



Air Quality Related Values (AQRVs) for Northern Great Plains Network (NGPN) Parks

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

Natural Resource Report NPS/NGPN/NRR—2016/1178



ON THE COVER

Photograph of air quality related values within various National Park units. Wildflowers, clear views, aquatic species, and lichens may all be threatened by air pollution.

Photographs courtesy of the National Park Service

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Summary

This report describes the Air Quality Related Values (AQRVs) of the Northern Great Plains Network (NGPN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. This report also describes air pollutant emissions and air quality in NGPN, 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 ozone (O_3); haze-causing particles; and airborne toxics.

The 13 parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Agate Fossil Beds National Monument (AGFO), Badlands National Park (BADL), Devils Tower National Monument (DETO), Fort Laramie National Historic Site (FOLA), Fort Union Trading Post National Historic Site (FOUS), Jewel Cave National Monument (JECA), Knife River Indian Villages National Historic Site (KNRI), Missouri National Recreational River (MNRR), Mount Rushmore National Memorial (MORU), Niobrara National Scenic River (NIOB), Scotts Bluff National Monument (SCBL), Theodore Roosevelt National Park (THRO), and Wind Cave National Park (WICA). Three of the parks (THRO, BADL, and WICA) are Class I areas, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA).

In general, air quality in the NGPN is considerably better than in most other areas of the United States. Nevertheless, there have been several large coal-burning power plants in North Dakota, Nebraska, and eastern Montana, and emissions from those facilities may impact NGPN parks to some degree. Several of the power plants are located very close to KNRI. Other network parks are more distant from large emissions sources. The parks are relatively remote from cities and associated air pollution sources, and there are few urban centers of any magnitude near this network, although Denver is close to the southwestern network boundary. Recent and future increases in oil and gas (O&G) development in eastern Montana, western North Dakota, and surrounding states may increase air pollution in the network area by an unknown, but potentially substantial, amount.

County-level sulfur dioxide (SO_2) emissions in 2012 were low in the NGPN region, except in the area along the Missouri River near KNRI, where several power plants emitted collectively around 80,000 tons per year (tpy) of SO_2 . Emissions were similar in magnitude in 2002, the emissions year used for two NPS risk assessments (Sullivan et al. 2011a, Sullivan et al. 2011b) referred to in this report. Annual county-level N emissions were higher than SO_2 emissions, and in the area near KNRI, power plant N oxides (NO_x) emissions were around 46,000 tpy in 2012. These emissions levels were lower than the 72,000 tpy of NO_x reported in 2002, due to more recent combustion controls. Power plant emissions of S and N are expected to further decrease in the future because of requirements of the Regional Haze Rule (RHR), intended to reduce haze and improve visibility in Class I areas.

Near THRO, hundreds of small oil wells adjacent to the park emit both N and S. While the emissions per well may not be large, the combined emissions of N from all the wells may be substantial. Some wells are very close to park boundaries where there could be acute or chronic impacts to vegetation and visibility on a local basis. The cumulative effects of the numerous small N sources collectively

constitute an important resource concern at THRO and elsewhere in NGPN, but emissions from these small, but very numerous, sources are not well quantified. Agricultural activities are also a source of N emissions, in the form of ammonia. Agricultural emissions in and near NGPN are also not well quantified.

Sulfur and N pollutants can cause acidification of streams, lakes, and soils. Surface waters in NGPN are likely well buffered against acidic inputs because they generally contain sufficient amounts of base cations, like calcium (Ca^{2+}) and magnesium (Mg^{2+}), that buffer deposition acidity. At this time, neither aquatic nor terrestrial effects from acidic deposition are expected to be important in this network.

Nitrogen pollutants can cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species diversity. Nitrogen deposition is relatively high in the southeastern portions of the network region, and vegetation in several of the parks may be at risk. Grasslands are known to be sensitive to N enrichment. Much of the northern Great Plains is covered by mixed-grass prairie or shortgrass prairie, with tallgrass species generally more common on microsites with higher soil moisture. The mixed-grass prairie of BADL is a good example of the highly valued prairie ecosystems that have largely been extirpated from their former range. Grasslands of the Great Plains have experienced invasions of non-native grasses and woody plant species that appear to be driven, at least in part, by N enrichment of soil and fire exclusion (Köchy and Wilson 2001, Tilman et al. 1997). In addition, recent studies suggest that low productivity, sparse badland shrublands may be even more sensitive than grasslands to N enrichment.

Ozone pollution can reduce plant growth and cause visible injury to foliage. Several O_3 -sensitive plant species, including ponderosa pine (*Pinus ponderosa*), are present in most parks in this network. Ozone exposure indices, including the W126 and SUM06, are low in most network parks, SCBL being the exception. Generally low soil moisture levels during the O_3 season (summer) likely preclude O_3 injury to plants, but plants have not been examined for O_3 injury in NGPN. Ozone exposure may become a more important concern in the future in response to local and regional NO_x emissions from continued O&G development.

Particulate pollution can cause haze, reducing visibility. Visibility is a key AQRV in this network, and a source of concern because of the magnificent vistas in and around the NGPN parks. Some parks in the network have experienced moderately impaired visibility. The majority of haze in all three monitored parks is attributable to SO_4^{2-} derived from SO_2 emissions, NO_3^- from NO_x emissions, coarse mass (e.g., soil), and organics. Increased O&G activities in the region are likely to increase haze levels in the future.

Background

There are three parks in Northern Great Plains Network (NGPN) that are larger than 100 square miles: Badlands National Park (BADL), Missouri National Recreational River (MNRR), and Theodore Roosevelt National Park (THRO). 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.

In addition, there are 10 smaller parks: Agate Fossil Beds National Monument (AGFO), Devils Tower National Monument (DETO), Fort Laramie National Historic Site (FOLA), Fort Union Trading Post National Historic Site (FOUS), Jewel Cave National Monument (JECA), KNRI, Mount Rushmore National Memorial (MORU), Niobrara National Scenic River (NIOB), Scotts Bluff National Monument (SCBL), and Wind Cave National Park (WICA). Three of the parks (THRO, BADL, and WICA) are Class I areas, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA). There are relatively few urban centers of any magnitude within the network area, although Denver is close to the southwestern network boundary. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people. Population centers are usually associated with air pollutant emissions from both stationary sources (e.g., smokestacks) and mobile sources (on- and off-road vehicles). Power plants contribute an important emissions source type in this network.

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 tall grass prairie to the east. These prairie environments now roughly correspond with the western rangelands, wheat belt, and corn/soybean region of the Midwest, respectively. Many prairie plant species are presumed sensitive to nutrient N enrichment impacts, which can cause loss of rare species and biodiversity. These grasslands evolved under relatively low levels of N inputs, and increased N from atmospheric deposition can preferentially favor some species at the expense of others. The levels of N deposition at which such changes occur are poorly known.

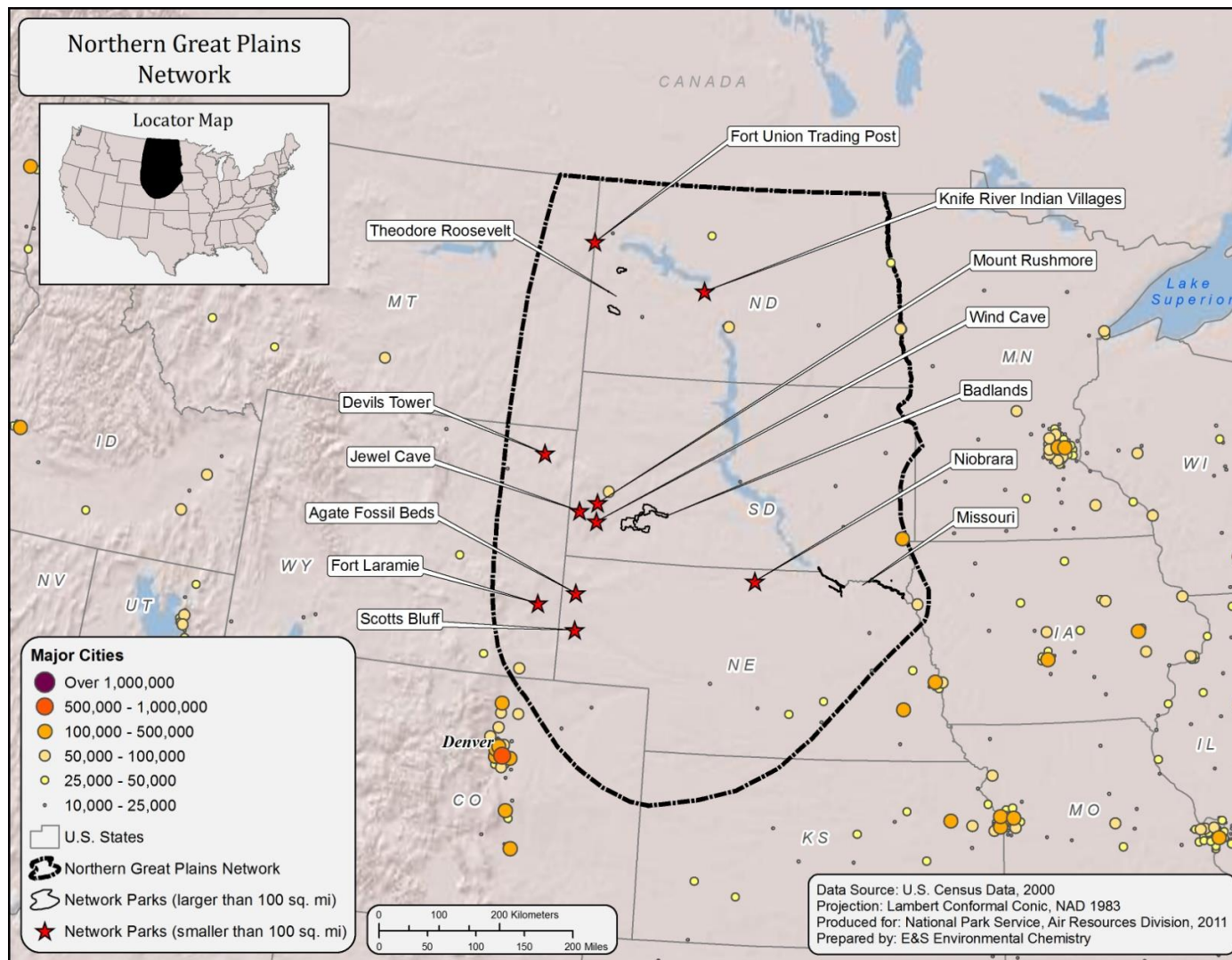
Atmospheric Emissions and Deposition

Emissions

In general, air quality in the northern Great Plains region is considerably better than in most other areas of the continental United States. This is primarily due to the absence of high levels of fossil fuel combustion commonly associated with metropolitan areas. The parks are relatively remote from cities and most large emissions sources. In addition, because air stagnation and inversions are infrequent, atmospheric conditions are not highly conducive to the formation and accumulation of O₃. Although current air quality is good in most areas of NGPN, some AQRVs may be affected by relatively low levels of pollution, and some pollutants may have potential impacts on national park resources in both the short- and long-term future (Peterson et al. 1998). Among the most significant

short-term threats is continued O&G development, which will likely contribute to higher N emissions and deposition in the future.

Previous NPS air pollution risk assessments were conducted using 2002 emissions data. Comparisons with 2012 emissions indicate that SO₂ emissions in this network region have not appreciably changed from 2002 levels. Nitrogen oxide emissions from large power plants have decreased somewhat, but these decreases may have been offset in part by increases in NO_x emissions from O&G development.



Map 1. Map showing network boundary and locations of parks and population centers with more than 10,000 people around NGPN.

County-level SO₂ emissions in 2002 were low in the NGPN region, in most areas less than 1 ton per square mile per year (Sullivan et al. 2011b). There were scattered areas of higher SO₂ emissions within the network, including the region around KNRI, where there are several large coal-burning power plants that emit significant quantities of SO₂. Other than power plants in North Dakota and Nebraska, point sources of SO₂ were few, and most emitted less than 5,000 tons of SO₂ per year. Annual county-level N emissions were higher than SO₂ emissions, ranging from less than 1 ton per square mile in some portions of the NGPN region to between 5 and 20 tons per square mile in others (Sullivan et al. 2011b). In general, annual county N emissions were less than 5 tons per square mile throughout most of the network region. There were several point sources of oxidized N, and one point source of reduced N, that were larger than about 2,000 tpy. Despite the relatively low levels of ambient S and N emissions in NGPN, there is concern that emissions may increase in the future, mainly in response to O&G development. In the central part of the United States from Texas to North Dakota, SO₂ emissions increased during the 1990s, with statistically significant increases in Colorado (11%), Wyoming (31%), and North Dakota (35%; Malm et al. 2002). Nevertheless, most large SO₂ sources will be installing emissions controls in the near future, decreasing SO₂ emissions from these sources in the region.

At THRO and FOUS, hundreds of small oil wells adjacent to the parks emit N and to a lesser extent S (ENVIRON 2012). While the emissions per well are not large, the combined emissions of all the wells may be substantial. Oil production from the Bakken formation in North Dakota and Montana increased from just over 2,000 barrels per day in 2000 to approximately 500,000 barrels per day in 2012. Natural gas production has also increased substantially (U.S. GAO 2012). Furthermore, some wells are very close to national park boundaries where there could be impacts to vegetation from nutrient N addition and/or O₃ exposure (catalyzed by atmospheric NO_x) on a local basis. The cumulative effects of the numerous small emissions sources constitute a significant concern at THRO. Additional SO₂, NO_x, and volatile organic carbon are potentially transported into THRO from industrial and electric-utility facilities in Montana. Although CASTNet data from 1999 to 2011 do not show a significant change in ambient atmospheric NO₃⁻ concentrations (from NO_x emissions) at THRO (AMEC 2013), it is possible that the significant decreases in NO_x emissions from large power plants in North Dakota observed from 2002 to 2012 have offset increases in NO_x from O&G production. In addition, O&G development and associated NO_x emissions are expected to increase substantially in the near future in this region.

The ongoing West-Wide Jump Start Air Quality Modeling Study (WestJump) provides data that are relevant to N emissions near NGPN parks. It is a multifaceted effort to develop county level emissions estimates by source type and to conduct air quality modeling in the western United States (Western Regional Air Partnership [WRAP] 2013). The WestJump study is managed by the Western Governors' Association as part of WRAP. It was designed initially to reflect year 2008 emissions and air quality conditions. The WestJump emissions database was developed in stages, including:

1. emissions projections to 2008, using the 2006 baseline WRAP Phase III project inventories for the Rocky Mountain region, including the Denver-Julesburg (CO), Piceance (CO), Uinta (UT), North San Juan (CO), South San Juan (NM), Wind River

- (WY), Powder River (WY), Greater Green River (WY), and Williston (MT and ND; data compilation pending) basins;
2. development of an independent 2008 Permian Basin (NM and TX) emissions inventory; and
 3. incorporation of emissions reported by states to EPA's 2008 National Emissions Inventory (NEI) for the remainder of the United States.

