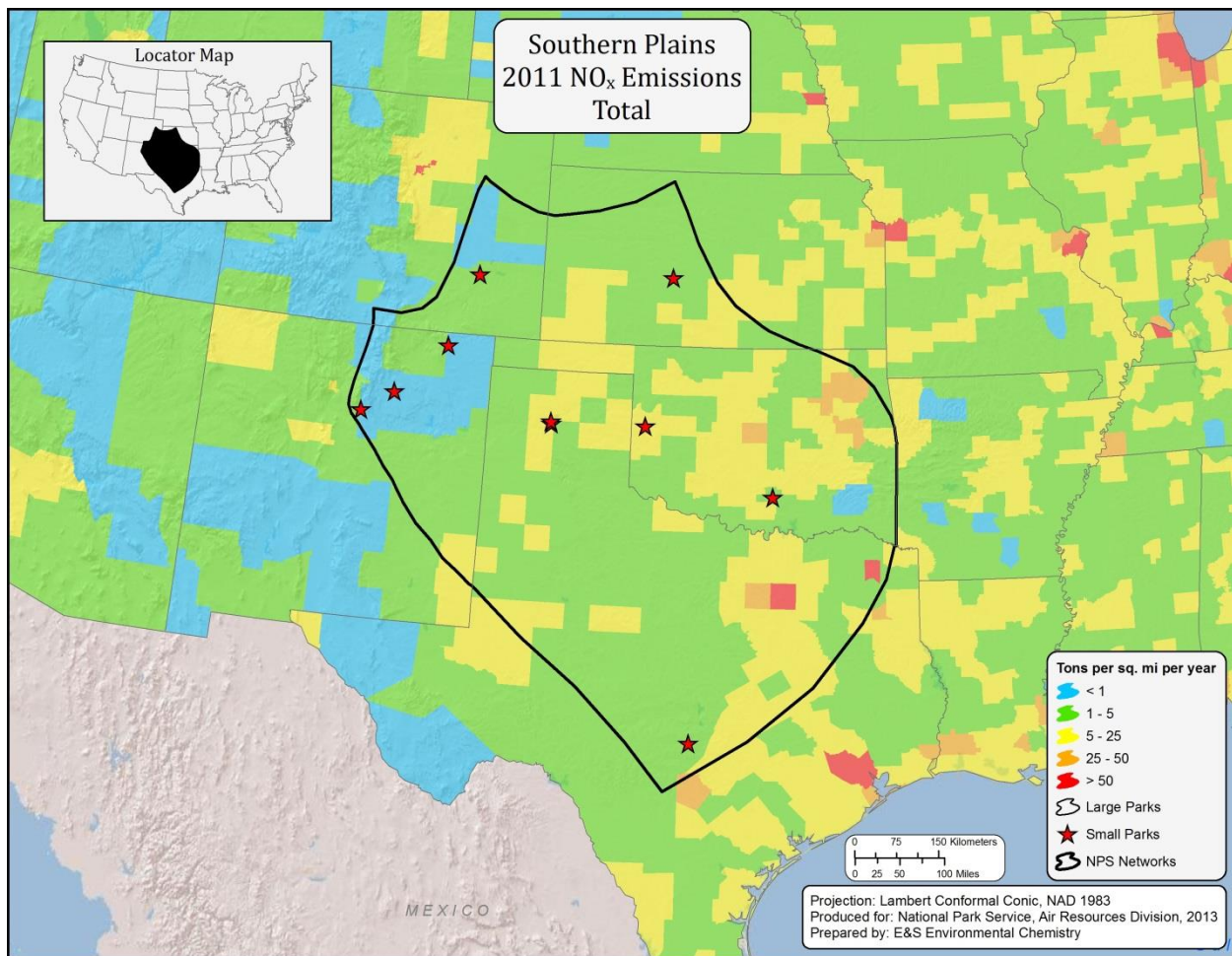
County-level emissions near the SOPN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and NH<sub>3</sub>, respectively. Most counties in the vicinity of SOPN parks had relatively low SO<sub>2</sub> emissions (<1 ton/mi<sup>2</sup>/yr; Map 2). Oxidized N emissions were higher, with highest values commonly in the range of 5 to 25 tons/mi<sup>2</sup>/yr (Map 3). Emissions of NH<sub>3</sub> near SOPN parks were variable (Map 4).



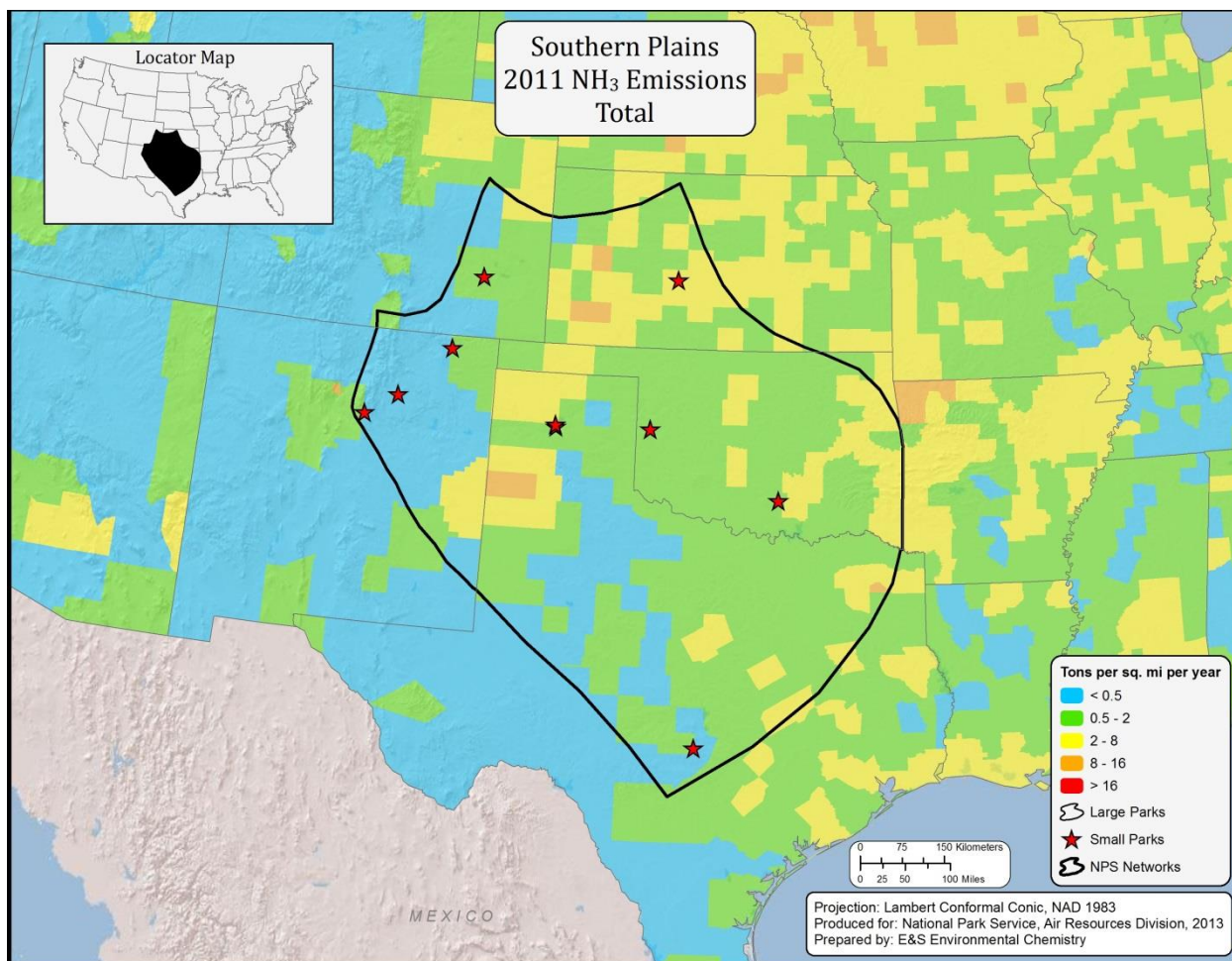
**Map 1.** Network boundary and locations of parks and population centers within the SOPN region.



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



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



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

Total S deposition in most of the SOPN ranged from less than 2 kg S/ha/yr up to 5 to 10 kg S/ha/yr in 2002 (Sullivan et al. 2011b). There were some scattered small areas with higher S deposition, one with more than 30 kg S/ha/yr. Total N deposition within the majority of this network ranged from less than 5 kg N/ha/yr to 10 to 15 kg N/ha/yr; a few scattered areas showed higher N deposition amounts. Both total S and total N deposition within this network generally increased from west to east.

Recently, Schwede and Lear (2014) documented a hybrid approach developed by the 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: 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.

Atmospheric S deposition levels have declined at SOPN parks since 2001, based on TDEP estimates (Table 1). Decreases in total S deposition were larger than 20% over the previous decade for many of the parks in this network. Changes in estimated total N deposition over that same time period were variable and generally modest. Oxidized and reduced N showed opposite patterns, with oxidized N generally decreasing and reduced N increasing at most parks in the network since the monitoring period 2000-2002.

Total S deposition in and around the SOPN for the period 2010-2012 was generally highest (2 to 5 kg S/ha/yr) in the southeastern and lowest (< 2 kg S/ha/yr) in the northwestern portion of the network area (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was variable throughout the park lands within the SOPN, ranging from generally less than 2 kg N/ha/yr in the western portions of the network to more than 5 kg/ha/yr to the east (Map 6). Most areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7). Total N deposition was less than 10 kg N/ha/yr at most park locations (Map 8).

## Acidification

The network and park rankings developed by Sullivan et al. (2011b) for acid Pollutant Exposure and Ecosystem Sensitivity to acidification yielded acidification risk rankings for parks in the SOPN that were generally low. Based on this coarse screening assessment of acidification risk, the overall level of concern for acidification effects on Inventory and Monitoring (I&M) parks within this network was judged by Sullivan et al. (2011b) to be Very Low. Note that SAND had not been designated as an I&M park at the time of preparation of the air pollution effects assessments of Sullivan et al. (2011a, 2011b).

Acid pollutant exposure in the SOPN varied from Very Low (two parks) to Moderate (six parks; Table 2). The other two parks were ranked Low. Ecosystem Sensitivity to acidification was ranked high for just one park (PECO). One additional park (LAMR) was ranked Moderate. The other parks were ranked Low (three parks) or Very Low (five parks) for this theme (Table 2). While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

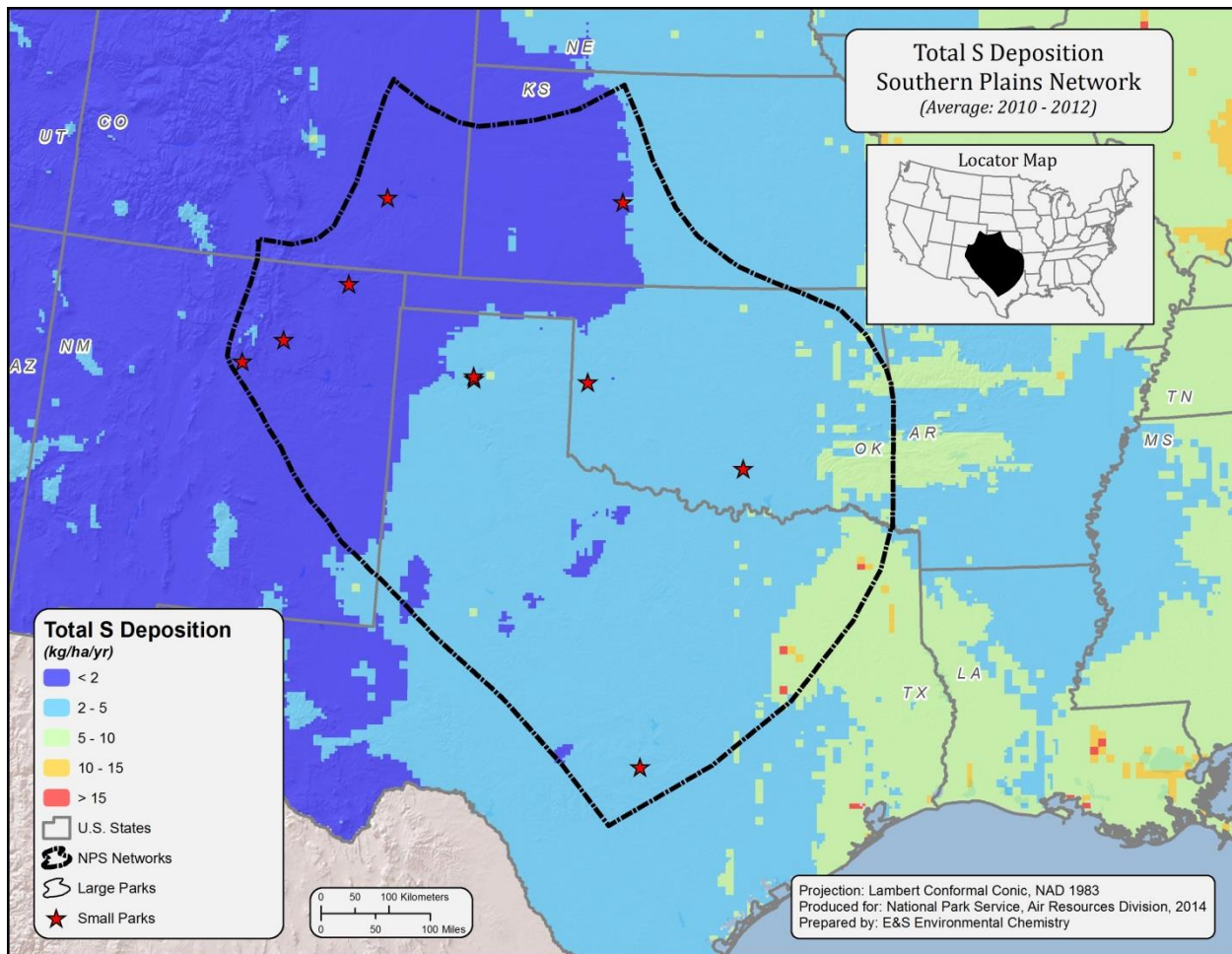
Ecosystem sensitivity to acidification rankings take into account land slope, which often influences the degree of acid neutralization provided by soils and bedrock within the watershed. Land slope within the parks that occur in this network is mostly less than 10°. However, the terrain in CAVO is steeper, with average slope more than 30°. This suggests increased potential for acid sensitivity of aquatic ecosystems in this park. Nevertheless, there is no information suggesting that aquatic ecosystems in CAVO or elsewhere in the SOPN have low acid neutralizing capacity or have been impacted by acidifying emissions. Similarly, information is generally not available that might suggest acid sensitivity of terrestrial resources in the SOPN. The geology of this region is not thought to be acid-sensitive (McNulty et al. 2007). It appears that weathering processes supply adequate calcium and other base cations that would neutralize acidic inputs.

**Table 1.** Average changes in S and N deposition between 2001 and 2011 across park grid cells at SOPN 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.

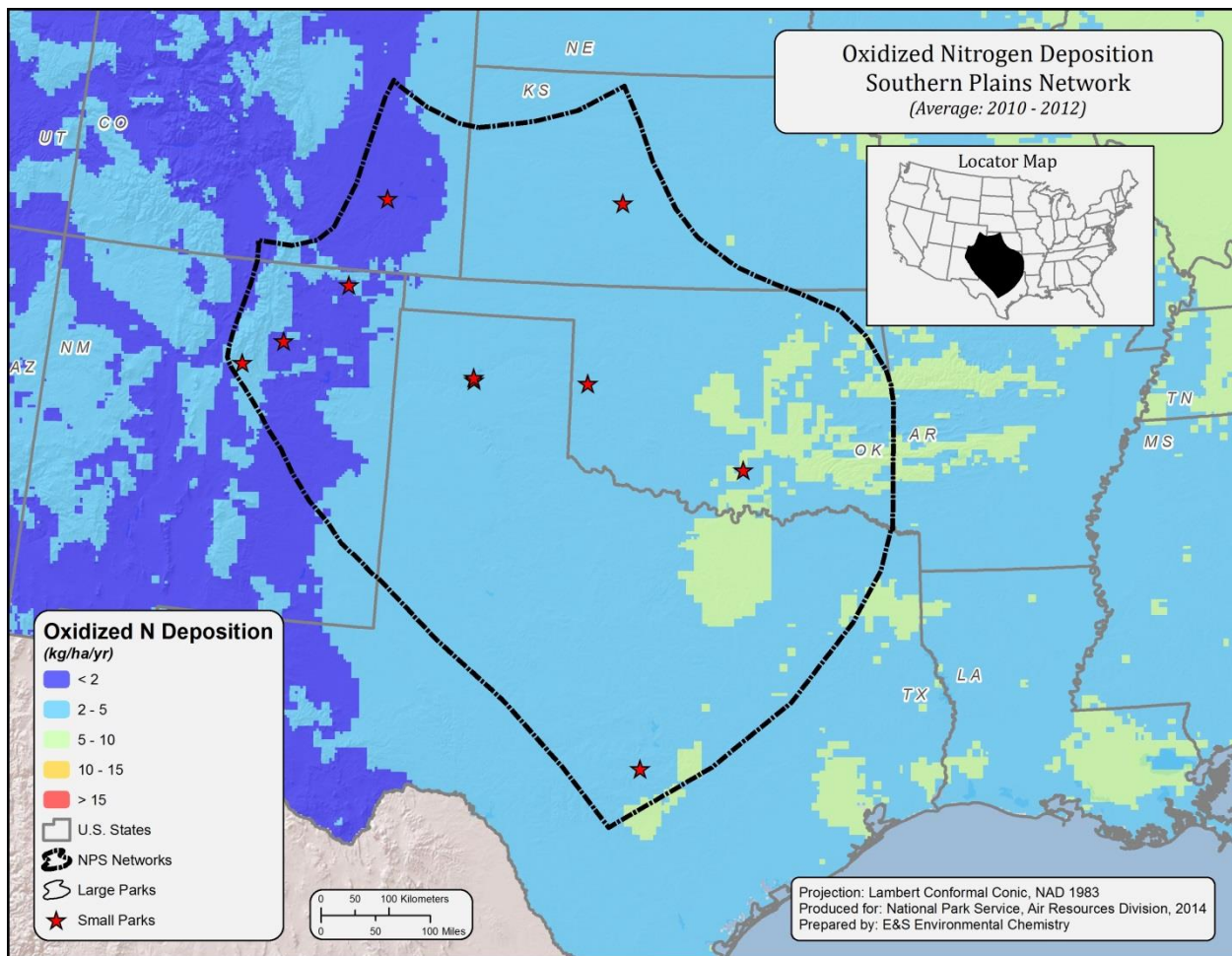
| 8 | Park Code | Park Name               | Parameter  | 2001<br>Average<br>(kg/ha/yr) | 2011<br>Average<br>(kg/ha/yr) | Absolute<br>Change<br>(kg/ha/yr) | Percent<br>Change | 2011<br>Minimum<br>(kg/ha/yr) | 2011<br>Maximum<br>(kg/ha/yr) | 2011<br>Range<br>(kg/ha/yr) |
|---|-----------|-------------------------|------------|-------------------------------|-------------------------------|----------------------------------|-------------------|-------------------------------|-------------------------------|-----------------------------|
|   |           |                         |            |                               |                               |                                  |                   |                               |                               |                             |
| 8 | ALFL      | Alibates Flint Quarries | Total S    | 5.89                          | 2.63                          | -3.26                            | -55.3%            | 2.63                          | 2.63                          | 0.00                        |
|   |           |                         | Total N    | 8.03                          | 7.46                          | -0.57                            | -7.1%             | 7.46                          | 7.46                          | 0.00                        |
|   |           |                         | Oxidized N | 4.06                          | 2.75                          | -1.32                            | -32.4%            | 2.75                          | 2.75                          | 0.00                        |
|   |           |                         | Reduced N  | 3.97                          | 4.72                          | 0.75                             | 18.8%             | 4.72                          | 4.72                          | 0.00                        |
|   | BEOL      | Bent's Old Fort         | Total S    | 0.82                          | 0.81                          | -0.02                            | -1.8%             | 0.81                          | 0.81                          | 0.00                        |
|   |           |                         | Total N    | 3.86                          | 4.15                          | 0.29                             | 7.6%              | 4.15                          | 4.15                          | 0.00                        |
|   |           |                         | Oxidized N | 1.99                          | 1.52                          | -0.47                            | -23.6%            | 1.52                          | 1.52                          | 0.00                        |
|   |           |                         | Reduced N  | 1.87                          | 2.64                          | 0.76                             | 40.7%             | 2.64                          | 2.64                          | 0.00                        |
|   | CAVO      | Capulin Volcano         | Total S    | 1.08                          | 1.05                          | -0.03                            | -2.9%             | 1.05                          | 1.05                          | 0.00                        |
|   |           |                         | Total N    | 3.78                          | 3.41                          | -0.37                            | -9.9%             | 3.41                          | 3.41                          | 0.00                        |
|   |           |                         | Oxidized N | 2.22                          | 1.96                          | -0.27                            | -12.0%            | 1.96                          | 1.96                          | 0.00                        |
|   |           |                         | Reduced N  | 1.56                          | 1.45                          | -0.11                            | -7.0%             | 1.45                          | 1.45                          | 0.00                        |
|   | CHIC      | Chickasaw               | Total S    | 4.99                          | 3.46                          | -1.53                            | -30.7%            | 3.41                          | 3.48                          | 0.07                        |
|   |           |                         | Total N    | 10.51                         | 9.00                          | -1.51                            | -14.4%            | 8.96                          | 9.04                          | 0.08                        |
|   |           |                         | Oxidized N | 6.23                          | 4.97                          | -1.26                            | -20.2%            | 4.95                          | 5.03                          | 0.08                        |
|   |           |                         | Reduced N  | 4.28                          | 4.03                          | -0.25                            | -5.9%             | 3.99                          | 4.05                          | 0.06                        |
|   | FOLS      | Fort Larned             | Total S    | 2.71                          | 1.94                          | -0.77                            | -28.4%            | 1.92                          | 1.95                          | 0.03                        |
|   |           |                         | Total N    | 9.48                          | 10.53                         | 1.05                             | 11.1%             | 9.69                          | 10.59                         | 0.89                        |
|   |           |                         | Oxidized N | 4.11                          | 3.10                          | -1.01                            | -24.5%            | 3.06                          | 3.11                          | 0.05                        |
|   |           |                         | Reduced N  | 5.37                          | 7.42                          | 2.06                             | 38.4%             | 6.63                          | 7.48                          | 0.85                        |