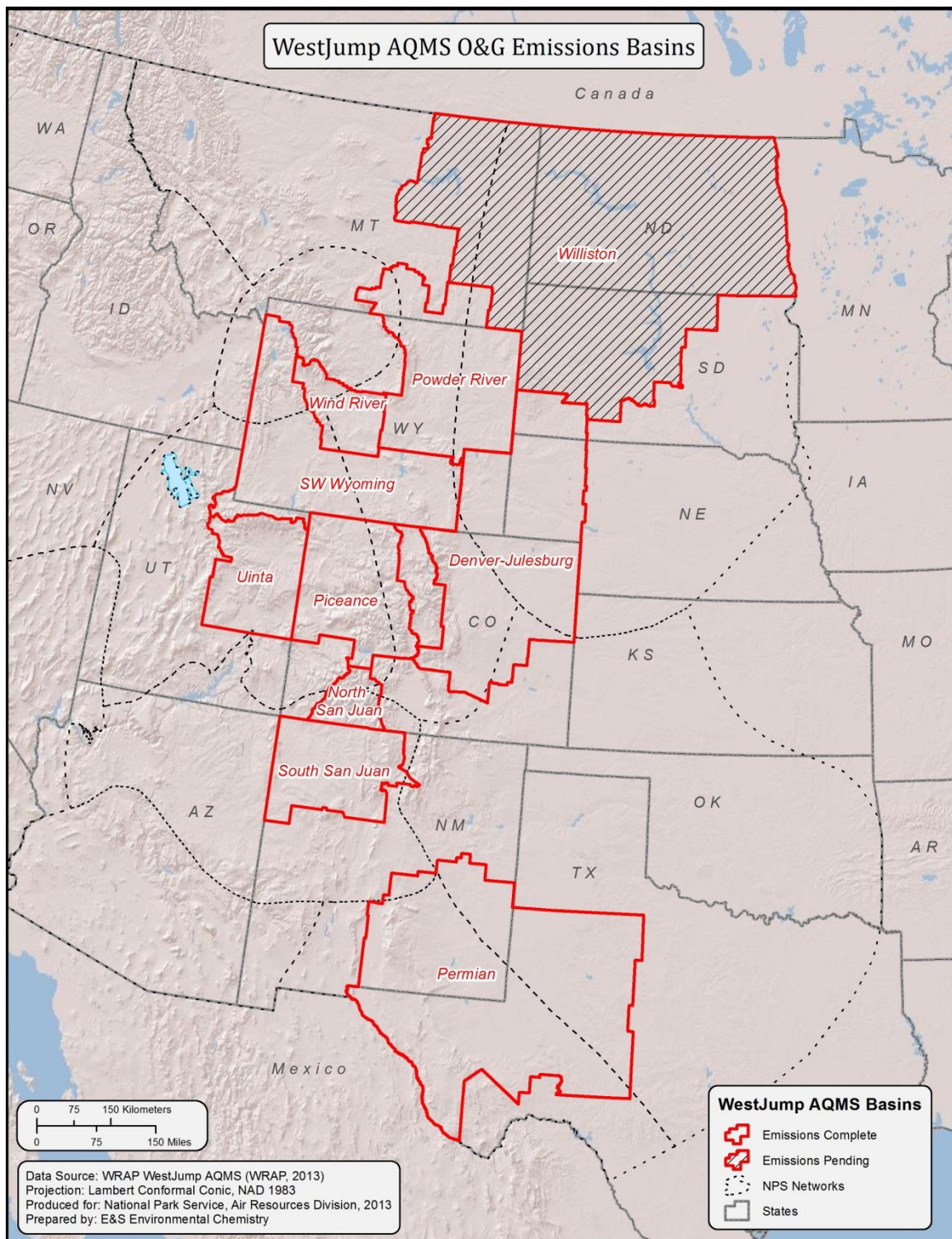
Prior to the WestJump study, WRAP developed an emissions inventory of all criteria air pollutants associated with O&G exploration and production activities for the year 2006 (WRAP Phase III; <http://www.wrapair2.org/PhaseIII.aspx>). This inventory only included the O&G emissions attributable to exploration and production; O&G-related emissions associated with activities such as transmission, distribution, storage and/or refining were categorized as other "area" and "point source" types. The baseline WRAP Phase III O&G inventory for 2006 represents the most comprehensive and complete O&G inventory currently available for the WRAP study region, which includes portions of Colorado, Montana, New Mexico, North Dakota, Utah and Wyoming. Emissions projections for 2008 have been constructed for much, but not all, of the WestJump region (Map 2); projections for the Williston Basin in North Dakota and Montana are in progress. Emissions estimates for the years since 2008 have not yet been generated at the time of this writing.

Oil and gas emissions were based on version 2.0 of the 2008 NEI database for areas not covered by WRAP Phase III Basins included in the WestJump study. Emissions from all sources unrelated to O&G activity were also obtained for this report from the NEI to generate estimates of total emissions for each county.

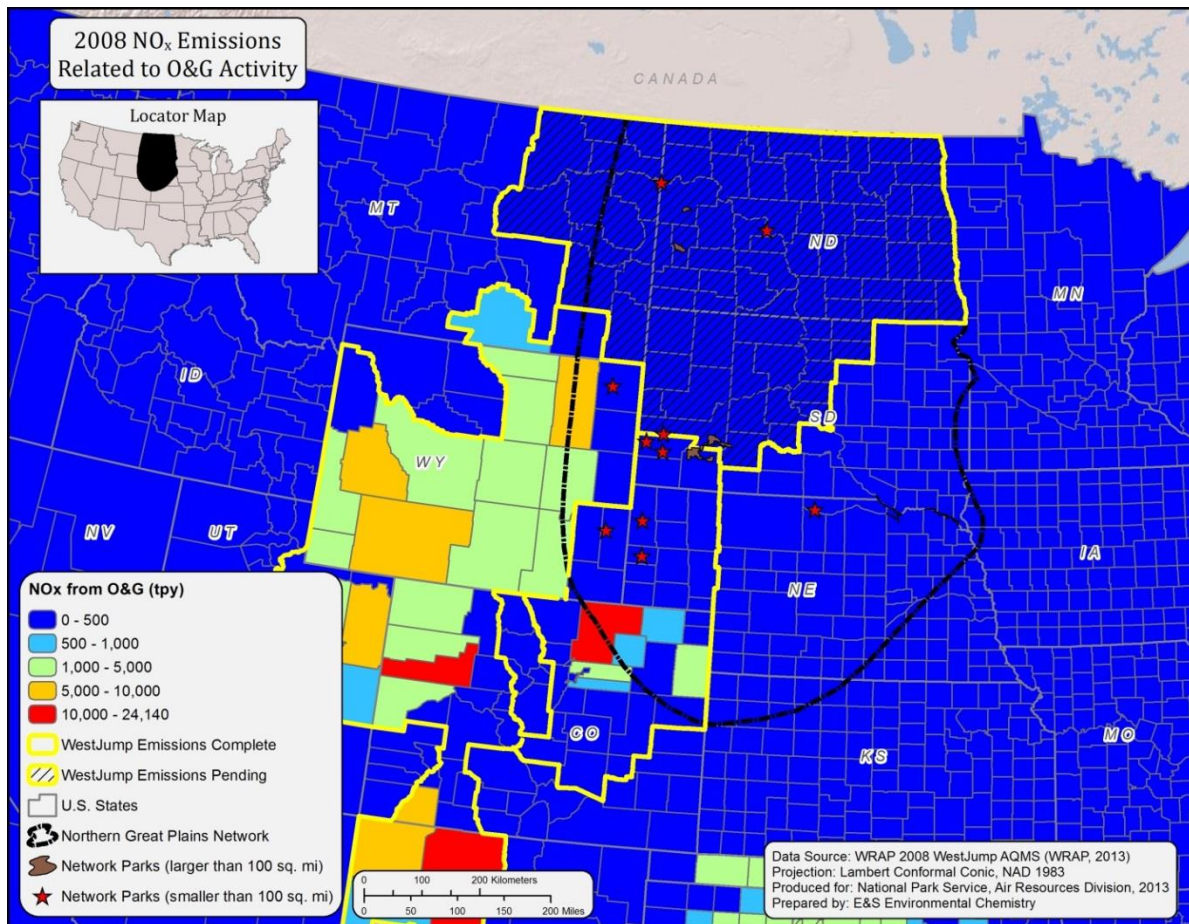
Although the WestJump inventory represents progress in understanding emissions from O&G development, up to this point it only represents 2006 and 2008 emissions and does not capture effects from the accelerated energy development that has occurred throughout the region in the interim. For most of the NGPN region, WestJump emissions estimates have not yet been constructed. However, estimates are available for a small part of the southwestern portion of the network region and lands to the west and southwest of the network boundary (Map 3).

The fraction of total NO_x emissions attributable to O&G exploration was between 5 and 50% in much of the western Wyoming portion of the WestJump study region (Map 4). Most counties in this area contributed between 1,000 and 5,000 tpy of NO_x emissions (Map 3). The highest county NO_x emission rate (approx. 13,800 tpy) that occurs in the southwest portion of the NGPN region is of similar magnitude to the rates of total NO_x emissions that occur in many of the large energy producing and densely populated counties east of the Mississippi River.

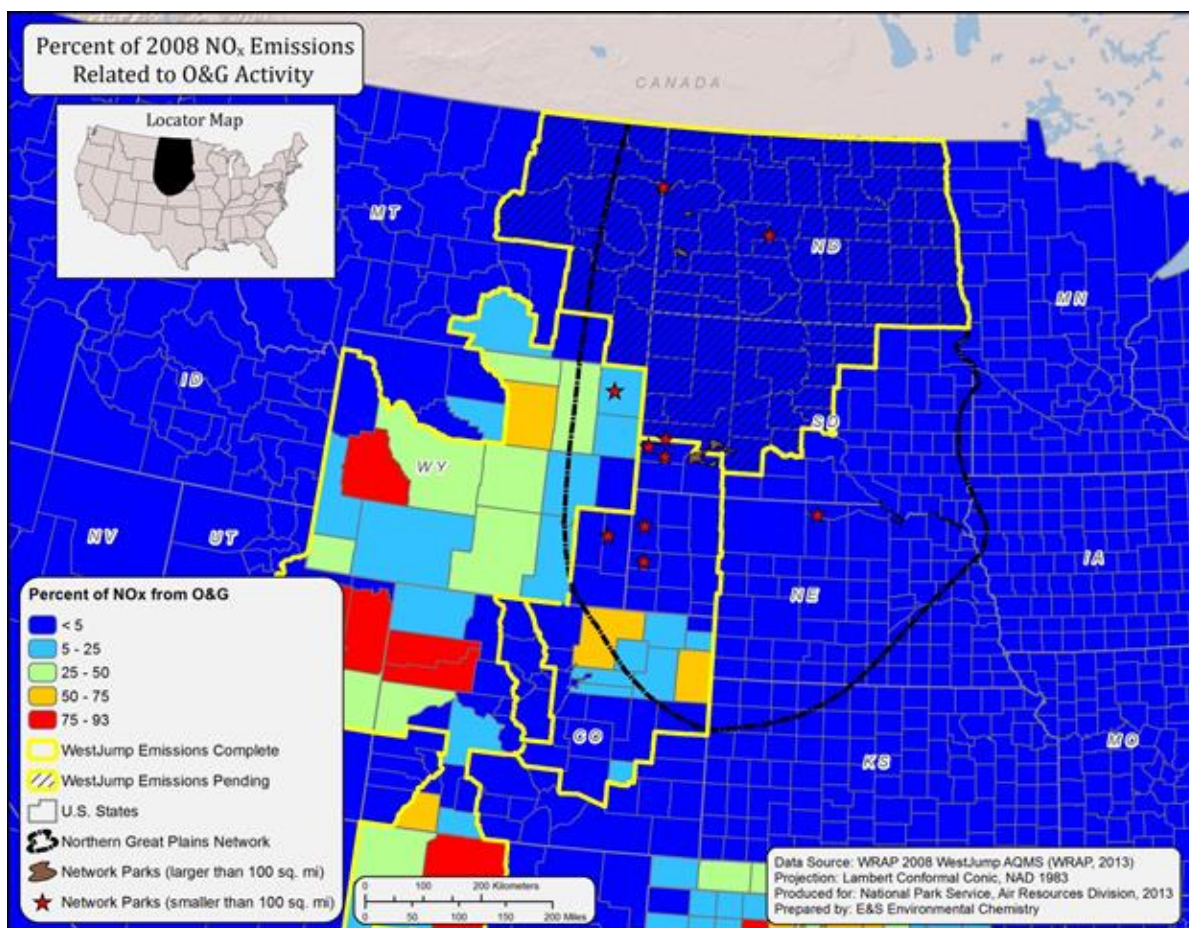
It is important to note that the magnitude of NO_x emissions associated with O&G exploration and production shown in Map 3 do not represent the accelerated growth in O&G exploration and production that has occurred within this region in recent years. In view of the high earlier (through 2008) estimates of O&G NO_x emissions for counties in and near the southwestern edge of NGPN, and the documented recent and ongoing increase in O&G production activities in and near NGPN, it will become increasingly important to track NO_x emissions levels in this region in the future.



Map 2. Basins included in the 2008 WestJump Air Quality Modeling Study. Emissions estimates for the Williston Basin are pending.



Map 3. Total NO_x emissions associated with O&G exploration and production by county included in the 2008 WestJump Air Quality Modeling Study. Note: O&G emissions depicted on this map within the Williston Basin are based on permitted sources represented in the 2008 National Emissions Inventory (NEI) database. Detailed emissions data for all sources related to O&G production and exploration are pending.



Map 4. Percent of total NO_x emissions associated with O&G exploration and production by county for those counties located near NGPN that were included in the 2008 WestJump Air Quality Modeling Study. Note: O&G emissions within the Williston Basin depicted on this map are based on permitted sources represented in the 2008 NEI database. Detailed emissions data for all sources related to O&G production and exploration are pending. Note that emissions estimates for areas outside of the WestJump boundary do not include detailed O&G related NO_x emissions.

Deposition

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, N₂O₅, NO, NO₂, HONO, and organic NO₃. 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 and N deposition levels have increased at some NGPN parks and decreased at others since 2001, based on TDEP estimates (Table 1). Reduced N deposition increased at nearly all parks

in this network, in many cases by sizeable amounts (> 20%), Oxidized N decreased at nearly all parks.

County-level emissions near NGPN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 5 through 7 for SO₂, oxidized N (NO_x), and reduced N (NH₃), respectively. Many counties to the north and west of NGPN parks had relatively high SO₂ emissions (> 50 tons/mi²/yr; Map 5). Spatial patterns in NO_x emissions were generally similar, with highest values to the northwest of NGPN parks (Map 6). Emissions of NH₃ near NGPN parks were somewhat lower, with most counties showing emissions levels below 8 tons/mi²/yr (Map 7).

Map 8 shows simulated total (wet plus dry) N deposition in 2006 for the NGPN region from the CMAQ air quality and deposition model. Deposition levels were elevated mainly in the southeastern half of the network region. However, in view of the large recent and ongoing O&G development to the west, NO_x deposition levels in NGPN may be higher than is shown in Map 8 now and in the near future. Continued monitoring will be important.

Total S deposition in and around NGPN for the period 2010-2012 was generally highest (> 5 kg S/ha/yr) to the north and lowest (< 2 kg S/ha/yr) in the southwest portion of the network area (Map 9). Oxidized inorganic N deposition for the period 2010-2012 was less than 5 kg N/ha/yr throughout the park land within NGPN (Map 10). Many areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 11); a few areas received higher amounts. Total N deposition was less than 10 kg N/ha/yr at most park locations (Map 12).

Acidification

There is no evidence to indicate that soil or water resources in the network are acidified by current levels of acidic deposition. This is likely attributable to generally low levels of atmospheric S and N deposition and variable levels of acid sensitivity. The network rankings developed by Sullivan et al. (2011b) for Acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking for NGPN that was below the middle of the distribution among networks. 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 Moderate.