**Table 1 (continued).** Average changes in S and N deposition between 2001 and 2011 across park grid cells at SOPN 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.

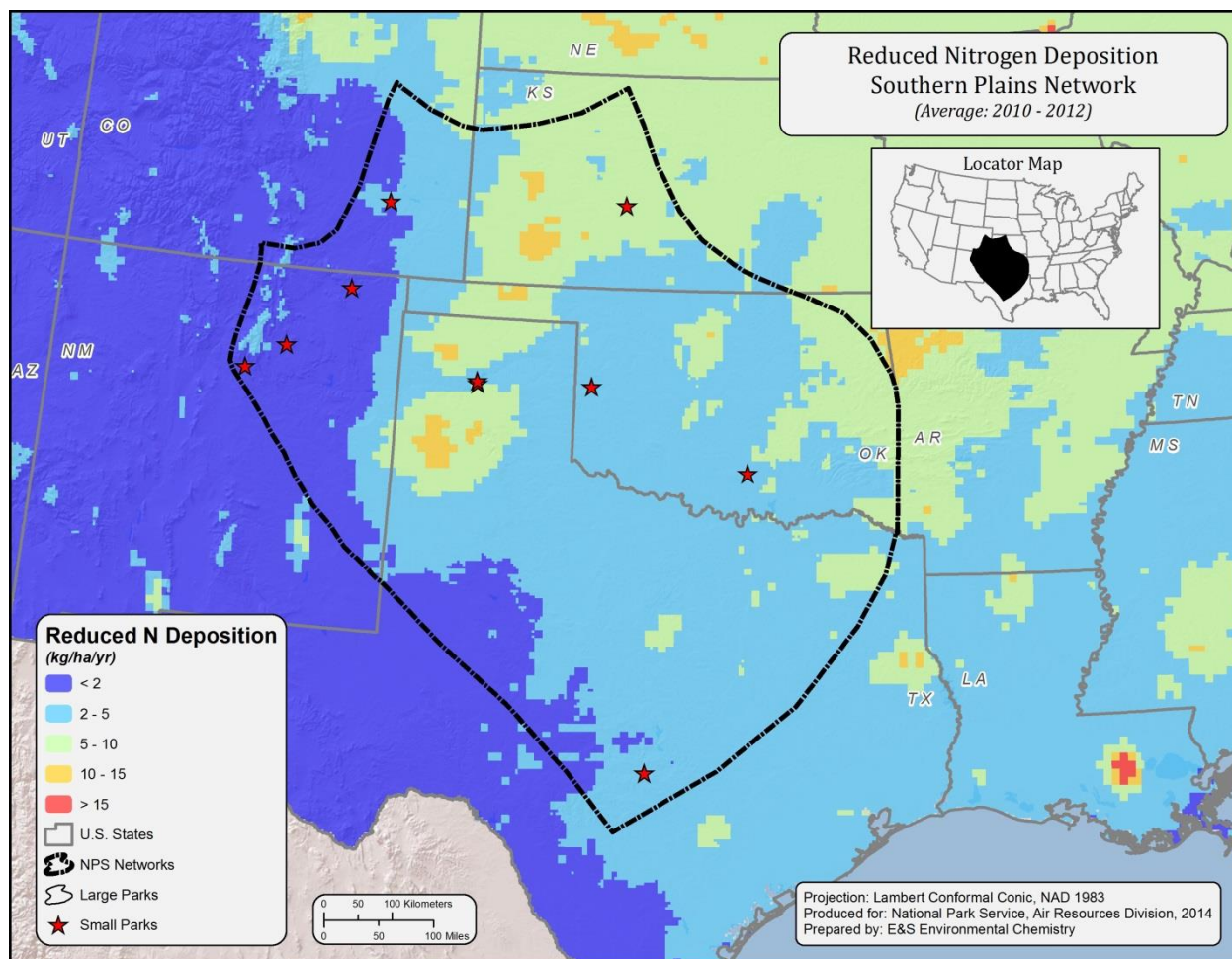
| Park Code | Park Name           | Parameter  | 2001 Average (kg/ha/yr) | 2011 Average (kg/ha/yr) | Absolute Change (kg/ha/yr) | Percent Change | 2011 Minimum (kg/ha/yr) | 2011 Maximum (kg/ha/yr) | 2011 Range (kg/ha/yr) |
|-----------|---------------------|------------|-------------------------|-------------------------|----------------------------|----------------|-------------------------|-------------------------|-----------------------|
| FOUN      | Fort Union          | Total S    | 1.17                    | 0.87                    | -0.30                      | -25.7%         | 0.86                    | 0.89                    | 0.03                  |
|           |                     | Total N    | 3.47                    | 2.95                    | -0.52                      | -14.8%         | 2.90                    | 3.11                    | 0.21                  |
|           |                     | Oxidized N | 2.26                    | 1.69                    | -0.57                      | -25.1%         | 1.67                    | 1.77                    | 0.11                  |
|           |                     | Reduced N  | 1.21                    | 1.26                    | 0.05                       | 4.2%           | 1.24                    | 1.34                    | 0.10                  |
| LAMR      | Lake Meredith       | Total S    | 5.86                    | 2.50                    | -3.36                      | -57.4%         | 2.29                    | 2.80                    | 0.52                  |
|           |                     | Total N    | 7.99                    | 7.50                    | -0.50                      | -6.1%          | 7.25                    | 8.07                    | 0.82                  |
|           |                     | Oxidized N | 4.04                    | 2.71                    | -1.34                      | -33.0%         | 2.56                    | 2.83                    | 0.27                  |
|           |                     | Reduced N  | 3.95                    | 4.79                    | 0.84                       | 21.5%          | 4.58                    | 5.24                    | 0.66                  |
| LYJO      | Lyndon B. Johnson   | Total S    | 4.40                    | 2.93                    | -1.47                      | -33.3%         | 2.90                    | 3.16                    | 0.26                  |
|           |                     | Total N    | 7.86                    | 7.18                    | -0.68                      | -8.6%          | 6.76                    | 7.28                    | 0.52                  |
|           |                     | Oxidized N | 5.08                    | 4.08                    | -1.00                      | -19.6%         | 4.05                    | 4.38                    | 0.33                  |
|           |                     | Reduced N  | 2.78                    | 3.10                    | 0.32                       | 11.4%          | 2.38                    | 3.21                    | 0.83                  |
| PECO      | Pecos               | Total S    | 1.20                    | 1.07                    | -0.13                      | -10.6%         | 0.99                    | 1.12                    | 0.13                  |
|           |                     | Total N    | 3.84                    | 4.22                    | 0.38                       | 9.7%           | 3.79                    | 4.41                    | 0.63                  |
|           |                     | Oxidized N | 2.77                    | 2.91                    | 0.14                       | 4.9%           | 2.57                    | 3.05                    | 0.48                  |
|           |                     | Reduced N  | 1.07                    | 1.31                    | 0.24                       | 22.1%          | 1.22                    | 1.36                    | 0.15                  |
| WABA      | Washita Battlefield | Total S    | 2.98                    | 2.16                    | -0.82                      | -27.7%         | 2.16                    | 2.16                    | 0.00                  |
|           |                     | Total N    | 8.35                    | 6.91                    | -1.44                      | -17.2%         | 6.91                    | 6.91                    | 0.00                  |
|           |                     | Oxidized N | 4.62                    | 3.32                    | -1.30                      | -28.1%         | 3.32                    | 3.32                    | 0.00                  |
|           |                     | Reduced N  | 3.73                    | 3.59                    | -0.14                      | -3.7%          | 3.59                    | 3.59                    | 0.00                  |