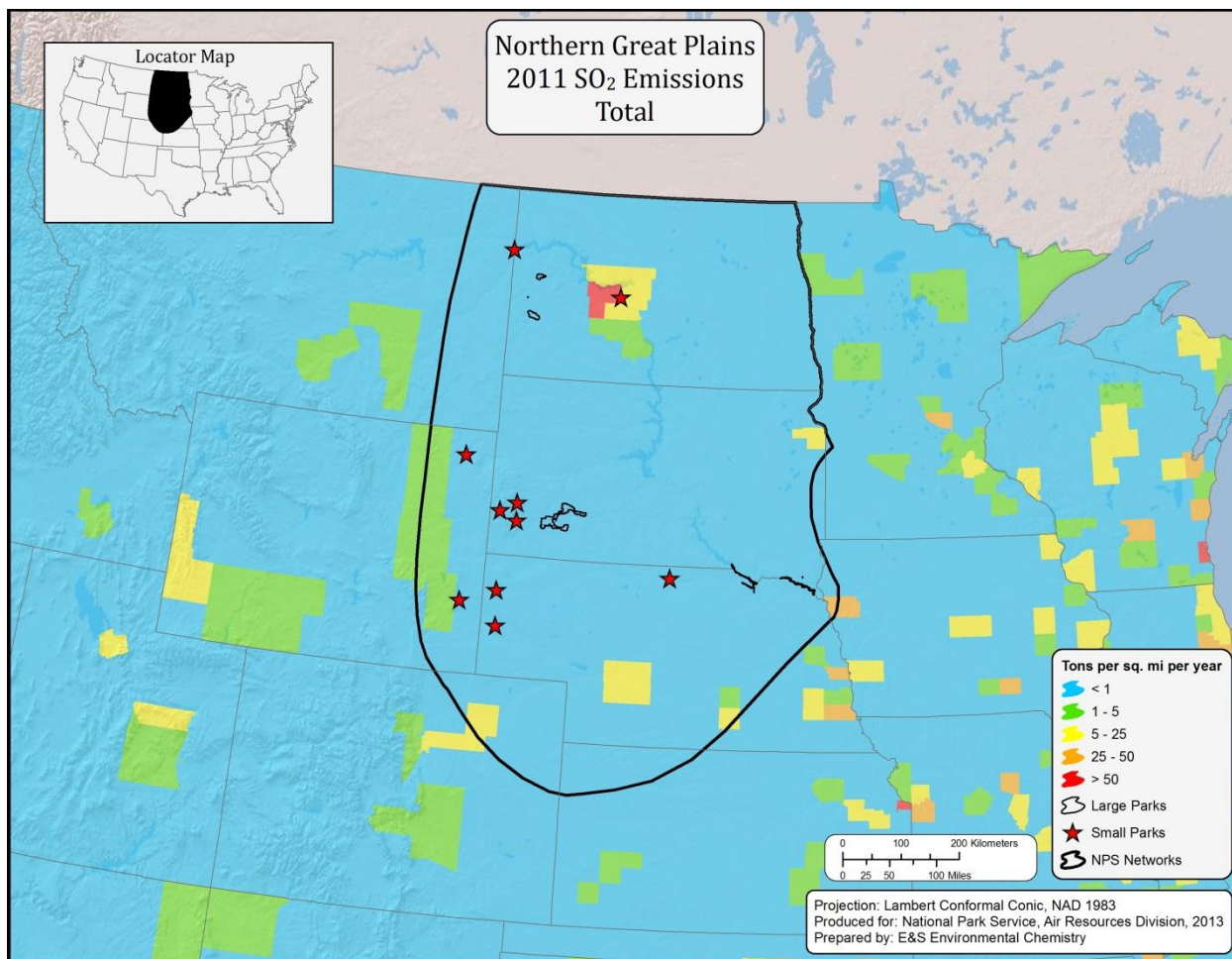
Two of the parks that are larger than 100 square miles, MNRR and THRO, were ranked Moderate for Acid Pollutant Exposure; BADL was ranked Very Low (Table 2). Acid Pollutant Exposure for each of the smaller parks was ranked by Sullivan et al. (2011b) in the second lowest or middle quintile. For Ecosystem Sensitivity to acidification, WICA was the only park in NGPN ranked in the highest quintile; JECA was ranked in the second highest quintile. All of the larger parks were ranked in the middle quintile for Ecosystem Sensitivity to acidification (Table 2). These relatively high-sensitivity rankings were based largely on topography and are not considered definitive in the

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

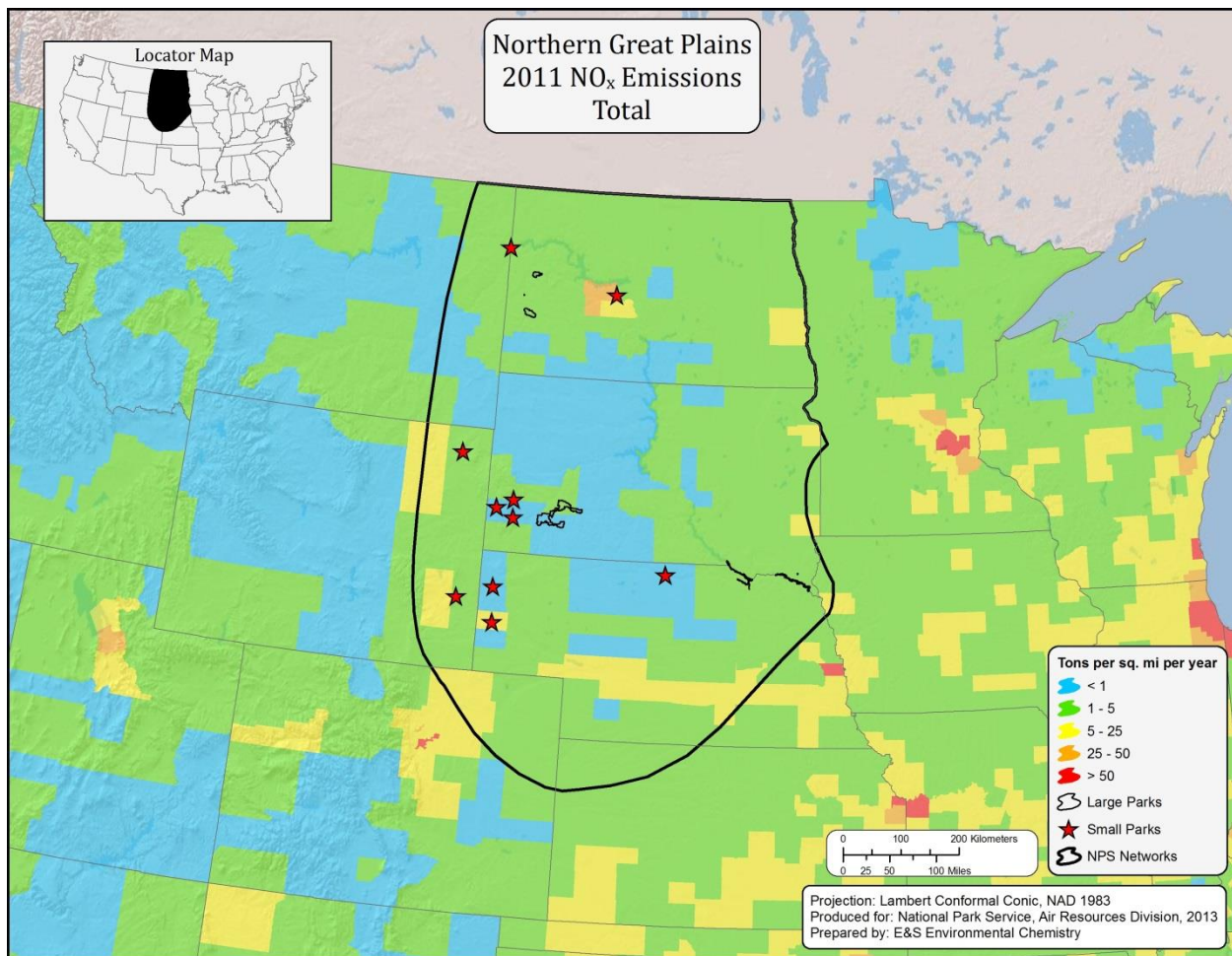
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
AGFO	Agate Fossil Beds	Total S	1.23	1.30	0.07	5.9%	1.29	1.31	0.02
		Total N	4.91	4.42	-0.49	-10.0%	4.34	4.47	0.13
		Oxidized N	2.46	1.90	-0.56	-22.7%	1.88	1.91	0.03
		Reduced N	2.45	2.52	0.06	3.3%	2.45	2.55	0.10
BADL	Badlands	Total S	1.31	1.23	-0.07	-5.7%	1.15	1.41	0.26
		Total N	4.73	3.90	-0.83	-17.5%	3.59	4.52	0.93
		Oxidized N	2.54	1.74	-0.80	-31.5%	1.64	2.02	0.38
		Reduced N	2.19	2.16	-0.03	-1.3%	1.95	2.50	0.55
DETO	Devils Tower	Total S	1.61	1.88	0.27	16.7%	1.88	1.89	0.01
		Total N	4.20	4.23	0.02	0.5%	4.22	4.25	0.03
		Oxidized N	2.53	2.11	-0.42	-16.7%	2.10	2.11	0.01
		Reduced N	1.68	2.12	0.44	26.4%	2.12	2.14	0.02
FOLA	Fort Laramie	Total S	1.20	1.12	-0.08	-6.8%	1.11	1.12	0.01
		Total N	4.31	3.87	-0.44	-10.2%	3.84	3.87	0.04
		Oxidized N	2.32	1.63	-0.69	-29.7%	1.62	1.63	0.01
		Reduced N	1.99	2.24	0.25	12.6%	2.21	2.24	0.03
FOUS	Fort Union Trading Post	Total S	2.25	2.41	0.16	7.2%	2.41	2.41	0.01
		Total N	3.82	4.31	0.49	12.9%	4.31	4.33	0.02
		Oxidized N	2.09	1.75	-0.35	-16.6%	1.75	1.75	0.01
		Reduced N	1.72	2.56	0.84	48.7%	2.56	2.57	0.01
JECA	Jewel Cave	Total S	1.50	2.03	0.53	35.6%	2.03	2.05	0.03
		Total N	4.69	4.98	0.28	6.0%	4.95	5.10	0.15
		Oxidized N	2.73	2.52	-0.21	-7.6%	2.51	2.56	0.05
		Reduced N	1.97	2.46	0.49	24.8%	2.44	2.54	0.10
KNRI	Knife River Indian Villages	Total S	6.75	5.85	-0.90	-13.3%	5.85	5.86	0.00
		Total N	5.62	5.66	0.04	0.7%	5.65	5.71	0.06
		Oxidized N	2.93	2.09	-0.85	-28.9%	2.07	2.13	0.06
		Reduced N	2.69	3.58	0.89	33.0%	3.57	3.58	0.00

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

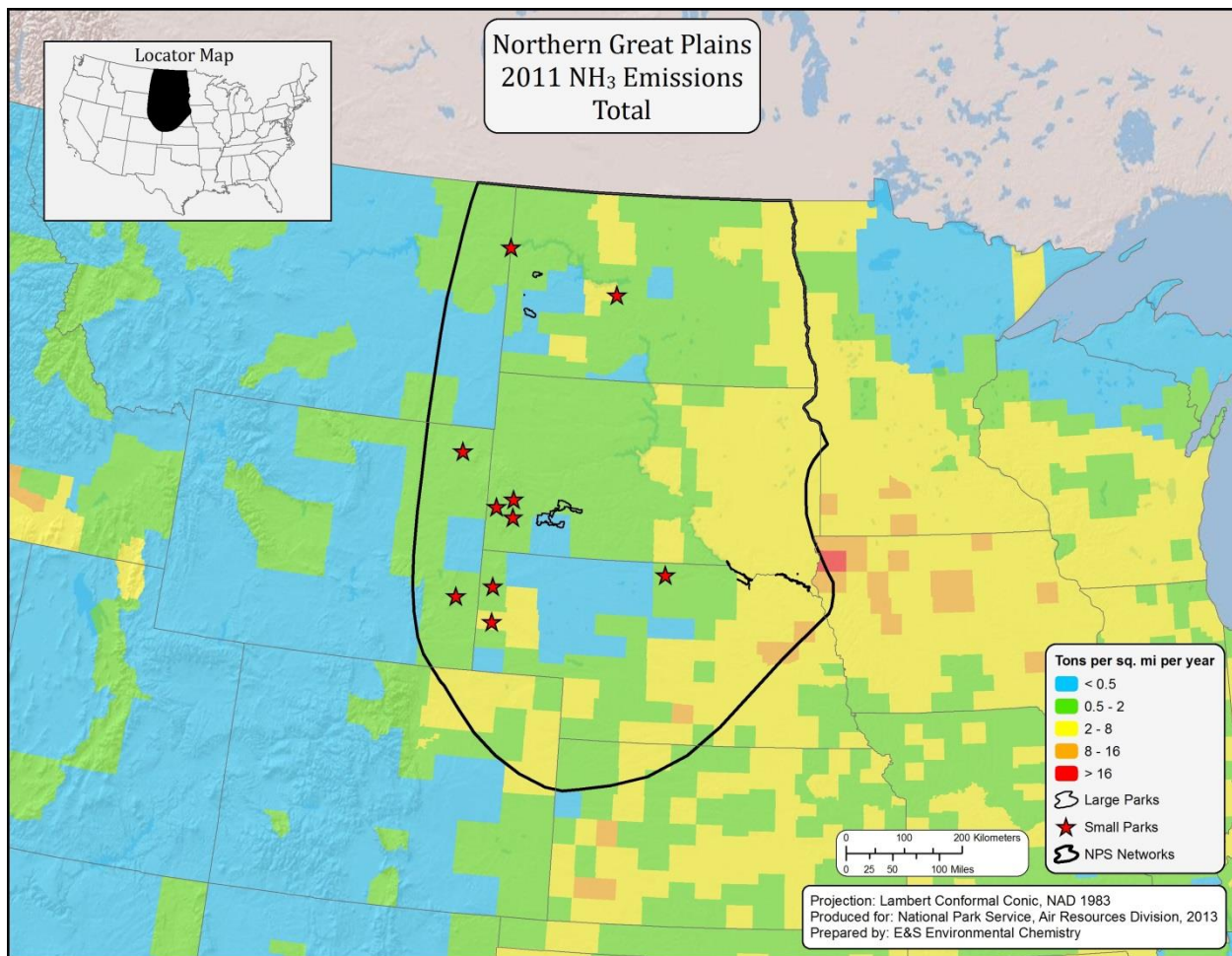
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
MNRR	Missouri	Total S	2.95	2.67	-0.28	-5.8%	2.29	3.28	0.99
		Total N	11.41	13.26	1.84	17.3%	10.51	15.69	5.18
		Oxidized N	3.79	3.19	-0.60	-15.6%	2.90	3.46	0.56
		Reduced N	7.62	10.07	2.45	34.3%	7.55	12.24	4.69
MORU	Mount Rushmore	Total S	1.80	2.14	0.34	18.8%	2.13	2.14	0.01
		Total N	5.09	5.97	0.88	17.3%	5.96	5.99	0.03
		Oxidized N	2.80	3.01	0.21	7.5%	3.01	3.01	0.01
		Reduced N	2.29	2.96	0.67	29.3%	2.95	2.99	0.04
NIOB	Niobrara	Total S	1.70	2.03	0.33	19.4%	1.69	2.26	0.57
		Total N	7.30	7.61	0.31	4.2%	5.93	9.07	3.14
		Oxidized N	3.05	2.75	-0.30	-10.0%	2.35	3.08	0.72
		Reduced N	4.24	4.86	0.62	14.8%	3.57	5.99	2.42
SCBL	Scotts Bluff	Total S	1.22	1.30	0.07	6.3%	1.16	1.37	0.21
		Total N	6.05	7.72	1.67	28.3%	6.80	8.28	1.48
		Oxidized N	2.49	1.97	-0.51	-20.7%	1.78	2.11	0.33
		Reduced N	3.56	5.75	2.19	63.3%	5.01	6.17	1.16
THRO	Theodore Roosevelt	Total S	2.61	2.22	-0.39	-15.1%	2.03	2.43	0.40
		Total N	4.26	4.25	-0.01	-0.3%	3.89	4.79	0.90
		Oxidized N	2.35	1.96	-0.39	-16.8%	1.82	2.05	0.23
		Reduced N	1.91	2.29	0.38	20.1%	2.03	2.80	0.78
WICA	Wind Cave	Total S	1.44	1.47	0.03	2.2%	1.34	1.78	0.44
		Total N	4.64	4.58	-0.06	-1.3%	4.24	5.32	1.07
		Oxidized N	2.60	2.11	-0.49	-18.7%	1.90	2.54	0.64
		Reduced N	2.04	2.47	0.43	20.9%	2.35	2.77	0.43



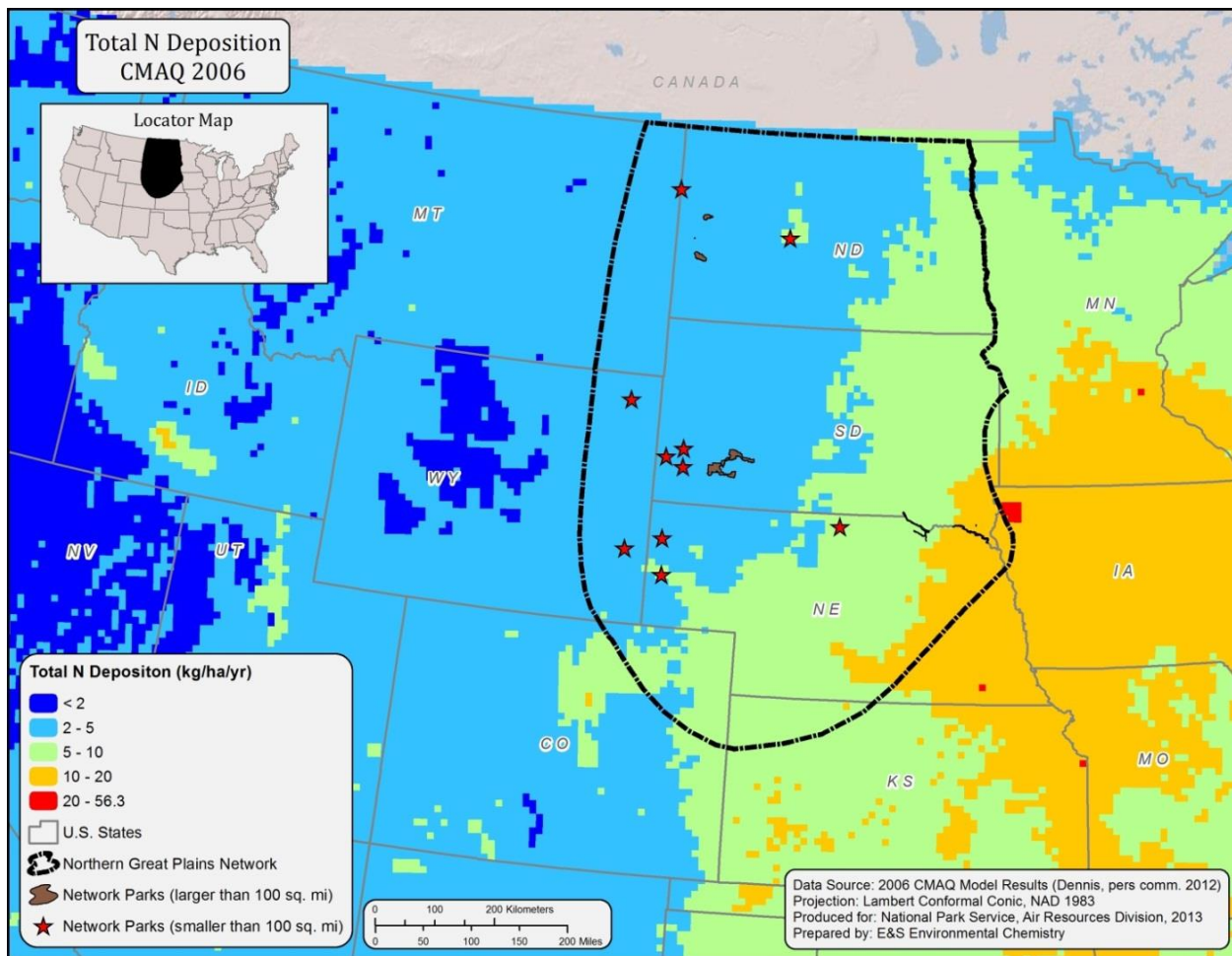
Map 5. Total SO₂ emissions, by county, near NGPN for the year 2011. Data from EPA's National Emissions Inventory.



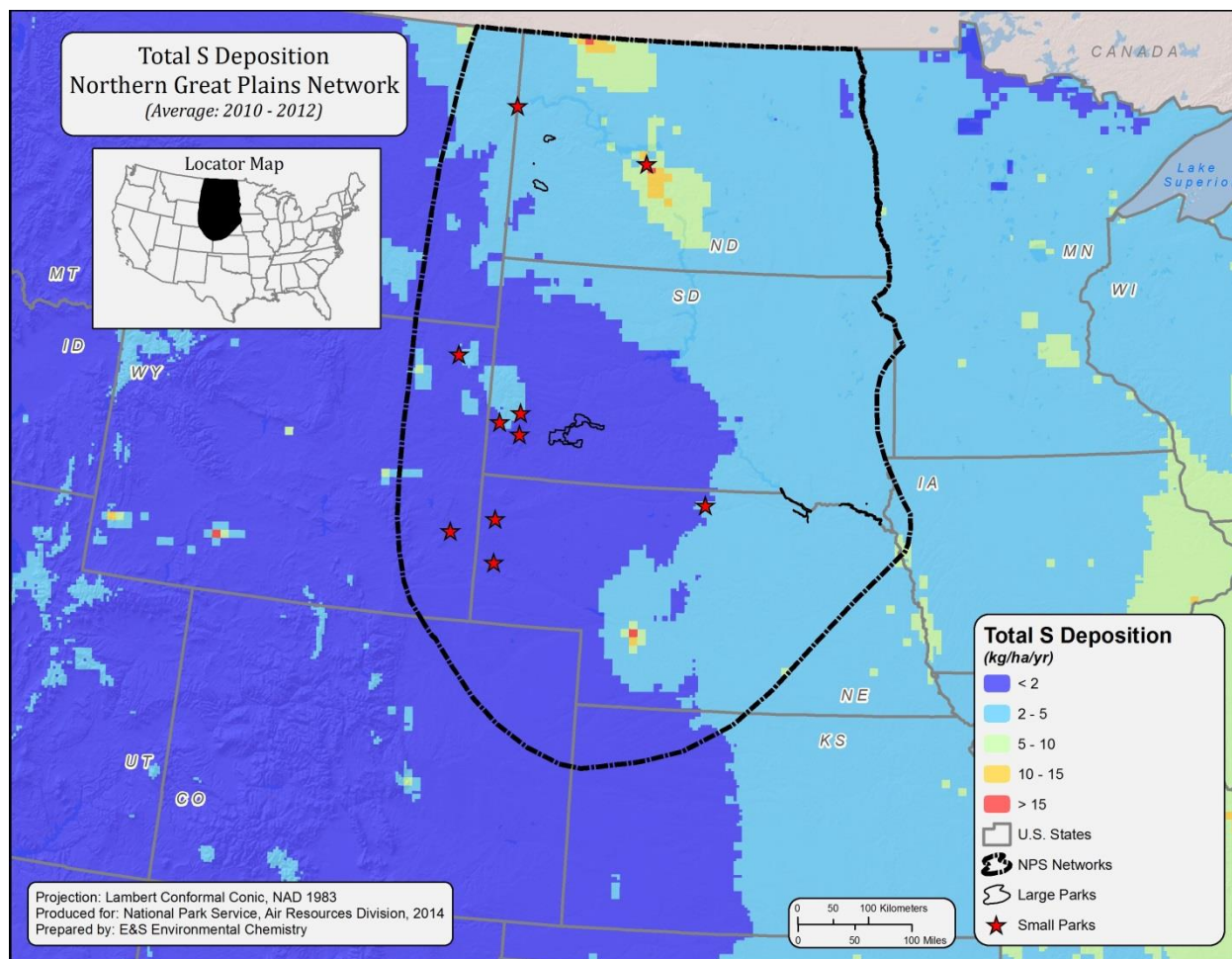
Map 6. Total NO_x emissions, by county, near NGPN for the year 2011. Data from EPA's National Emissions Inventory.



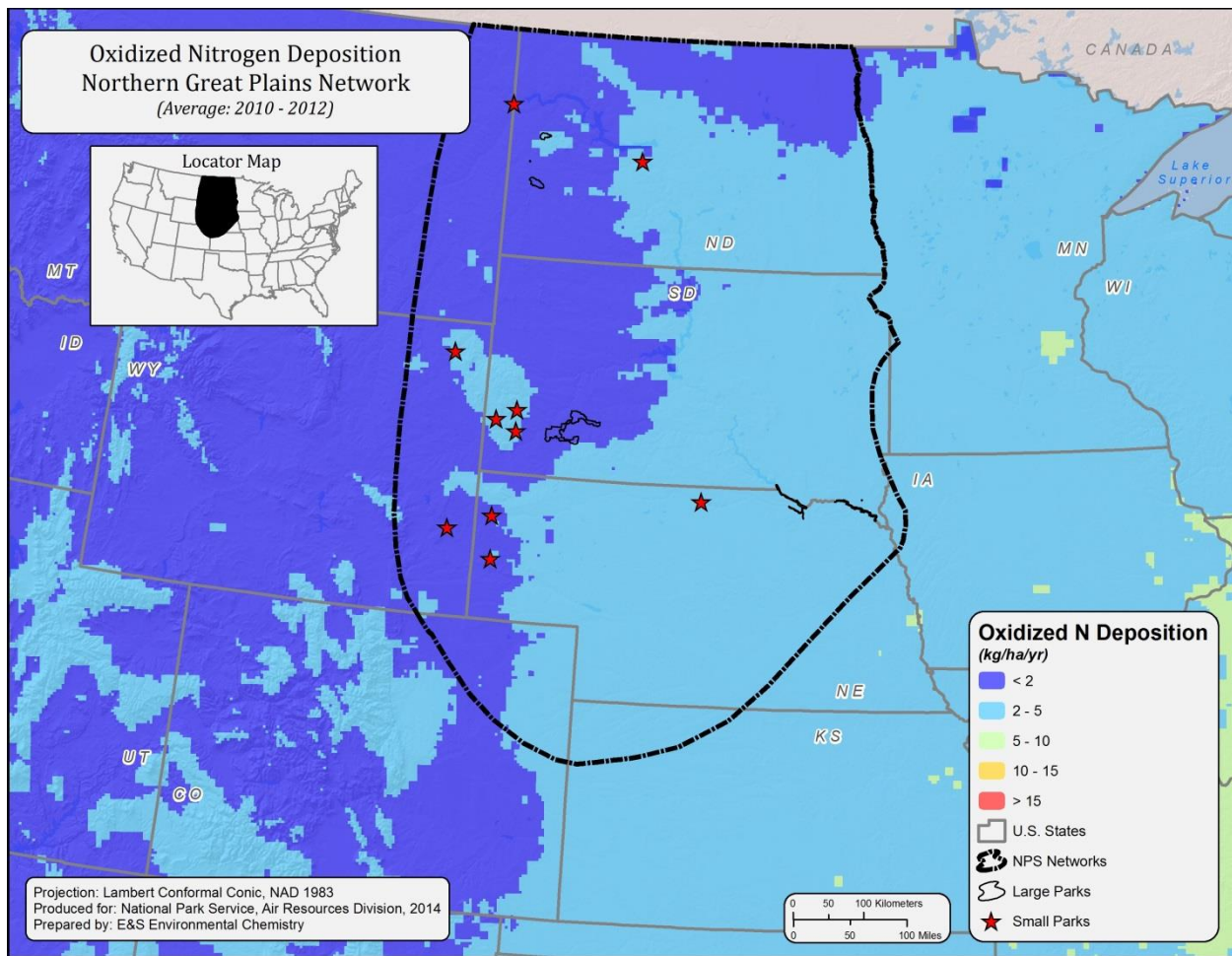
Map 7. Total NH₃ emissions, by county, near NGPN for the year 2011. Data from EPA's National Emissions Inventory.



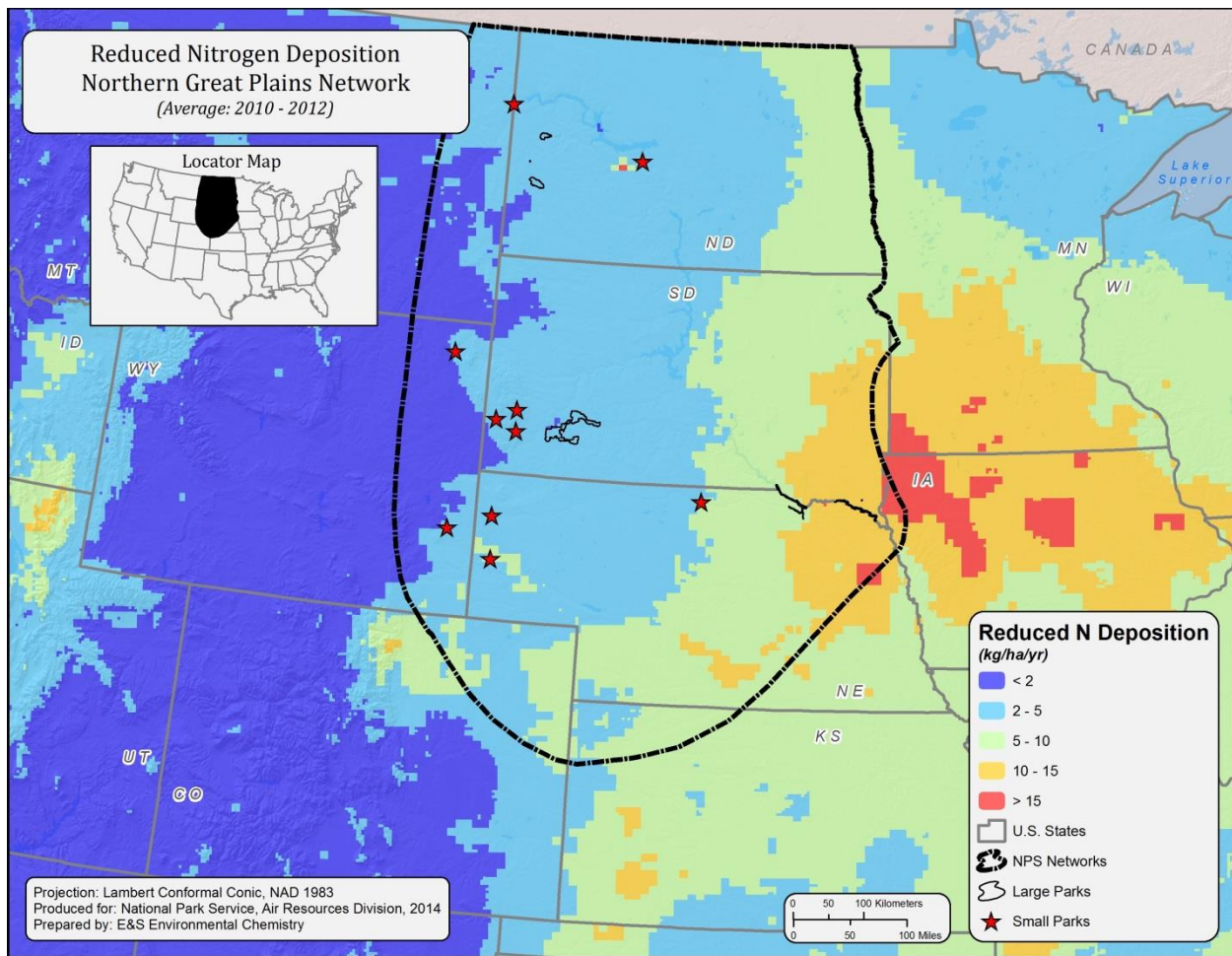
Map 8. CMAQ model results showing total N deposition for the year 2006.



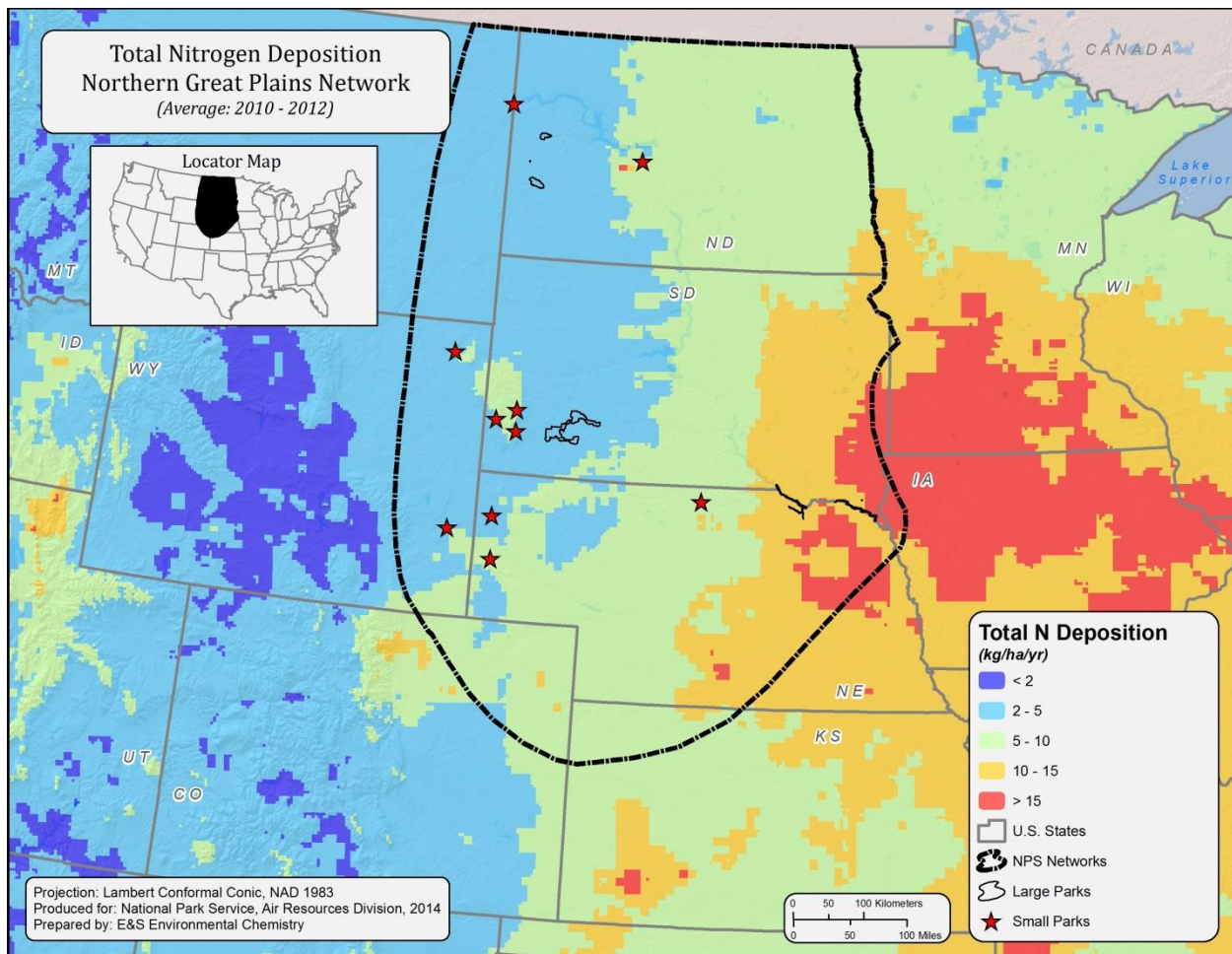
Map 9. Total S deposition for the three-year period centered on 2011 in and around NGPN. (Source: Schwede and Lear 2014)



Map 10. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around NGPN. (Source: Schwede and Lear 2014)



Map 11. Reduced inorganic N deposition for the three-year period centered on 2011 in and around NGPN. (Source: Schwede and Lear 2014)



Map 12. Total N deposition for the three-year period centered on 2011 in and around NGPN. (Source: Schwede and Lear 2014)

Table 2. Estimated I&M park rankings¹ according to risk of acidification impacts on sensitive receptors (Source: Sullivan et al. 2011b).