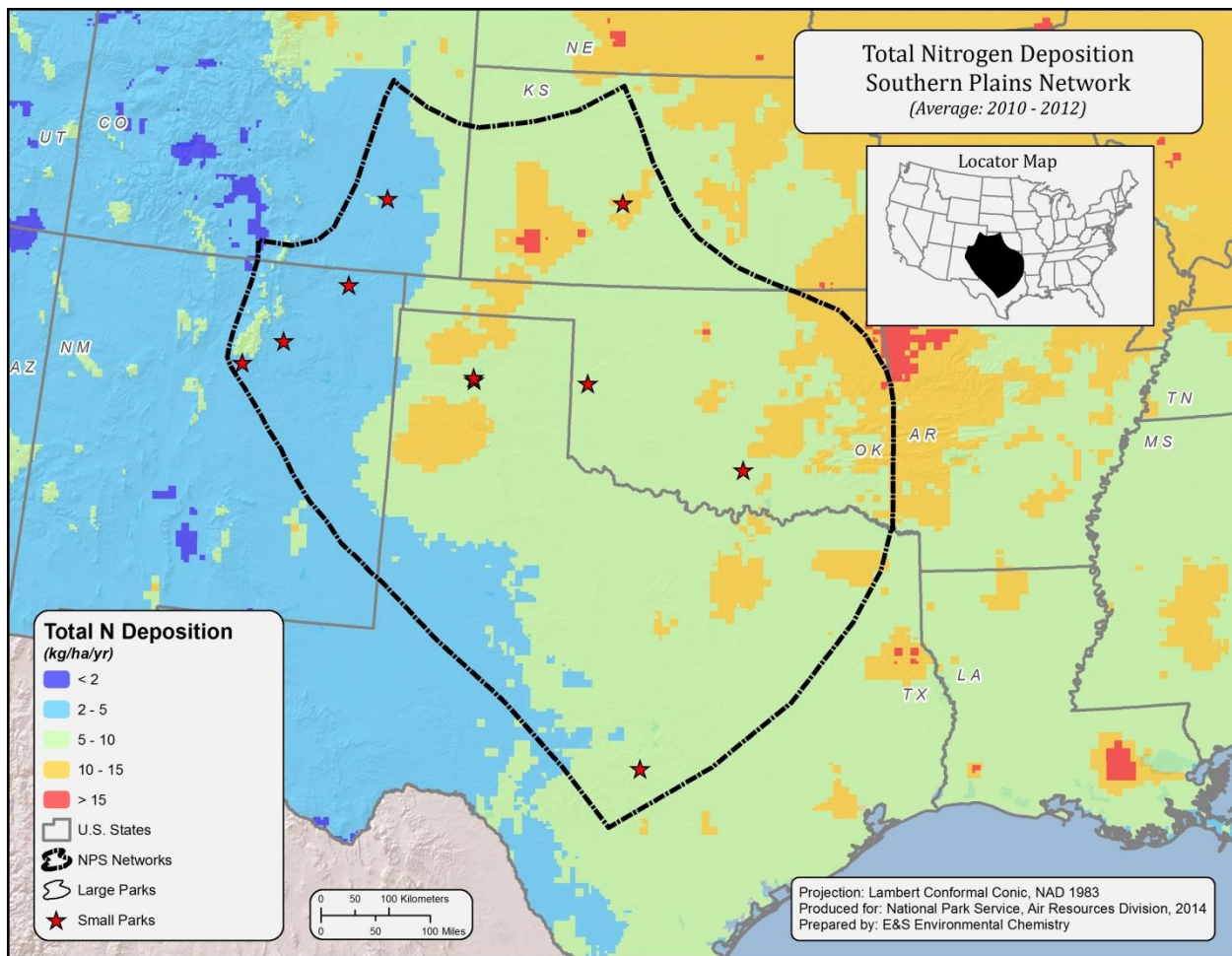
**Map 5.** Total S deposition for the three-year period centered on 2011 in and around SOPN. (Source: Schwede and Lear 2014)



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



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



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

**Table 2.** Estimated I&M park rankings<sup>1</sup> according to risk of acidification impacts on sensitive receptors in the SOPN (Source: Sullivan et al. 2011b); Sand Creek Massacre National Historic Site was not included, as it had not yet been added to the NPS Inventory and Monitoring Program when the rankings were developed.

| Park Name               | Park Code | Estimated Acid Pollutant Exposure | Estimated Ecosystem Sensitivity to Acidification |
|-------------------------|-----------|-----------------------------------|--------------------------------------------------|
| Alibates Flint Quarries | ALFL      | Moderate                          | Low                                              |
| Bent's Old Fort         | BEOL      | Low                               | Very Low                                         |
| Capulin Volcano         | CAVO      | Very Low                          | Low                                              |
| Chickasaw               | CHIC      | Moderate                          | Low                                              |
| Fort Larned             | FOLS      | Moderate                          | Very Low                                         |
| Fort Union              | FOUN      | Very Low                          | Very Low                                         |
| Lake Meredith           | LAMR      | Moderate                          | Moderate                                         |
| Lyndon B. Johnson       | LYJO      | Moderate                          | Very Low                                         |
| Pecos                   | PECO      | Low                               | High                                             |
| Washita Battlefield     | WABA      | Moderate                          | Very 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).

## 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 regions of the Midwest, respectively.

All of the parks in the SOPN except PECO occur within the Great Plains ecoregion. Those to the east, primarily CHIC and LYJO, occur within the tallgrass prairie portion of that ecoregion but do not contain tallgrass prairie vegetation. These grasslands are mainly N-limited or co-limited by N, P and/or water. Many plant species respond rapidly to changing environmental conditions (Clark 2011, Hooper and Johnson 1999, Knapp and Smith 2001, Vitousek and Howarth 1991). It is difficult to ascertain the likely effects of N addition to these ecosystems 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 nitrogen ( $\text{NO}_3^-$ ) increased, and plant species composition shifted 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). Experimental N fertilization of a tallgrass prairie in Texas decreased arthropod richness because of a shift from herbaceous to woody plant species (Hartley et al. 2007). Shortgrass prairie, more characteristic of BEOL, CAVO, FOUN, and PECO, is probably less sensitive to N addition than tallgrass prairie because the former is more likely to experience water limitation (Clark 2011, Hooper and Johnson 1999, Lauenroth et al. 1978).

I&M park rankings were developed in a coarse screening assessment by Sullivan et al. (2011b) for nutrient N Pollutant Exposure and Ecosystem Sensitivity to nutrient N enrichment. Nutrient N Pollutant Exposure was ranked High, in the second highest quintile among parks, for one park in this network, CHIC (Table 3). Other parks were ranked in the lowest (two parks) to middle (five parks) quintile for this theme. Ecosystem Sensitivity to nutrient N enrichment was ranked in the highest quintile for three parks: FOUN, PECO, and WABA, and in the second highest quintile for BEOL and FOLS, but in the middle (four parks) to second lowest (one park) quintile in the other parks (Table

3). 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.

Nitrogen addition to desert grassland on the Colorado Plateau at levels of 10, 20, and 40 kg N/ha/yr over a period of two years affected vegetation biomass (Schwinning et al. 2005). The most conspicuous response was an increase in the biomass of the invasive Russian thistle (*Salsola iberica*) at the highest level of N addition. There was also a shift in plant dominance to favor cool season grasses such as Indian ricegrass (*Oryzopsis hymenoides*) over warm season grasses such as galleta (*Hilaria jamesii*).

Pardo et al. (2011) 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. Data on empirical CL for nutrient N deposition in the parks in the SOPN are limited. Pardo et al. (2011) mainly reported empirical CL values in the Great Plains ecoregion for the protection of mycorrhizal fungi and herbaceous plants and for the prevention of NO<sub>3</sub><sup>-</sup> leaching in drainage waters (Table 4). Reported empirical CL were generally not exceeded by ambient N deposition at the parks in the SOPN for protection of mycorrhizal fungi, lichens, or forests, or for prevention of NO<sub>3</sub><sup>-</sup> leaching. The only exception was estimated CL exceedance for preventing NO<sub>3</sub><sup>-</sup> leaching at CHIC; ambient N deposition at this park was estimated by Pardo et al. (2011) to be slightly higher than the lower limit of the reported CL range for the Great Plains ecoregion. The lower end of the reported range of CL for the protection of herbaceous plants in this ecoregion was 5 kg N/ha/yr. Ambient N deposition reported by Pardo et al. (2011) was higher than that at six parks in the network: ALFL, CHIC, FOLS, LAMR, LYJO, and WABA. This suggests the possibility of CL exceedance for protecting herbaceous plants at these parks.

**Table 3.** Estimated park rankings<sup>1</sup> according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011b); Sand Creek Massacre National Historic Site was not included, as it had not yet been added to the NPS Inventory and Monitoring Program when the rankings were developed.

| Park Name               | Park Code | Estimated Nutrient N<br>Pollutant Exposure | Estimated Ecosystem<br>Sensitivity to Nutrient N<br>Enrichment |
|-------------------------|-----------|--------------------------------------------|----------------------------------------------------------------|
| Alibates Flint Quarries | ALFL      | Moderate                                   | Moderate                                                       |
| Bent's Old Fort         | BEOL      | Low                                        | High                                                           |
| Capulin Volcano         | CAVO      | Very Low                                   | Moderate                                                       |
| Chickasaw               | CHIC      | High                                       | Low                                                            |
| Fort Larned             | FOLS      | Moderate                                   | High                                                           |
| Fort Union              | FOUN      | Very Low                                   | Very High                                                      |
| Lake Meredith           | LAMR      | Moderate                                   | Moderate                                                       |
| Lyndon B. Johnson       | LYJO      | Moderate                                   | Moderate                                                       |
| Pecos                   | PECO      | Low                                        | Very High                                                      |
| Washita Battlefield     | WABA      | Moderate                                   | Very High                                                      |

<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).

**Table 4.** Empirical critical loads for nitrogen in the SOPN, by ecoregion and receptor from Pardo et al. (2011). Ambient N deposition reported by Pardo et al. (2011) is compared to the lowest critical load for a receptor to identify potential exceedance, indicated by graying. A critical load exceedance suggests that the receptor is at increased risk for harmful effects.

| NPS Unit                   | Ecoregion                       | N Deposition<br>(kg N/ha/yr) | Critical Load (kg N/ha/yr) |           |                     |        |                     |
|----------------------------|---------------------------------|------------------------------|----------------------------|-----------|---------------------|--------|---------------------|
|                            |                                 |                              | Mycorrhizal<br>Fungi       | Lichen    | Herbaceous<br>Plant | Forest | Nitrate<br>Leaching |
| Alibates Flint Quarries NM | Great Plains                    | 7.1                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Bents Old Fort NHS         | Great Plains                    | 3.0                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Capulin Volcano NM         | Great Plains                    | 2.5                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Chickasaw NRA              | Great Plains                    | 10.6                         | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Fort Larned NHS            | Great Plains                    | 8.7                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Fort Union NM              | Great Plains                    | 3.3                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Lake Meredith NRA          | Great Plains                    | 7.8                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Lyndon B. Johnson NHP      | Great Plains                    | 8.4                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Pecos NHP                  | Northwestern Forested Mountains | 3.2                          | 5 - 10                     | 2.5 - 7.1 | 4 - 10              | 4 - 17 | 4 - 17              |
| Sand Creek Massacre NHS    | Great Plains                    | 4.4                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |
| Washita Battlefield NHS    | Great Plains                    | 8.5                          | 12 - 12                    | NA        | 5 - 25              | NA     | 10 - 25             |

## 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 in the SOPN 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. One park in this network (ALFL) did not contain any sensitive or bioindicator species. Each of the remaining parks in this network contained at least 2, and as many as 12, O<sub>3</sub>-sensitive and/or bioindicator species.

The W126 (a measure of cumulative O<sub>3</sub> exposure that preferentially weights higher concentrations) and SUM06 (a measure of cumulative exposure that includes only hourly O<sub>3</sub> concentrations over 60 ppb) exposure indices calculated by NPS staff are given in Table 6, along with Kohut's (2007) O<sub>3</sub> risk ranking. The two ranking systems differ. The NPS ranking system (NPS 2010) is a quick assessment of O<sub>3</sub> condition; it simply ranks O<sub>3</sub> exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of the W126 or the SUM06 metrics over a 3-month period. The W126 was classified as Moderate at values between 7 and 13 ppm-hr, as defined by NPS (2010). Values higher than 13 ppm-hr were classified as High, and values lower than 7 ppm-hr were classified as Low. 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).

Kohut's approach constitutes a 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. Ozone condition, as rated by NPS, was Moderate to High in the SOPN parks. Kohut's evaluation of risk to plants ranged from Low to High for the various parks in the network. The only park that was consistently ranked High in all three indices was CHIC.

The results of both ranking systems should be considered when evaluating the potential for O<sub>3</sub> injury to park vegetation in the SOPN. The Kohut approach considered environmental conditions that 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 SOPN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at <https://irma.nps.gov/NPSpecies/Report>.

| Species                                                | Common Name          | Park |      |      |      |      |      |      |      |      |      |
|--------------------------------------------------------|----------------------|------|------|------|------|------|------|------|------|------|------|
|                                                        |                      | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | WABA |
| No Species Present                                     |                      | x    |      |      |      |      |      |      |      |      |      |
| <i>Apios americana</i> *                               | Groundnut            |      |      |      | x    |      |      |      |      |      |      |
| <i>Apocynum androsaemifolium</i> *                     | Spreading dogbane    |      |      | x    |      |      |      |      |      |      |      |
| <i>Apocynum cannabinum</i>                             | Dogbane, Indian hemp |      | x    | x    | x    | x    |      | x    |      | x    | x    |
| <i>Artemisia ludoviciana</i> spp. <i>Ludoviciana</i> * | Silver wormwood      |      |      |      |      |      |      | x    |      |      |      |
| <i>Artemisia ludoviciana</i> *                         | Silver wormwood      |      |      | x    | x    | x    | x    |      |      | x    | x    |
| <i>Asclepias syriaca</i> *                             | Common milkweed      |      |      |      |      | x    |      |      |      |      | x    |
| <i>Cercis canadensis</i> var. <i>canadensis</i> *      | Redbud               |      |      |      |      |      |      |      | x    |      |      |
| <i>Cercis canadensis</i> *                             | Redbud               |      |      |      | x    | x    |      |      |      |      | x    |
| <i>Eupatorium rugosum</i> *                            | White snakeroot      |      |      |      | x    |      |      |      |      |      |      |
| <i>Fraxinus americana</i> *                            | White ash            |      |      |      | x    |      |      |      |      |      |      |
| <i>Fraxinus pennsylvanica</i>                          | Green ash            |      | x    |      | x    | x    |      |      | x    |      |      |
| <i>Parthenocissus quinquefolia</i>                     | Virginia creeper     |      |      |      | x    |      |      |      | x    |      |      |
| <i>Pinus ponderosa</i> *                               | Ponderosa pine       |      |      |      |      |      |      |      |      | x    |      |
| <i>Platanus occidentalis</i> *                         | American sycamore    |      |      |      | x    |      |      |      | x    |      |      |
| <i>Populus tremuloides</i> *                           | Quaking aspen        |      |      | x    |      |      |      |      |      |      |      |
| <i>Prunus serotina</i> *                               | Black cherry         |      |      |      | x    |      |      |      |      |      |      |
| <i>Prunus virginiana</i>                               | Choke cherry         |      |      | x    |      |      |      | x    |      |      |      |
| <i>Rhus copallinum</i>                                 | Winged sumac         |      |      |      | x    |      |      |      |      |      |      |
| <i>Rhus trilobata</i> *                                | Skunkbush            |      |      | x    |      |      | x    |      |      | x    |      |
| <i>Robinia pseudoacacia</i>                            | Black locust         |      |      |      | x    |      |      | x    |      |      |      |
| <i>Salix gooddingii</i>                                | Gooding's willow     |      |      |      |      |      |      |      |      | x    |      |
| <i>Sapium sebiferum</i> *                              | Chinese tallowtree   |      |      |      |      |      |      |      | x    |      |      |

\* Bioindicator species

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

| Park Name               | Park Code | W126           |          | Sum06          |          | Kohut O <sub>3</sub> Risk Ranking |
|-------------------------|-----------|----------------|----------|----------------|----------|-----------------------------------|
|                         |           | Value (ppm-hr) | Ranking  | Value (ppm-hr) | Ranking  |                                   |
| Alibates Flint Quarries | ALFL      | 9.34           | Moderate | 10.74          | Moderate | Low                               |
| Bent's Old Fort         | BEOL      | 17.50          | High     | 24.57          | High     | Low                               |
| Capulin Volcano         | CAVO      | 13.62          | High     | 18.20          | High     | Low                               |
| Chickasaw               | CHIC      | 13.46          | High     | 17.98          | High     | High                              |
| Fort Larned             | FOLS      | 11.12          | Moderate | 14.94          | Moderate | Low                               |
| Fort Union              | FOUN      | 12.29          | Moderate | 15.91          | High     | Low                               |
| Lake Meredith           | LAMR      | 9.36           | Moderate | 10.79          | Moderate | Low                               |
| Lyndon B. Johnson       | LYJO      | 10.24          | Moderate | 12.10          | Moderate | Moderate                          |
| Pecos                   | PECO      | 11.90          | Moderate | 15.06          | High     | Low                               |
| Washita Battlefield     | WABA      | 10.87          | Moderate | 14.15          | Moderate | No Rank                           |

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

# Visibility Degradation

## Natural Background and Ambient Visibility Conditions

The Clean Air Act set a specific goal for visibility protection in Class I areas: “the prevention of any future, and the remedying of any existing, impairment of visibility<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. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic emissions. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network and is typically reported using the haze index deciview<sup>2</sup> (dv).

There were no IMPROVE sites located within any of the I&M parks in the SOPN. However, data are available that are considered to be representative of visibility conditions in three of the parks in this network. 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. The IMPROVE monitor at Cedar Bluff, KS (CEBL1), is representative of FOLS; the Bandelier NM (BAND1) monitor is representative of PECO; and the Ellis, OK (ELLI1), monitor is representative of WABA. 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 (Table 7).

Natural haze levels in PECO were low compared with all other monitored I&M parks (Table 7). Natural haze levels in FOLS and WABA were somewhat higher compared with other I&M parks. Natural haze does not appear to be an important component of visibility in PECO, and is of moderate importance in FOLS and WABA, especially on the 20% clearest and average days.

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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.