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Agate Fossil Beds	AGFO	Low	Moderate
<i>Badlands</i>	BADL	Very Low	Moderate
Devils Tower	DETO	Low	Moderate
Fort Laramie	FOLA	Moderate	Low
Fort Union Trading Post	FOUS	Low	Very Low
Jewel Cave	JECA	Low	High
Knife River Indian Villages	KNRI	Moderate	Very Low
<i>Missouri</i>	MNRR	Moderate	Moderate
Mount Rushmore	MORU	Low	Low
Niobrara	NIOB	Low	Moderate
Scotts Bluff	SCBL	Moderate	Low
<i>Theodore Roosevelt</i>	THRO	Moderate	Moderate
Wind Cave	WICA	Low	Very High

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

² Park names are printed in bold italic for parks larger than 100 mi².

absence of field data. While rankings provide a suggestion of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

Data regarding surface water acidification sensitivity were reported for two parks (WICA and THRO) within NGPN by Peterson et al. (1998). WICA is located in the southeastern portion of the Black Hills, which constitute the easternmost extension of the Rocky Mountains. They comprise an isolated and unglaciated group of mountains that rise above the surrounding plains. Surface waters in WICA are well buffered against acidic inputs. Peterson et al. (1998) analyzed EPA's STORET data base, which contained 1,971 pH measurements for southwestern South Dakota, in an area that includes BADL and WICA. Only one measurement showed pH less than 6.1, and it was either due to an error or to direct acid discharge (e.g., acid mine drainage). In addition, 99% of the measured pH values were higher than 6.6, and 99% of the Ca²⁺ measurements (n=236) were higher than 10 mg/L (500 µeq/L). Surface water SO₄²⁻ concentrations tended to be very high due to geological sources of SO₄²⁻. The median SO₄²⁻ concentration (n=77) in the data set was 88 mg/L (1,800 µeq/L). There was no evidence to suggest that surface waters in BADL or WICA would be responsive to acidic deposition inputs or that aquatic biota would be affected by acidification (Peterson et al. 1998).

The major surface water resource in THRO is the Little Missouri River. The river flows through 14 km of the park's South Unit and 21 km of the North Unit, and forms the eastern boundary of the Elkhorn Unit. Most other streams within THRO are intermittent, with little or no flow during summer. Water quality data from 76 locations in and around THRO were reported by Peterson et al. (1998). Sampling site locations were situated along the Little Missouri River and many of its

tributaries. Measured pH values were around 8.0 at all monitoring sites except one, which had a very low value of 3.1. The low pH site, at the Frank Mine, also had an extremely high specific conductance (2560 $\mu\text{S}/\text{cm}$). This site was apparently impacted by acid mine drainage. There were two sites with moderate concentrations of base cations ($\text{Ca}^{2+} + \text{Mg}^{2+}$ in the range of 250 to 300 $\mu\text{eq}/\text{L}$); all other sites had base cation concentrations at least twice as high as these. Water quality data reported by Peterson et al. (1998) for THRO did not suggest sensitivity to potential acidification from acidic deposition. Aquatic effects from acidic deposition are not important in this park.

Nutrient Nitrogen Enrichment

The overall level of concern for nutrient N enrichment effects on I&M parks within NGPN was judged by Sullivan et al. (2011a) to be Moderate. Park-specific nutrient N Pollutant Exposure rankings for the three parks in this network that are larger than 100 square miles indicated that MNRR was relatively high, in the second highest quintile, in nutrient N Pollutant Exposure; BADL and THRO were in the lowest and second lowest quintiles, respectively, among all I&M parks. Nutrient N Pollutant Exposure for each of the smaller parks was ranked in the second lowest or middle quintile (Table 2). Nutrient N exposure in this network is likely increasing now, and will likely continue to increase in the near future, in response to ongoing and continued O&G development.

Among the larger parks, BADL and THRO were ranked in the second highest quintile, and MNRR in the middle quintile with respect to Ecosystem Sensitivity to nutrient N enrichment (Table 3). The smaller parks exhibited a range of Ecosystem Sensitivity to nutrient N enrichment rankings, from the lowest quintile (JECA and MORU) to the highest quintile (AGFO, SCBL, and WICA). 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.

The predominant vegetation type in NGPN is grassland, and it may be highly sensitive to nutrient N enrichment, particularly in low-productivity soil types. Much of the northern Great Plains is covered by mixed-grass prairie. These grasslands are comprised of a diversity of grass, shrub, and forb species. The dominant species include western wheatgrass (*Pascopyrum smithii*), needlegrasses (*Hesperostipa* and *Nassella* spp.), gramas (*Bouteloua* spp.), prairie junegrass (*Koeleria macrantha*), and buffalo grass (*Buchloe dactyloides*). Various species of sagebrush (*Artemisia* spp.), as well as western snowberry (*Symphoricarpos occidentalis*), skunkbrush sumac (*Rhus trilobata*), and leadplant (*Amorpha canescens*) are the most common shrub species mixed with different grassland types.

Mixed-grass prairie is an important AQRV that is sensitive to nutrient enrichment impacts from atmospheric N deposition. Nutrient N enrichment can alter the species composition in a grassland community and reduce biodiversity. Much of the work on eutrophication effects of N deposition on grasslands has been conducted in Europe. Nitrophilous plant species have been shown to have increased in abundance, and N-sensitive species to have declined in European grasslands, over approximately the last half of the 20th century (Bobbink et al. 1998). The clearest evidence that long-

Table 3. Estimated park rankings¹ according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a)

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
Agate Fossil Beds	AGFO	Low	Very High
<i>Badlands</i>	BADL	Very Low	High
Devils Tower	DETO	Low	High
Fort Laramie	FOLA	Moderate	High
Fort Union Trading Post	FOUS	Low	Moderate
Jewel Cave	JECA	Low	Very Low
Knife River Indian Villages	KNRI	Moderate	Moderate
<i>Missouri</i>	MNRR	High	Moderate
Mount Rushmore	MORU	Low	Very Low
Niobrara	NIOB	Moderate	High
Scotts Bluff	SCBL	Moderate	Very High
<i>Theodore Roosevelt</i>	THRO	Low	High
Wind Cave	WICA	Low	Very High

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

² Park names are printed in bold italic for parks larger than 100 mi².

term atmospheric N deposition over a large region has impacted terrestrial biodiversity was provided by Stevens et al. (2004), who reported results of a survey of 68 4-m² plots across a range of atmospheric N deposition from 5 to 35 kg N/ha/yr. Species richness was found to decline as a linear function of N deposition, with a reduction on average of one plant species in 4 m² for every 2.5 kg N/ha/yr of N input.

Grasslands in NGPN may be mainly N-limited or co-limited by N and water. Many species in other grasslands have been shown to 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 to grassland ecosystems 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 NO₃⁻

increased, and plant species composition shifted over time in response to N addition (Clark and Tilman 2008, Clark et al. 2009). How these studies relate to mixed grass prairie is unknown.

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 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 arundinacea*) increased 2-fold (Clark et al. 2003, Jorgensen et al. 2005). Shortgrass prairie 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).

Smith (2012) investigated response thresholds of Northern Great Plains mixed prairie grasslands in BADL and WICA to N addition over a two-year period. She found significant effects for N addition on above-ground net primary production, leaf tissue N content, and soil N at relatively high levels of N input. No consistent effects were seen on total species richness or plant community diversity metrics. These results may have been caused, at least in part, by the short duration of the experiment.

Grasslands of the Great Plains have also experienced invasions of woody plant species (Kleb and Wilson 1997) that appear to be driven, at least in part, by N enrichment of soil and fire exclusion (Tilman 1987). Fertilization may increase the water use efficiency of woody species (Bert et al. 1997), and enable them to colonize temperate grassland sites (Köchy and Wilson 2001). Accelerated rates of N cycling (Carreiro et al. 2000) give advantage to trees (Aerts et al. 1999, Köchy and Wilson 2001).

High N deposition has been shown to be correlated with an increase of tall plant species in nutrient-poor European grasslands (Bobbink et al. 1998). Similarly, Köchy and Wilson (2001) quantified forest invasion of aspen trees into grasslands in six national parks in western Canada that received a range of levels of atmospheric N deposition. The rate of aspen expansion was measured from aerial photographs taken over a period of six decades. Forests in high-deposition parks expanded 10 times faster than forests in low-deposition parks. The average forest expansion rate was 1% per year in high-deposition parks (Köchy and Wilson 2001). Woody encroachment of juniper (*Juniperus* spp.) may be more relevant to NGPN, but has not been studied as an impact of N input as far as we know.

Paschke et al. (2000) manipulated the N supply to shortgrass steppes northeast of Fort Collins, Colorado. Nitrogen additions of up to 100 kg N/ha/yr to old field plots resulted in increased abundance of annual forbs and grasses relative to perennials at all of the previously cultivated sites. Paschke et al. (2000) concluded that N availability is an important factor controlling the rate and course of vegetation community redevelopment on abandoned croplands in the shortgrass steppe. This might be relevant to NGPN, given that some parks in the network (e.g., FOUS, FOLA) have grasslands that have developed on abandoned croplands.

To date, many of the N effects studies in the U.S. have either relied on N gradients, which cannot identify the lowest deposition level at which there is no effect on biodiversity, or on N addition experiments, which are usually conducted over a relatively short time period (less than 10 years) and also have limited ability to identify impacts at low levels of added N. In an analysis of European

data, Payne et al. (2013) found that, because of limitations with gradient or experimental addition studies, they could not identify the lowest level of N deposition at which individual species declined. They concluded that, for certain grassland types, the only way to have no harm over time is to have no N air pollution (Payne et al. 2013).

Pardo et al. (2011) compiled data on empirical CL for protecting sensitive resources in Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. Available data on nutrient-N empirical CL for parks in NGPN are summarized in Table 4. For many of the parks, the lower end of the estimated CL ranged from about 2.5 to 5 kg N/ha/yr for protecting mycorrhizal fungi, lichens, herbaceous plants, and trees and for preventing NO₃⁻ leaching in drainage water. For many of the parks in this network, Pardo et al.'s (2011) estimate of ambient N deposition was lower than the CL. In some cases, however, the ambient N deposition was higher than the CL for protecting sensitive resources, especially lichens and herbaceous plants, suggesting CL exceedance.

Table 4. Empirical critical loads for nitrogen in NGPN, 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 (kg N/ha/yr)	Critical Load (kg N/ha/yr)				
			Mycorrhizal Fungi	Lichen	Herbaceous Plant	Forest	Nitrate Leaching
Agate Fossil Beds NM	Great Plains	3.7	12	NA	5 - 25	NA	10 - 25
Badlands NP	Great Plains	3.5	12	NA	5 - 25	NA	10 - 25
Devils Tower NM	Northwestern Forested Mountains	3.2	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Fort Laramie NHS	Great Plains	3.6	12	NA	5 - 25	NA	10 - 25
Fort Union Trading Post NHS	Great Plains	3.3	12	NA	5 - 25	NA	10 - 25
Jewel Cave NM	Northwestern Forested Mountains	3.6	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Knife River Indian Villages NHS	Great Plains	4.8	12	NA	5 - 25	NA	10 - 25
Missouri NRR	Great Plains	13.7	12	NA	5 - 25	NA	10 - 25
Mount Rushmore NMem	Northwestern Forested Mountains	3.9	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Niobrara NSR	Great Plains	6.9	12	NA	5 - 25	NA	10 - 25
Scotts Bluff NM	Great Plains	5.6	12	NA	5 - 25	NA	10 - 25
Theodore Roosevelt NP	Great Plains	4.0	12	NA	5 - 25	NA	10 - 25
Wind Cave NP	Northwestern Forested Mountains	3.4	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or expected to occur within the I&M parks found in NGPN are listed in Table 5. Those considered to be bioindicators display visible and easily recognizable O₃ injury symptoms, and are designated by an asterisk. Each park within the network contains at least three O₃-sensitive and/or bioindicator species. In addition to causing visible injury (necrosis, stippling), O₃ can reduce photosynthesis and growth. Effects are usually induced by cumulative exposures over time, which are expressed as the W126 or SUM06 metrics, calculated by summing up hourly O₃ concentrations over a period of time, usually 3 months during the growing season.

The W126 and SUM06 O₃ exposure indices and associated rankings calculated by NPS staff (NPS 2010) are given in Table 6, along with Kohut's (2007) O₃ risk ranking. The two ranking systems differ. The NPS ranking system (NPS 2010) ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997). Kohut's rankings consider O₃ exposure, but also consider environmental conditions, especially soil moisture. Soil moisture is important because dry conditions induce stomatal closure in plants, which has the effect of limiting O₃ uptake and injury. In areas where low soil moisture levels correspond with high O₃ exposure, uptake and injury are limited by stomatal closure even when exposures are relatively high.

Although O₃ conditions are rated as High or Moderate by NPS in some network parks, Kohut concluded that the risk to vegetation is Low in all parks in this network because of generally dry soil conditions during the summer. Nevertheless, vegetation in these parks could be at risk during years of high spring or early summer precipitation.

The most common tree species in the Black Hills portion of NGPN is ponderosa pine. It is also one of the most O₃-sensitive western tree species, and the most O₃-sensitive conifer in western North America. Extensive data are available on field (Miller and Millecan 1971, Peterson and Arbaugh 1988, Pronos and Vogler 1981) and experimental (Temple et al. 1992) exposures of ponderosa pine to O₃. The evidence for O₃ impacts on this tree species is based on observable symptoms of foliar chlorosis and reduced growth (Peterson et al. 1991, Peterson and Arbaugh 1992) as well as physiological data (Bytnerowicz and Grulke 1992, Darrall 1989). The cause-effect relationship, especially for trees growing in forests of southern California and the southern Sierra Nevada, is clear and quantifiable. The Rocky Mountain variety of ponderosa pine (var. *scopulorum*), which occurs in NGPN, is known to be somewhat more tolerant to O₃ and has a higher threshold for symptoms of injury under experimental exposures than var. *ponderosa*, which occurs to the west (Aitken et al. 1984).

Ponderosa pine is the dominant tree throughout WICA, MORU, JECA, and DETO. In some areas, it encroaches into grasslands and riparian areas. Although ponderosa pine is not common in BADL, it is present in the Sheep Mountain area on approximately 80 ha.