**Table 7.** Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008<sup>1</sup>. CEBL1 is at Cedar Bluff, KS; BAND1 is at Bandelier, NM; ELLI1 is at Ellis, OK.

| Park Name                        | Park Code | Site ID | Estimated Natural Haze (dv) |                  |              |
|----------------------------------|-----------|---------|-----------------------------|------------------|--------------|
|                                  |           |         | 20% Clearest Days           | 20% Haziest Days | Average Days |
| Alibates Flint Quarries          | ALFL      | No Site |                             |                  |              |
| Bent's Old Fort                  | BEOL      | No Site |                             |                  |              |
| Capulin Volcano                  | CAVO      | No Site |                             |                  |              |
| Chickasaw                        | CHIC      | No Site |                             |                  |              |
| Fort Larned <sup>2</sup>         | FOLS      | CEBL1   | 2.93                        | 7.50             | 5.09         |
| Fort Union                       | FOUN      | No Site |                             |                  |              |
| Lake Meredith                    | LAMR      | No Site |                             |                  |              |
| Lyndon B. Johnson                | LYJO      | No Site |                             |                  |              |
| Pecos <sup>2</sup>               | PECO      | BAND1   | 1.29                        | 6.26             | 3.37         |
| Washita Battlefield <sup>2</sup> | WABA      | ELLI1   | 3.10                        | 7.33             | 5.11         |

| 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  |
| Alibates Flint Quarries          | ALFL      | No Site |                                                     |         |                  |          |              |          |
| Bent's Old Fort                  | BEOL      | No Site |                                                     |         |                  |          |              |          |
| Capulin Volcano                  | CAVO      | No Site |                                                     |         |                  |          |              |          |
| Chickasaw                        | CHIC      | No Site |                                                     |         |                  |          |              |          |
| Fort Larned <sup>2</sup>         | FOLS      | CEBL1   | 8.74                                                | High    | 21.44            | High     | 14.84        | High     |
| Fort Union                       | FOUN      | No Site |                                                     |         |                  |          |              |          |
| Lake Meredith                    | LAMR      | No Site |                                                     |         |                  |          |              |          |
| Lyndon B. Johnson                | LYJO      | No Site |                                                     |         |                  |          |              |          |
| Pecos <sup>2</sup>               | PECO      | BAND1   | 4.41                                                | Low     | 11.74            | Very Low | 7.85         | Very Low |
| Washita Battlefield <sup>2</sup> | WABA      | ELLI1   | 9.01                                                | High    | 21.40            | High     | 15.01        | High     |

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

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

Current visibility estimates reflect current pollution levels and were used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and air pollution. Rankings range from very low haze (very good visibility) to very high haze (very poor visibility). Only parks with on-site 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.

Ambient haze levels were relatively low in PECO compared with all of the monitored I&M parks. PECO was ranked Low for measured ambient haze on the 20% clearest days and Very Low for the 20% haziest days and average days. In FOLS and WABA, however, the ranking was High for all groups (20% clearest, average, and 20% haziest days). Ambient haze is an important concern in these latter two parks.

IMPROVE data allow estimation of visual range (VR). Data indicate that at the BAND1 monitor (representative of PECO), pollution has reduced average VR from 170 to 95 miles (274 to 153 km).

On the haziest days, VR has been reduced from 120 to 60 miles (193 to 97 km). Severe haze episodes occasionally reduce visibility to 4 miles (6 km). At the ELLI1 monitor, representative of WABA, pollution has reduced average VR from 140 to 45 miles (225 to 72 km). On the haziest days, VR has been reduced from 120 to 25 miles (193 to 40 km). Severe haze episodes occasionally reduce visibility to 9 miles (14 km). At the CEBL1 monitor, representative of FOLS, pollution has reduced average VR from 140 to 45 miles (225 to 72 km). On the haziest days, VR has been reduced from 110 to 25 miles (177 to 40 km). Severe haze episodes occasionally reduce visibility to 12 miles (19 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  $\text{SO}_2$  emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from  $\text{NO}_x$  emissions from combustion sources including vehicles, power plants, industry, and fires. Organic compounds are emitted from a variety of both natural (biogenic) and anthropogenic sources, including agriculture, industry, and fires. 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 monitored parks in the SOPN. Sulfate is the largest contributor to haze in all three of the parks, for all groups (20% clearest, 20% haziest, and average days). In FOLS, the contribution from  $\text{SO}_4^{2-}$  is 35.8% on the 20% clearest days, which increases to 40.1% on the 20% haziest days. In PECO, the contribution of  $\text{SO}_4^{2-}$  is higher on the 20% clearest days than on the 20% haziest days (34.3% and 31.3%, respectively). WABA has the highest contribution from  $\text{SO}_4^{2-}$ : 46.4% on the 20% haziest days. Nitrates, organics, and coarse mass also contribute substantially to haze in these monitored parks in the SOPN. Nitrate plays a particularly important role on the 20% haziest days in FOLS (34.5% of total particulate light extinction [ $b_{\text{ext}}$ ]) and WABA (28.5% of  $b_{\text{ext}}$ ). In contrast,  $\text{NO}_3^-$  is of relatively minor importance in PECO (9% on the 20% clearest days to 10.4% on the 20% haziest days).

### **Trends in Visibility**

Available haze monitoring data are shown in Figure 2 for the period of record at each park. In general, haze levels appear to be decreasing at each monitored park, especially PECO, which exhibited about a 2 dv decrease in haze on the 20% clearest, 20% haziest, and average days over the past decade.

During the period 1990 to 1999, atmospheric  $\text{SO}_2$  concentrations at IMPROVE and Clean Air Status and Trends Network (CASTNET) monitoring sites decreased in the northeastern United States by about 28% and the West by about 15%; there was little change in the Southeast and a 15% increase over Texas, New Mexico, and Colorado (Malm et al. 2002).

## **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). There are no Class I area parks in the SOPN which would fall under the RHR. Nevertheless, SOPN parks will benefit from emissions controls that target visibility improvement in Class I areas.

Progress to date in meeting the national visibility goal is illustrated in Figure 3 using a uniform rate of progress glideslope. The data suggest that haze levels on the 20% haziest days at the monitored parks are probably decreasing sufficiently to date in order to comply with the glideslope for visibility improvement in Class I areas required by the RHR. Additional data are needed to determine the rate of progress towards eventual compliance with the RHR in Class I areas near SOPN.

## Toxic Airborne Contaminants

Airborne toxics, including mercury (Hg) and other heavy metals, can accumulate in food webs, reaching toxic levels in top predators. The Texas Department of State Health Services has issued a fish consumption advisory for walleye in Lake Meredith because of elevated levels of Hg (<http://www.tpwd.state.tx.us/regulations/outdoor-annual/fishing/general-rules-regulations/fish-consumption-bans-and-advisories>). Further information on the potential impacts of air toxics on sensitive resources in the SOPN is generally not available.

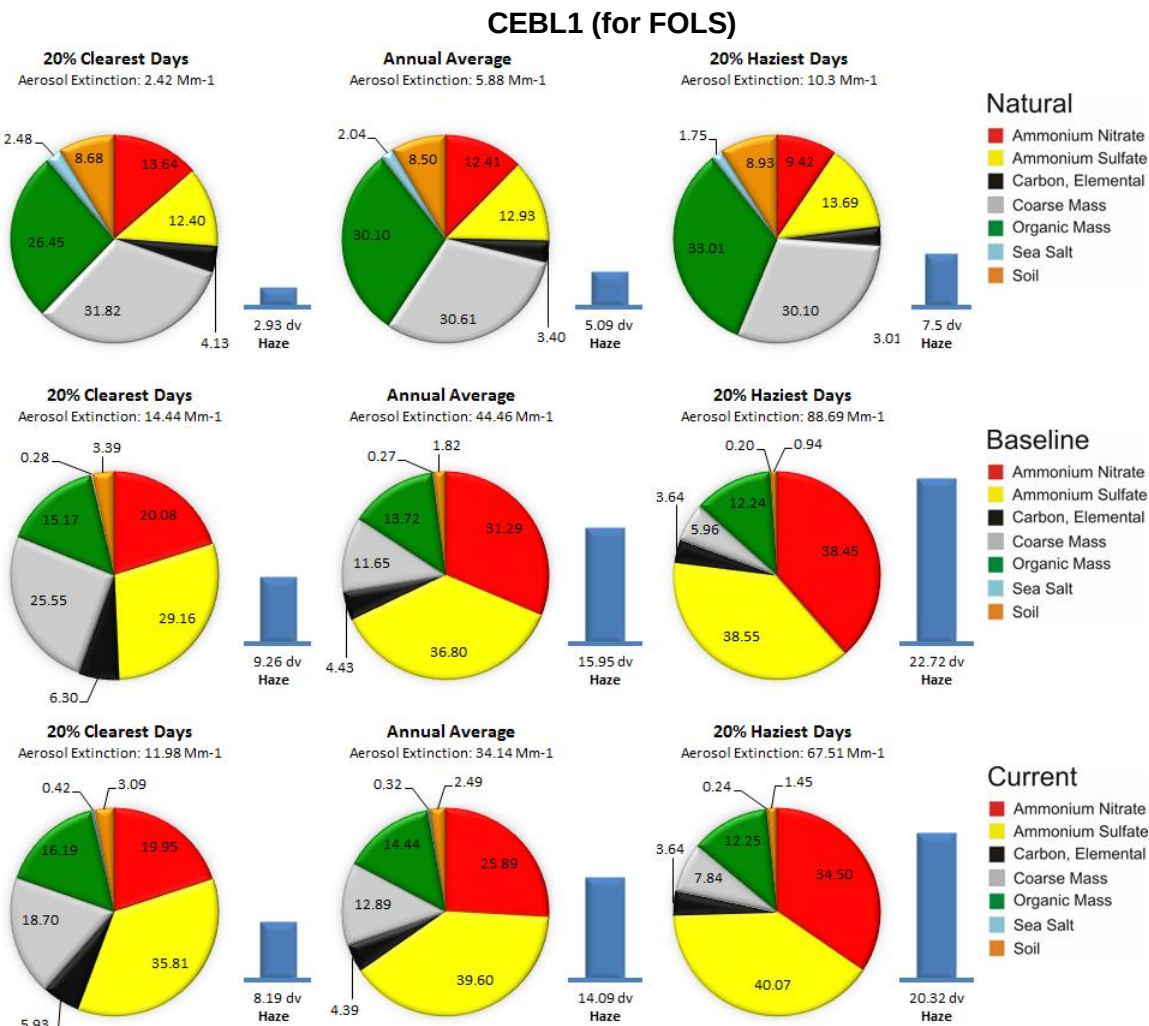


**Figure 1a.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for FOLS, PECO, and WABA. Data for all three of these parks were taken from representative IMPROVE sites. FOLS and WABA have no valid, measured or substituted data for the years 2000-2002. Data Source: NPS-ARD

## BAND1 (for PECO)

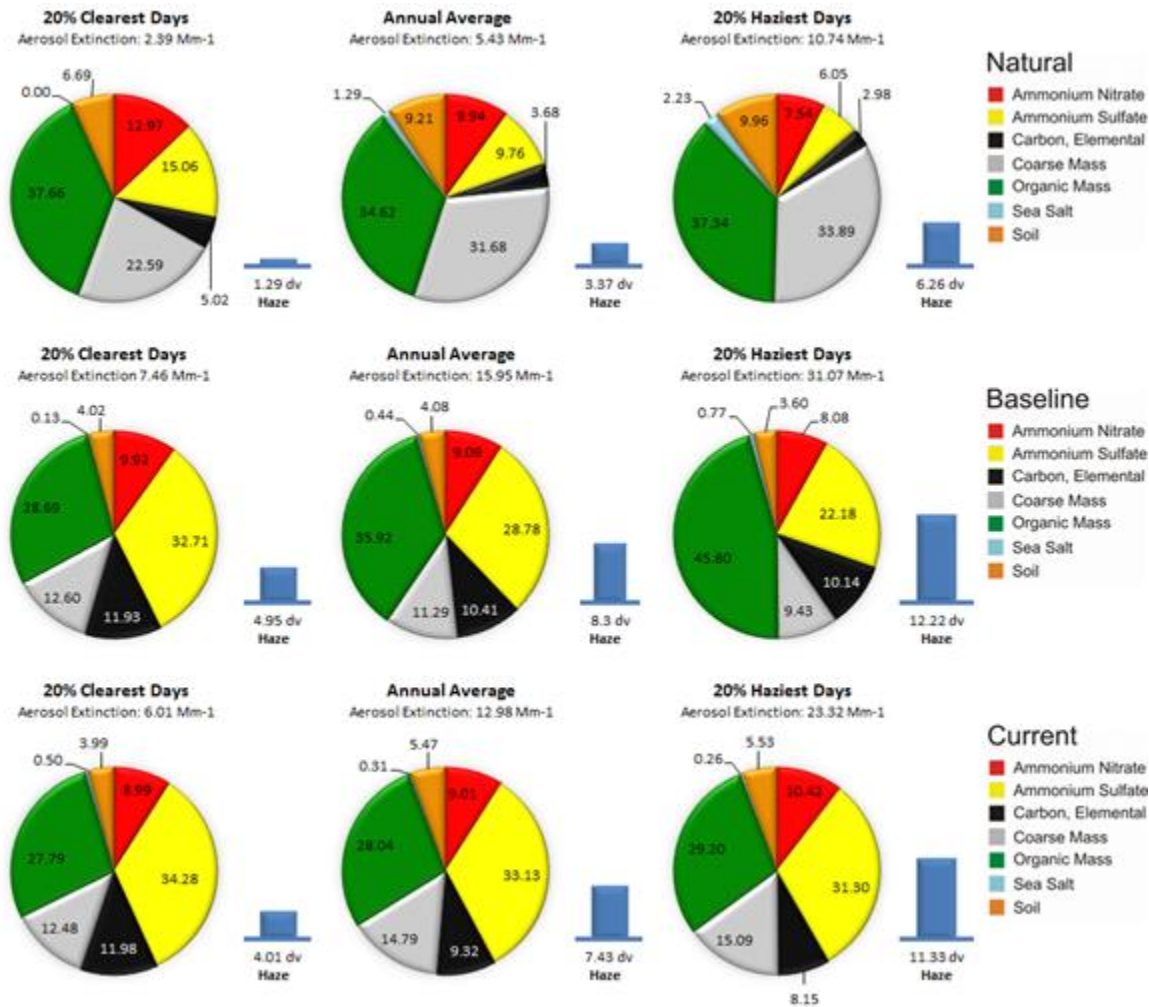


**Figure 1b.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for FOLS, PECO, and WABA. Data for all three of these parks were taken from representative IMPROVE sites. FOLS and WABA have no valid, measured or substituted data for the years 2000-2002. Data Source: NPS-ARD

### ELLI1 (for WABA)

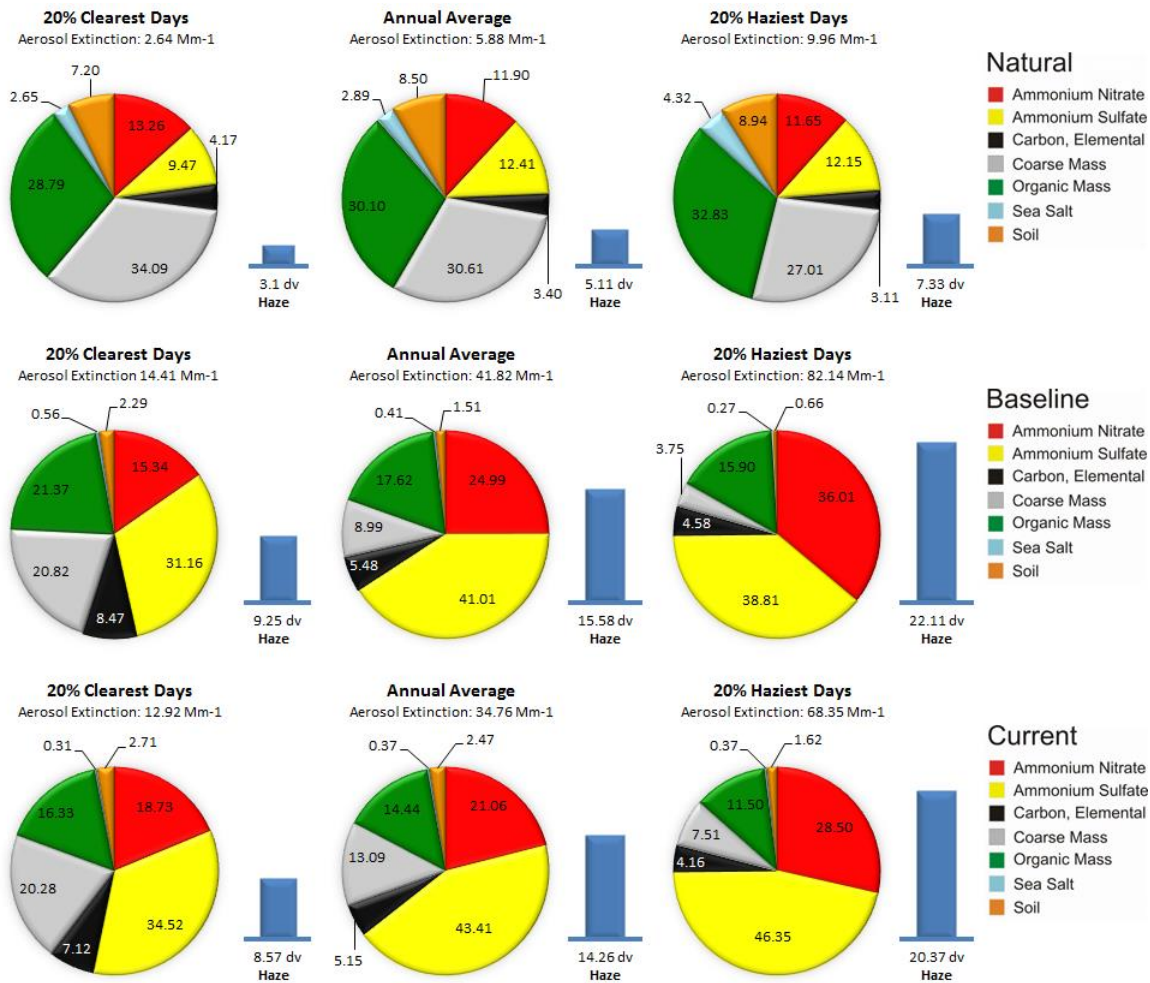


**Figure 1c.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for FOLS, PECO, and WABA. Data for all three of these parks were taken from representative IMPROVE sites. FOLS and WABA have no valid, measured or substituted data for the years 2000-2002. Data Source: NPS-ARD

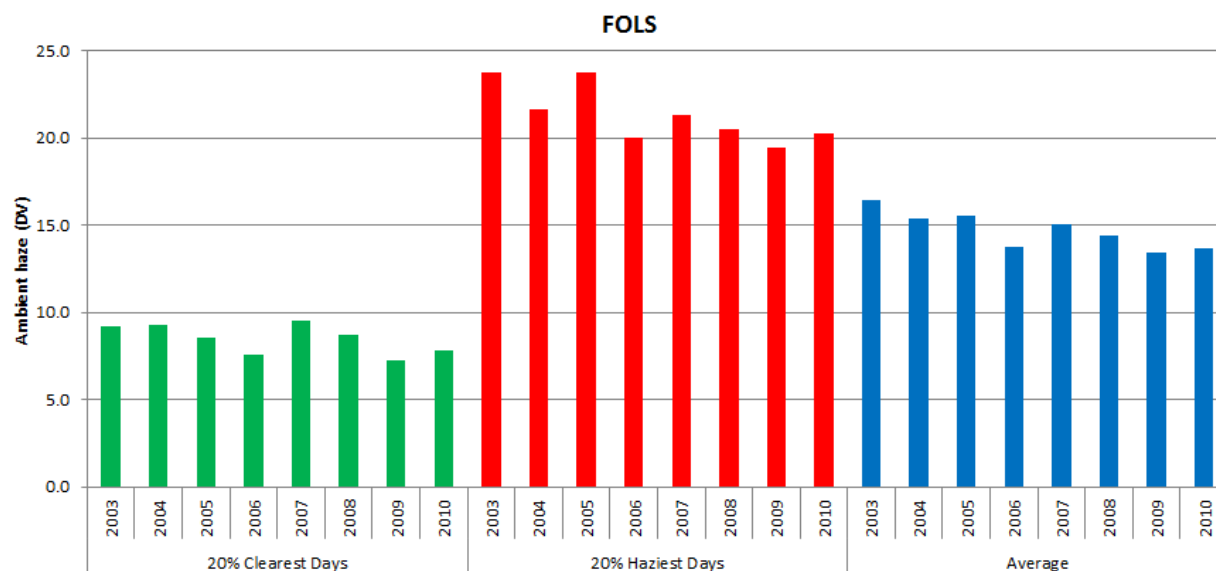


**Figure 2a.** Trends in ambient haze levels at FOLS, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all three of these parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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)