Quaking aspen (*Populus tremuloides*) is a common hardwood tree species present in some NGPN parks that is known to be sensitive to O₃. It is a potential secondary sensitive receptor after ponderosa

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

Ozone Sensitive Species	Common Name	Park ¹													
		AGFO	BADL	DETO	FOLA	FOUS	JECA	KNRI	MNRR	MORU	NIOB	SCBL	THRO	WICA	
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry					x	x	x		x			x	x	
<i>Amelanchier alnifolia</i> var. <i>alnifolia</i>	Saskatoon serviceberry			x											
<i>Apios americana</i> *	Groundnut										x				
<i>Apocynum androsaemifolium</i> *	Spreading dogbane			x			x	x		x	x		x	x	
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp	x	x	x	x	x		x	x		x	x	x	x	
<i>Artemisia ludoviciana</i> spp. <i>Ludoviciana</i> *	White sagebrush		x				x		x						
<i>Artemisia ludoviciana</i> var. <i>ludoviciana</i> *	Silver wormwood				x			x							
<i>Artemisia ludoviciana</i> *	Silver wormwood	x				x				x	x	x	x	x	
<i>Asclepias incarnata</i>	Swamp milkweed								x					x	
<i>Asclepias incarnata</i> spp. <i>incarnata</i>	Swamp milkweed	x									x	x			
<i>Asclepias syriaca</i> *	Common milkweed							x	x						
<i>Clematis virginiana</i>	Virgin's bower								x				x		
<i>Corylus americana</i> *	American hazelnut										x				
<i>Fraxinus pennsylvanica</i>	Green ash		x	x	x	x		x	x	x	x	x	x	x	
<i>Parthenocissus quinquefolia</i>	Virginia creeper		x						x		x		x		
<i>Pinus ponderosa</i> *	Ponderosa pine		x	x			x			x	x	x	x	x	
<i>Populus tremuloides</i> *	Quaking aspen			x			x	x		x	x		x	x	
<i>Prunus virginiana</i>	Choke cherry		x			x	x	x	x	x	x	x	x		
<i>Prunus virginiana</i> var. <i>melanocarpa</i>	Choke cherry			x										x	
<i>Rhus trilobata</i> var. <i>trilobata</i> *	Skunkbush	x	x				x								
<i>Rhus trilobata</i> *	Skunkbush			x								x	x	x	
<i>Robinia pseudoacacia</i>	Black locust								x						
<i>Rubus parviflorus</i>	Thimbleberry									x					
<i>Rudbeckia laciniata</i> *	Cutleaf coneflower								x					x	
<i>Sambucus nigra</i> spp. <i>canadensis</i> *	American elder										x				
<i>Sambucus racemosa</i> *	Red elderberry									x					
<i>Symphoricarpos albus</i> var. <i>albus</i> *	Common snowberry			x											
<i>Symphoricarpos albus</i> *	Common snowberry		x				x			x			x	x	

¹ Park acronyms are printed in bold italic for parks larger than 100 mi².

* Bioindicator species

Table 6. NPS ozone conditions and risk to vegetation for I&M parks in NGPN1. NPS Condition is based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009. Risk to vegetation is based on several factors that contribute to injury in plants, including ozone exposure and environmental variables (Kohut 2007).

Park Name ²	Park Code	W126		SUM06		Risk to Vegetation
		Value (ppm-hr)	NPS Condition	Value (ppm-hr)	NPS Condition	
Agate Fossil Beds	AGFO	12.81	Moderate	10.46	Moderate	Low
<i>Badlands</i>	BADL	9.32	Moderate	11.96	Moderate	Low
Devils Tower	DETO	9.18	Moderate	12.49	Moderate	Low
Fort Laramie	FOLA	14.37	High	14.75	Moderate	Low
Fort Union Trading Post	FOUS	4.53	Low	3.86	Low	Low
Jewel Cave	JECA	8.50	Moderate	10.37	Moderate	Low
Knife River Indian Villages	KNRI	3.70	Low	2.66	Low	Low
<i>Missouri</i>	MNRR	4.87	Low	4.17	Low	Low
Mount Rushmore	MORU	7.15	Moderate	8.51	Moderate	Low
Niobrara	NIOB	6.48	Low	7.31	Low	Low
Scotts Bluff	SCBL	15.50	High	15.43	High	Low
<i>Theodore Roosevelt</i>	THRO	4.60	Low	3.94	Low	Low
Wind Cave	WICA	8.92	Moderate	10.91	Moderate	Low

¹ Parks are classified into one of three ranks (Low, Moderate, High).

² Park names are printed in bold italic for parks larger than 100 mi².

pine. In NGPN parks, aspen tends to grow in isolated pockets, often in riparian areas and other relatively high soil-moisture areas. Numerous studies have documented the sensitivity of this species (Berrang et al. 1986). Green ash (*Fraxinus pennsylvanica*), another O₃-sensitive species, is also present in many NGPN parks. Because of their tendency to grow in higher moisture areas, quaking aspen and green ash may not experience the dry soil conditions during the O₃ season that generally preclude O₃ uptake in many drier areas of the NGPN.

Visibility Degradation

Natural Background and Ambient Visibility Conditions

Visibility is a source of concern for all parks in NGPN because of the magnificent vistas in and around the parks. Visibility is a key AQRV in this network. The most prominent feature of BADL and THRO, in particular, is the dramatic scenery that can be observed throughout the park lands. Erosional landscapes and a variety of geological substrates of different ages present a visual diversity of colors and patterns. The Sage Creek Wilderness at Badlands NP, surrounded by cliffs and pinnacles, provides vistas of colorful buttes amidst grassland ecosystems.

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 in mandatory Class I federal areas which impairment results from manmade air pollution” (42 U.S.C. 7491). In 1999, EPA passed the RHR, which requires each state to develop a plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions in 2064. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic emissions. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network and typically reported using the haze index deciview¹ (dv). Visibility conditions are monitored by IMPROVE for BADL, THRO, and WICA in NGPN. Data are also available that are considered to be representative of visibility conditions in two of the other parks, FOUS and MORU. 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.

Most of the parks in NGPN receive relatively low levels of visibility-impairing atmospheric pollutants. Regional and local pollution sources that appear to contribute to visibility impairment² throughout the northern Great Plains include automobiles, O&G development, coal- and oil-fired power plants, smelters, wildfires, and urban emissions. Recent O&G development has been rapid, and potential impacts of ongoing O&G development in this network are not known.

Current visibility estimates reflect ambient pollution levels and also include natural background conditions, that is, conditions that would exist in the absence of human-caused pollution. Estimates were used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and haze-causing 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

¹ 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.

² *Visibility impairment* means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions

IMPROVE monitors were used in generating the 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 used for the relative ranking of visibility for BADL, FOUS, MORU, THRO, and WICA. Measured dv values in all five parks were moderately higher than the estimated natural condition. Ambient haze was ranked Moderate in BADL, FOUS, and THRO and Low in MORU and WICA for all groups (20% clearest, 20% haziest, and average days). NPS Air Resources Division (ARD) rated average visibility conditions at the five parks as Moderate for the period 2005-2009 (NPS ARD In preparation).

Representative photos of a selected vista in BADL under three different visibility conditions are shown in Figure 1. Photos were selected to correspond with the clearest 20% of visibility conditions, haziest 20% of visibility conditions, and annual average visibility conditions at that location. This series of photos provides a graphic illustration of the visual effect of these differences in haze level of a representative vista in this park. IMPROVE data from BADL, THRO, and WICA show that air pollution has reduced average visual range (VR) from 140-150 miles to 70-80 miles (225-241 km to 113-129 km). On the haziest days, VR has been reduced from 110 to 40-50 miles (177 to 64-81 km). Severe haze episodes occasionally reduce visibility to 10 miles (16 km).

Table 7. Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008¹.

Park Name ²	Park Code	Site ID	Estimated Natural Background Haze (dv)					
			20% Clearest Days	20% Haziest Days	Average Days			
Agate Fossil Beds	AGFO	No Site						
Badlands	BADL	BADL1	2.86	8.06	5.01			
Devils Tower	DETO	No Site						
Fort Laramie	FOLA	No Site						
Fort Union Trading Post ³	FOUS	MELA1	2.96	7.89	5.01			
Jewel Cave	JECA	No Site						
Knife River Indian Villages	KNRI	No Site						
Missouri	MNRR	No Site						
Mount Rushmore	MORU	WICA1	1.88	7.71	4.24			
Niobrara	NIOB	No Site						
Scotts Bluff	SCBL	No Site						
Theodore Roosevelt	THRO	THRO1	3.04	7.80	5.05			
Wind Cave	WICA	WICA1	1.88	7.71	4.24			
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
Agate Fossil Beds	AGFO	No Site						
Badlands	BADL	BADL1	6.91	Moderate	16.73	Moderate	11.55	Moderate
Devils Tower	DETO	No Site						
Fort Laramie	FOLA	No Site						
Fort Union Trading Post ³	FOUS	MELA1	6.64	Moderate	18.47	Moderate	12.01	Moderate
Jewel Cave	JECA	No Site						
Knife River Indian Villages	KNRI	No Site						
Missouri	MNRR	No Site						
Mount Rushmore	MORU	WICA1	4.78	Low	15.74	Low	9.74	Low
Niobrara	NIOB	No Site						
Scotts Bluff	SCBL	No site						
Theodore Roosevelt	THRO	THRO1	6.83	Moderate	17.67	Moderate	11.95	Moderate
Wind Cave	WICA	WICA1	4.78	Low	15.74	Low	9.74	Low

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

² Park names are printed in bold italic for parks larger than 100 mi².

³ Data are borrowed from a nearby IMPROVE 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.

Badlands

20% Clearest Days

Taken: 9:00 AM

Haze = 7 dv

$B_{\text{ext}} = 20 \text{ Mm}^{-1}$

VR = 200 km



20% Haziest Days

Taken : 9:00 AM

Haze = 17 dv

$B_{\text{ext}} = 56 \text{ Mm}^{-1}$

VR = 70 km



Average Days

Taken = 9:00 AM

Haze = 12 dv

$B_{\text{ext}} = 34 \text{ Mm}^{-1}$

VR = 115 km



Figure 1. Three representative photos of the same view in BADL illustrating the 20% clearest visibility, the 20% haziest visibility, and the annual average visibility. B_{ext} is total particulate light extinction; VR is the visual range.

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 (C), coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO₂ emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, power plants, industry, O&G development, and fires. Organic compounds and reduced N 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 2 shows estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze and its composition for BADL, FOUS, MORU, THRO, and WICA. 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 three or fewer 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 at THRO because data were not available for this park in 2000. Except for MORU and WICA on the 20% haziest days, the majority of the recent total particulate light extinction (b_{ext}) in all five parks for all three conditions (20% clearest days, 20% haziest days, and annual average) was attributable to SO₄²⁻. Nitrates, coarse mass, and organics are also responsible for an appreciable portion of the haze in all of these monitored parks (Figure 2). Nitrate was proportionally more important on the 20% haziest days at FOUS (30.4%) and THRO (25.1%) than at the other monitored parks. Organics were particularly important on the 20% haziest days at MORU and WICA (38.7%) and BADL (23.5%). An analysis of data from the BADL site showed that from 2005 to 2008, IMPROVE fine particle concentrations of SO₄²⁻ were highest in spring; NO₃⁻ concentrations were highest in winter; organics and fine soil mass concentrations were highest in summer; and light-absorbing C was highest in fall (Hand et al. 2011).

Although the primary contributors to haze are sulfates and nitrates, analyses conducted by WRAP indicated that organics from natural emissions sources, including wildfire and biogenic sources (vegetation), contribute to substantial visibility impairment throughout the western United States, including within NGPN. In addition, air pollution sources outside the region, including international off-shore shipping and sources from Mexico, Canada, and Asia, can in some cases be substantial contributors to haze (Suarez-Murias et al. 2009).

Trends in Visibility

Available haze monitoring data are shown in Figure 3 for the period of record at each park. There are no clear patterns of change in haze over time. The data do suggest, however, slight improvement on the 20% clearest days over the monitoring period.

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 4 using a uniform rate of progress glideslope specified in the RHR. From 2000-2009, visibility on the 20% clearest days improved at MORU, THRO, and WICA. There were no trends on the clearest days at BADL and FOUS, and no trends on the 20% haziest days at any of the parks (NPS-ARD In preparation).

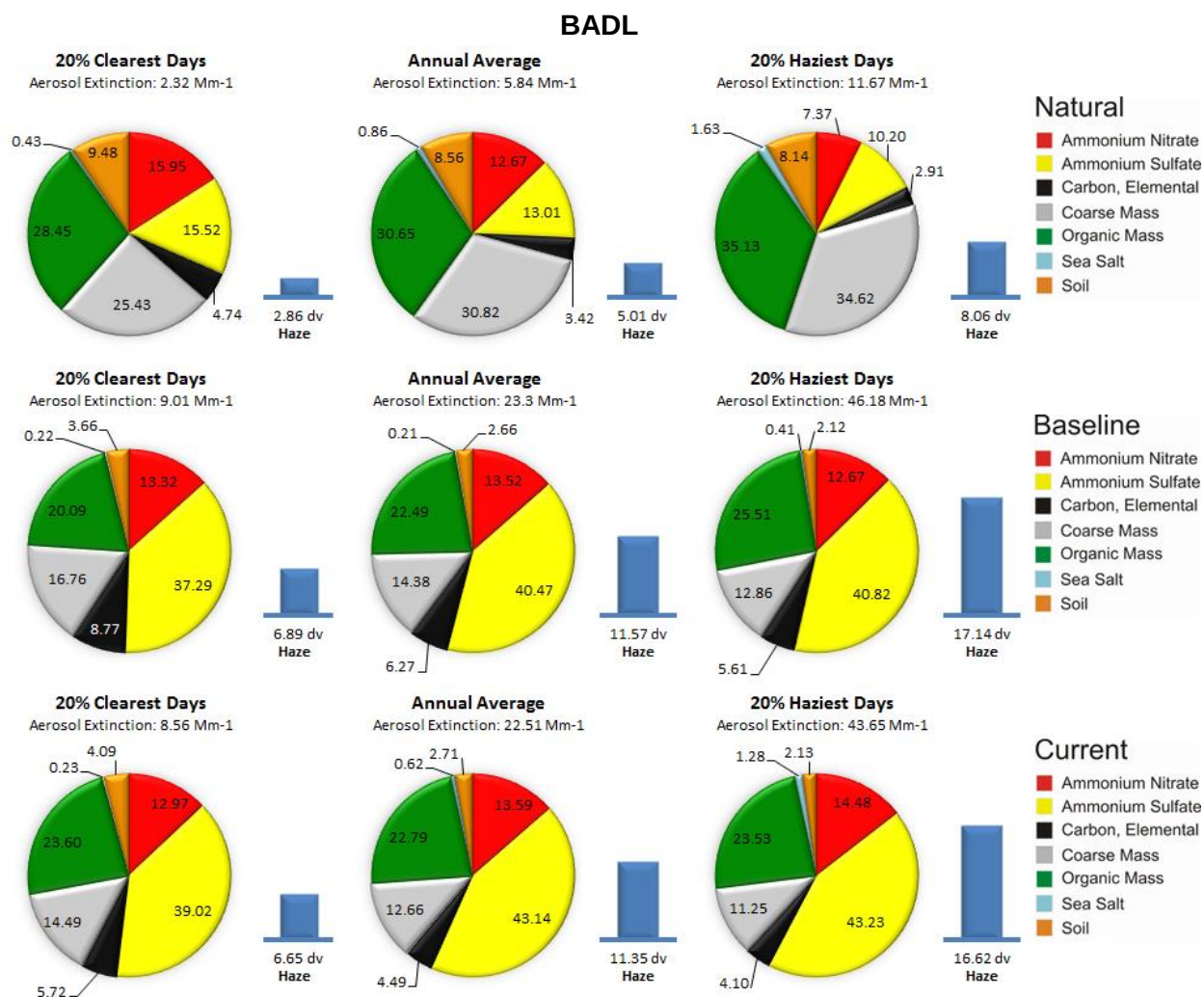


Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for BADL. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000
Data Source: NPS-ARD.

FOUS

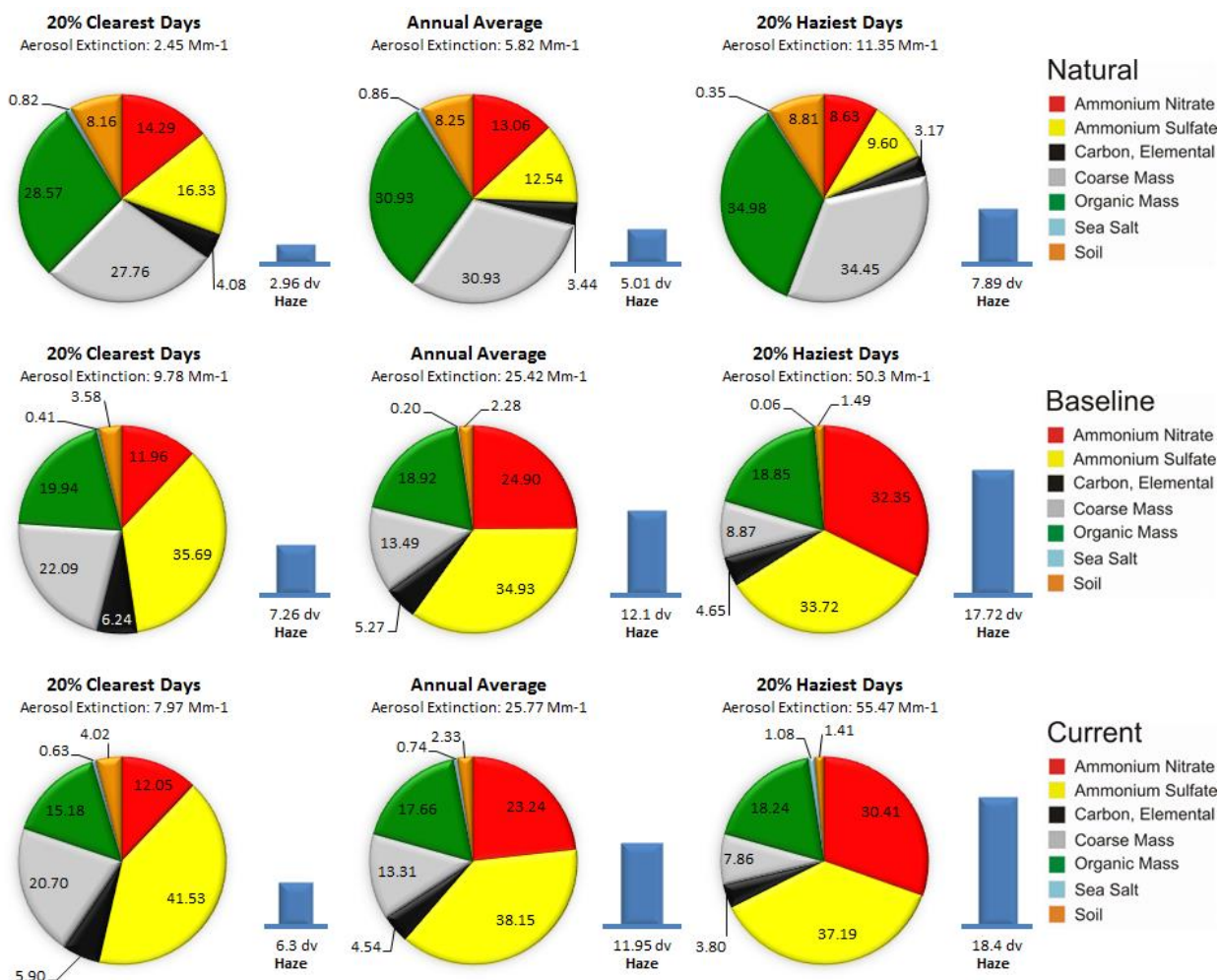


Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for FOUS. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000
Data Source: NPS-ARD.

MORU and WICA

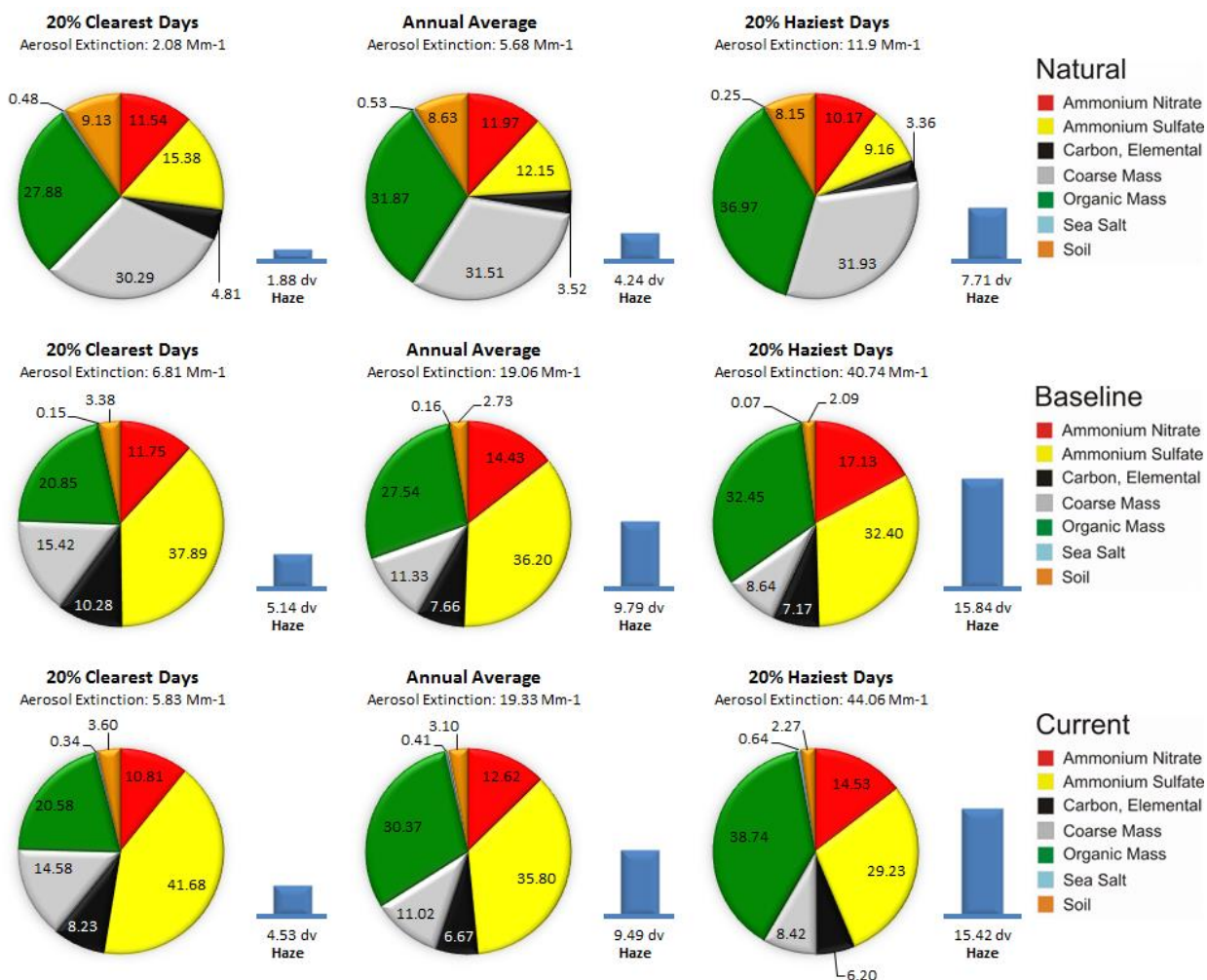


Figure 2c. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for MORU and WICA. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000 Data Source: NPS-ARD.

THRO

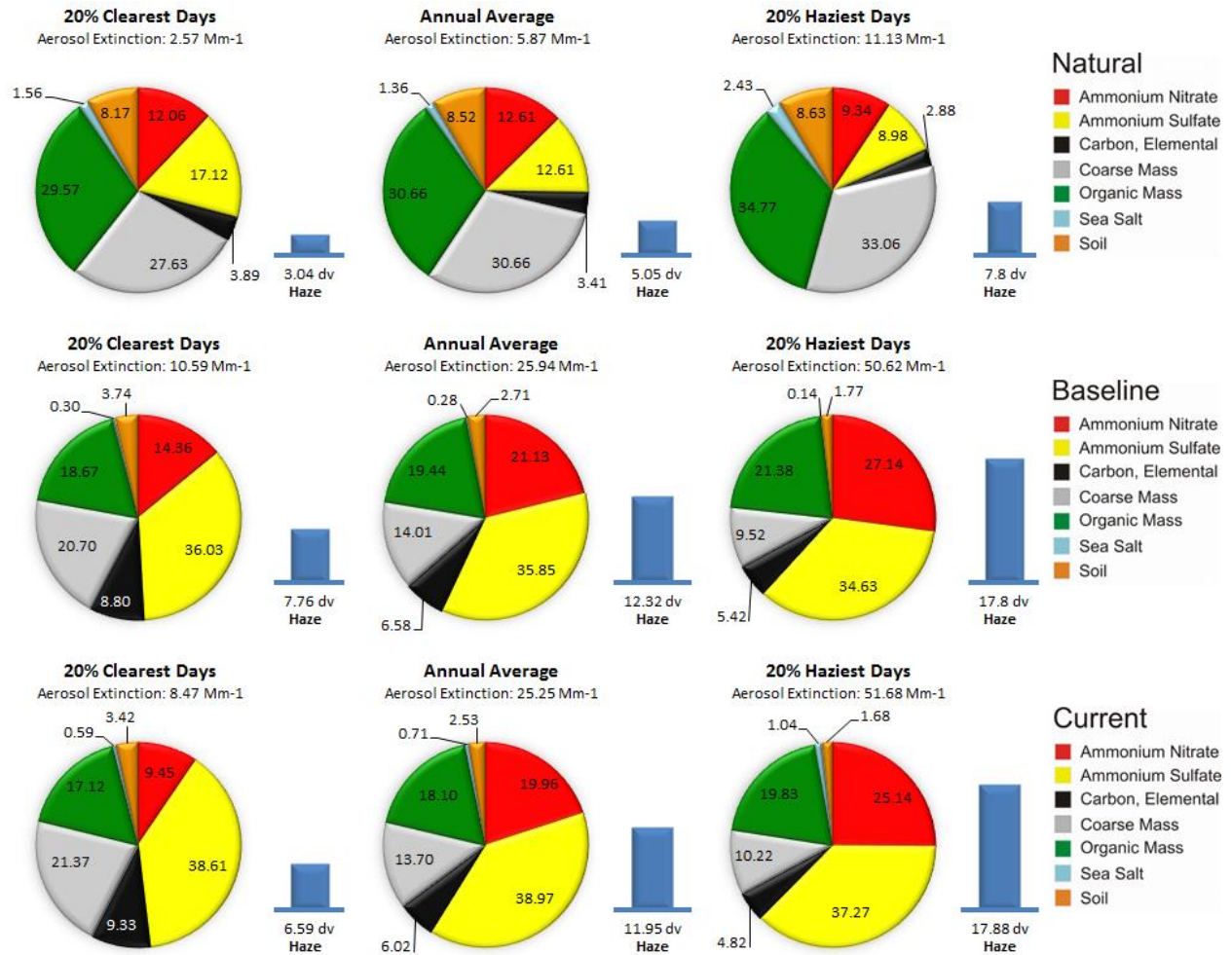


Figure 2d. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for THRO. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000
Data Source: NPS-ARD.

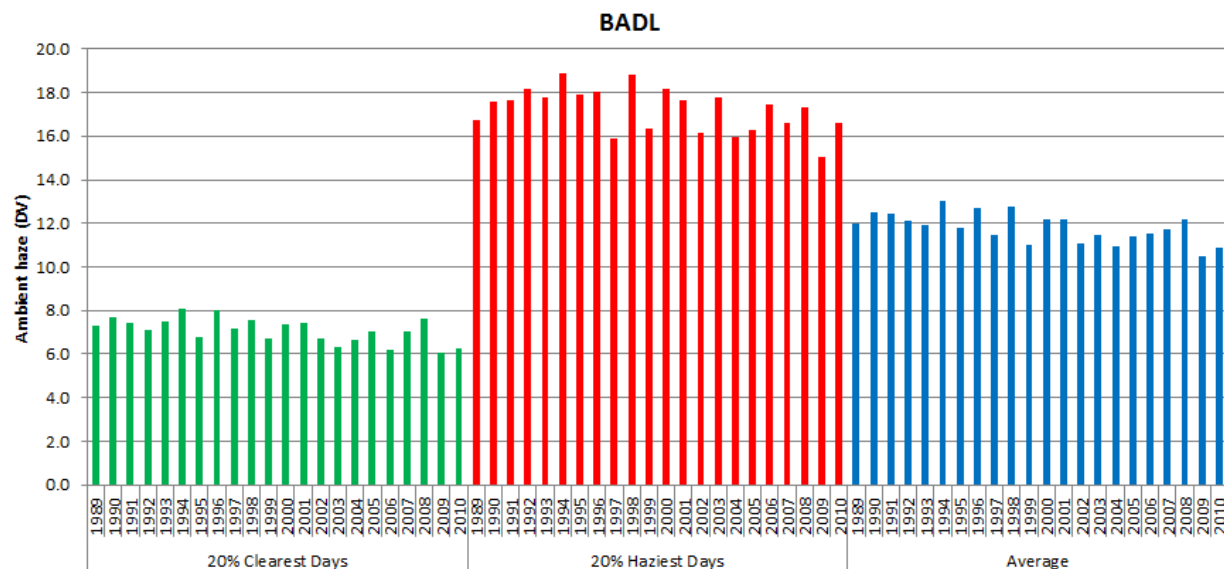


Figure 3a. Trends in ambient haze levels at BADL, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

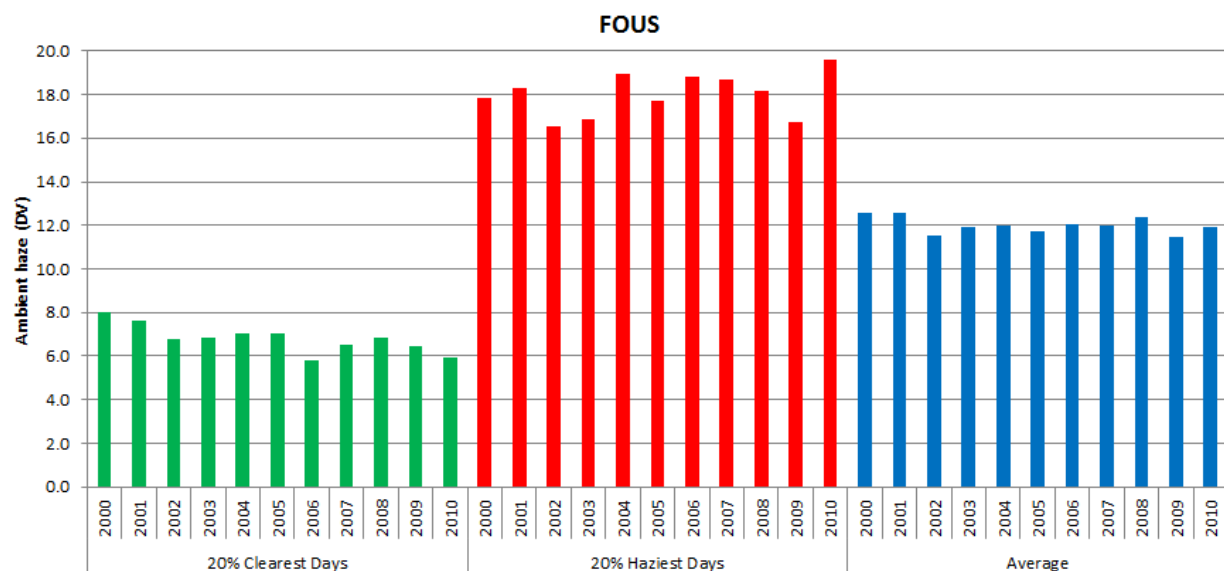


Figure 3b. Trends in ambient haze levels at FOUS, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