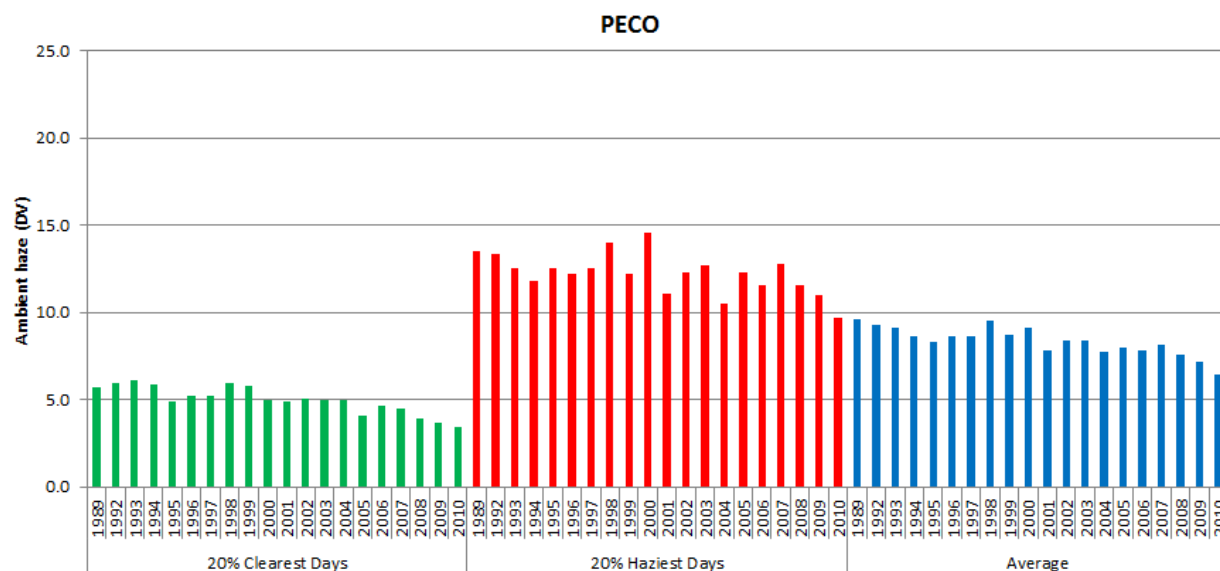


**Figure 2b.** Trends in ambient haze levels at PECO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all three of these parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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)

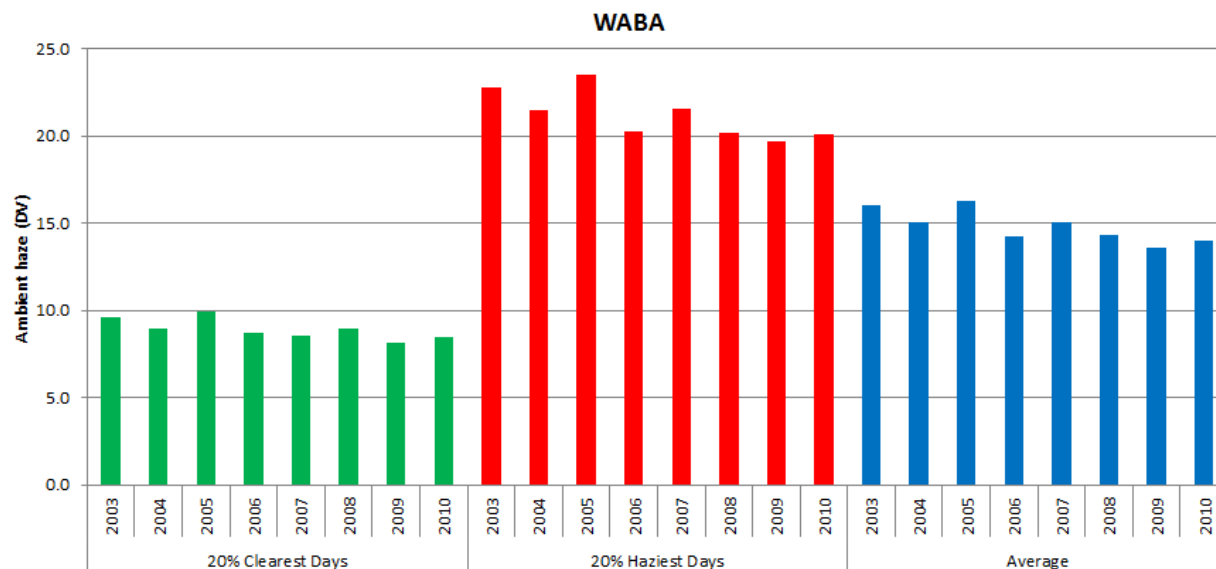


**Figure 2c.** Trends in ambient haze levels at WABA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for all three of these parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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)

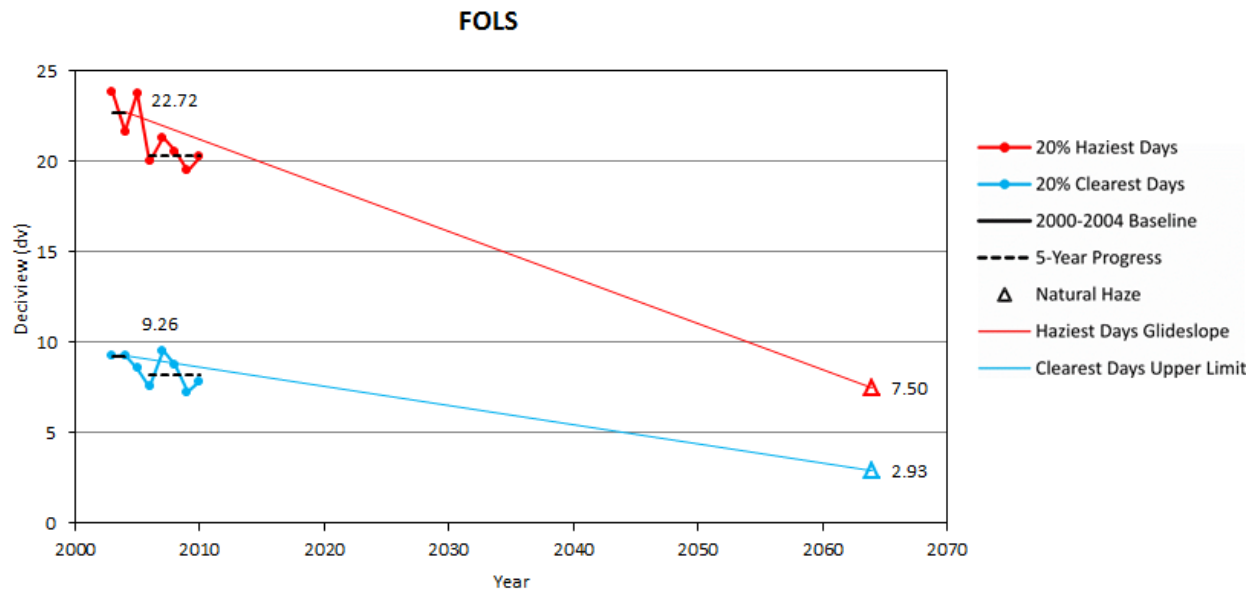


**Figure 3a.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in FOLS. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for all three parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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)

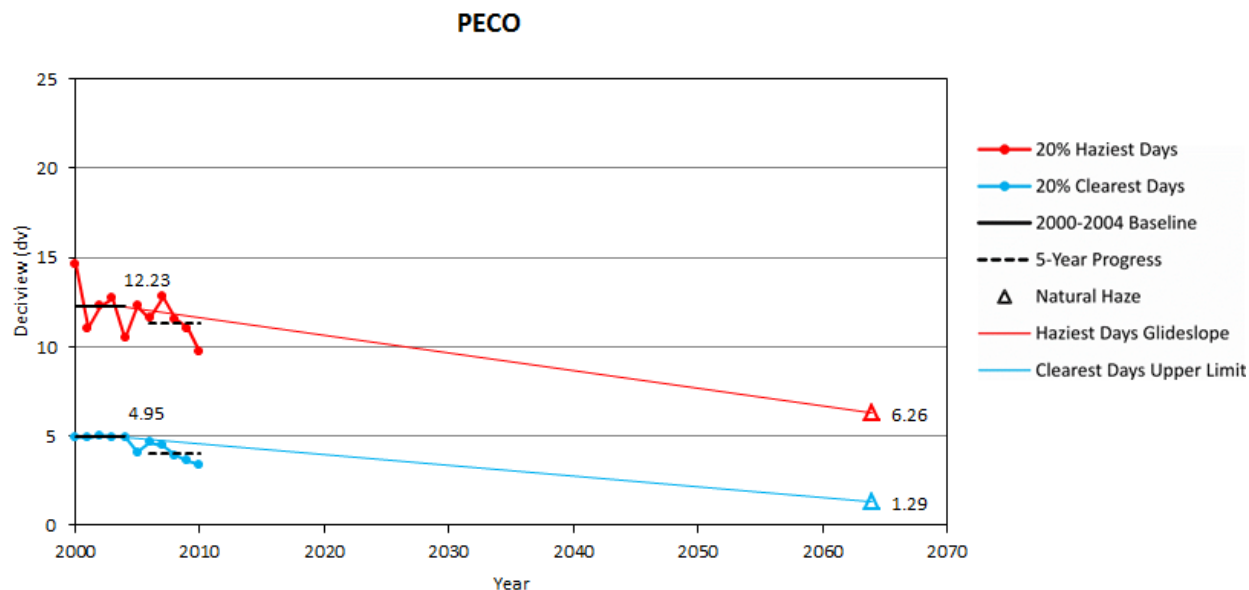


**Figure 3b.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in PECO. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for all three parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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 3c.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in WABA. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for all three parks were taken from representative IMPROVE sites (CEBL1 for FOLS, BAND1 for PECO, ELLI1 for WABA). FOLS and WABA 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)

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NPS 960/132352, April 2016

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