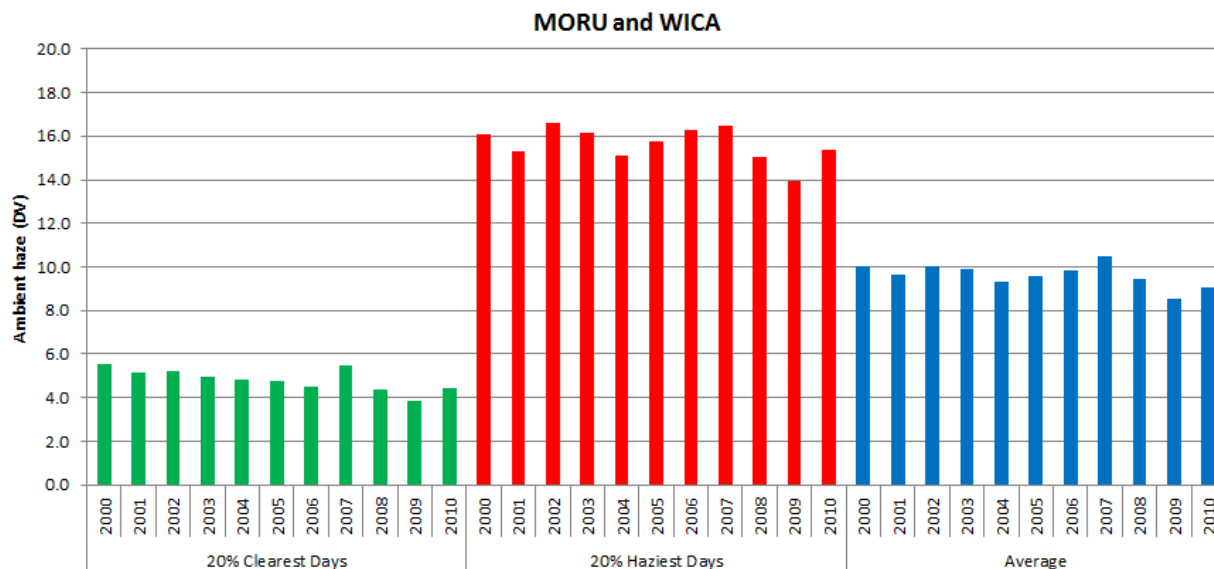


Figure 3c. Trends in ambient haze levels at MORU and WICA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

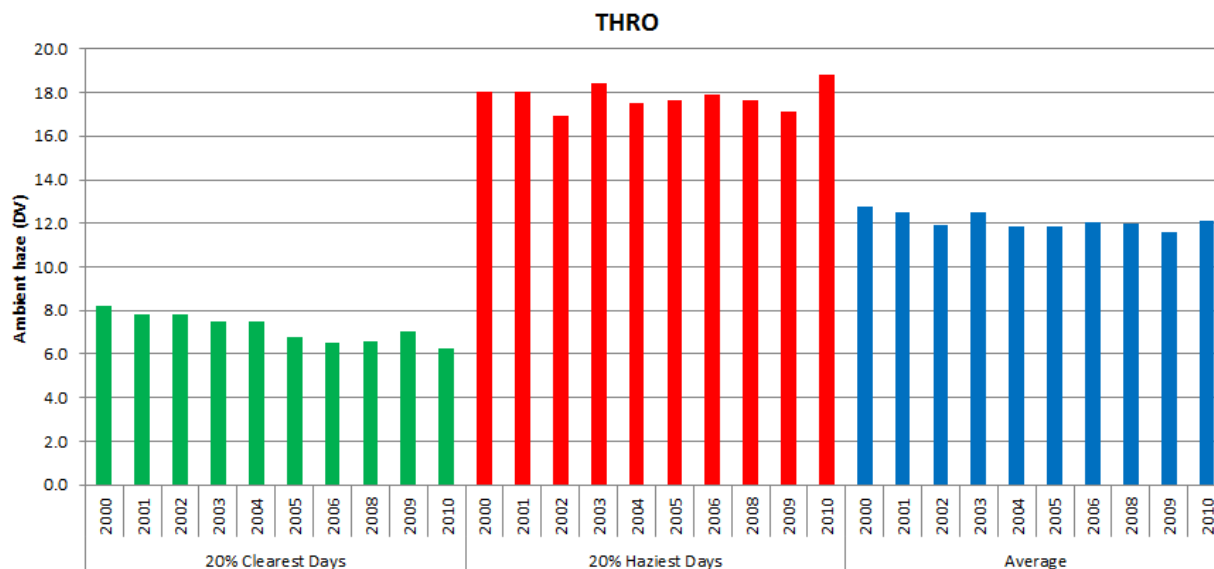


Figure 3d. Trends in ambient haze levels at THRO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for FOUS and MORU were taken from nearby sites. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

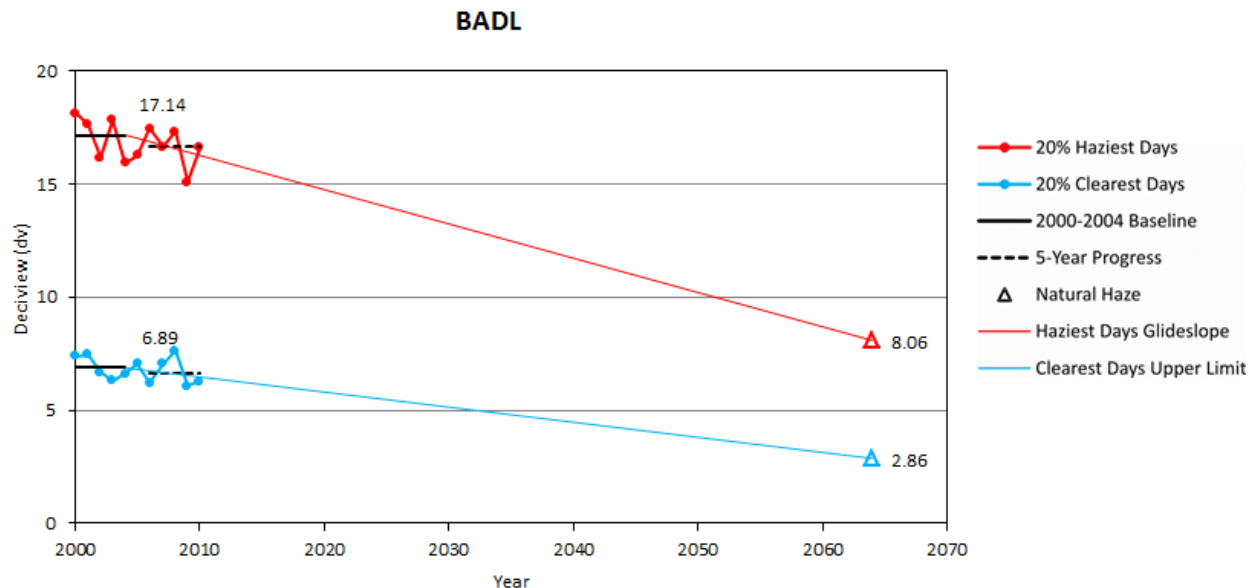


Figure 4a. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in BADL. Data for FOUS and MORU were taken from nearby sites. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; 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. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source:

http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm



Figure 4b. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in FOUS. Data for FOUS and MORU were taken from nearby sites. 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. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source:

http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

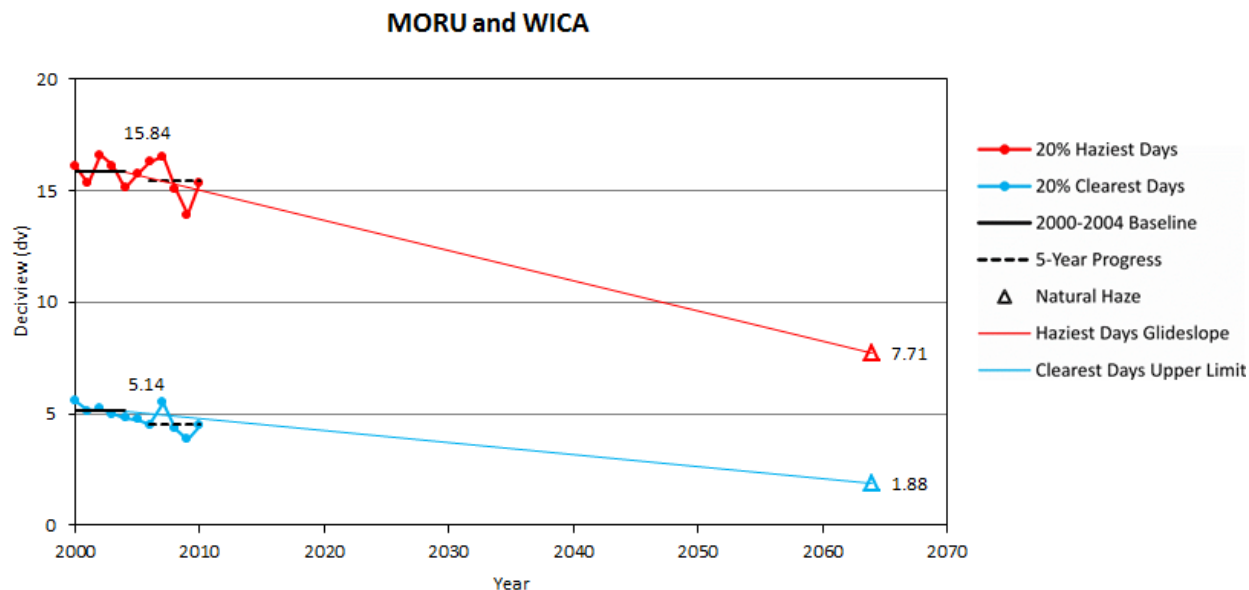


Figure 4c. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in MORU and WICA. Data for FOUS and MORU were taken from nearby sites. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; 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. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

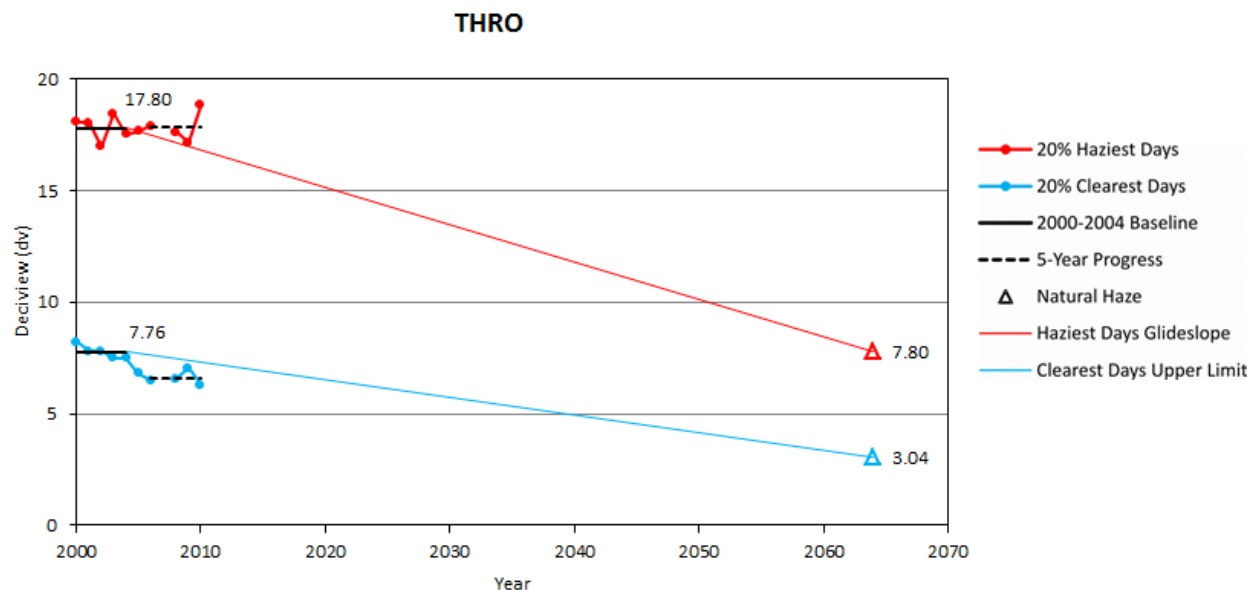


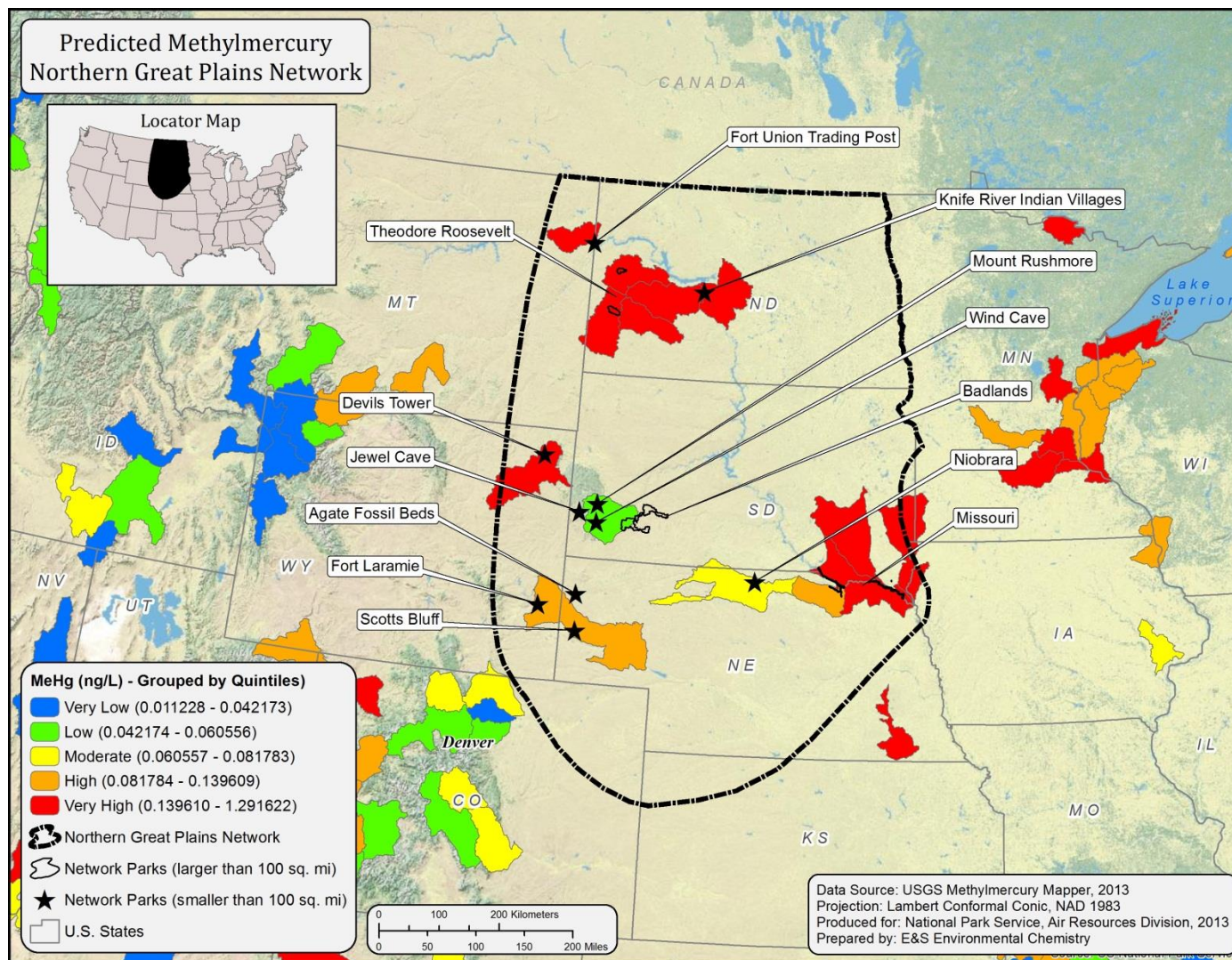
Figure 4d. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in THRO. Data for FOUS and MORU were taken from nearby sites. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; 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. THRO has no valid, measured data for the years 2000 and 2007, but has RHR2_VS substituted data for the year 2000. Data Source:

http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Toxic Airborne Contaminants

Information is generally not available regarding possible effects of air toxics deposition on sensitive park resources in NGPN. However, Bennett and Wetmore (2000) sampled two species of lichen (*Parmelia sulcata* and *Xanthoparmelia chlorochroa*) at THRO 16 years apart and analyzed them for their elemental content. Sulfur and mercury (Hg) were both highly enriched in the lichen tissue compared to soil, suggesting atmospheric contributions of these elements to lichens in the park. Both S and Hg are emitted by coal-burning power plants as well as other emissions source types. The concentrations of Hg and cadmium (Cd) in lichen tissue both decreased about 30% during the time between sample collections (1982 and 1998).

Estimates of Hg methylation potential generated by the U.S. Geological Survey (USGS; 2012) for watershed boundaries (based on eight-digit hydrologic unit codes [HUCs]) containing national park lands in NGPN suggested high methylation potential at most parks considered in this analysis (Map 13). This result is likely driven mainly by relatively high concentrations of total organic C in some surface waters in this network. Methylmercury (MeHg) can bioaccumulate in the food chain, reaching toxic levels in fish and wildlife, posing a potential risk for wildlife and humans that consume fish. The current threat level in NGPN parks is not known.



Map 13. Predicted methylmercury (MeHg) concentrations in surface waters by HUCs that contain national parklands in the Northern Great Plains Network. Estimates were generated by USGS (2012). Rankings are based on quintile distributions across all I&M parks having estimates by USGS.

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