



Air Quality Related Values (AQRVs) for Northern Colorado Plateau Network (NCPN) Parks

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

Natural Resource Report NPS/NCPN/NRR—2016/1169



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 Colorado Plateau Network (NCPN). AQRVs are those resources sensitive to air quality. They include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The NCPN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Arches National Park (ARCH), Black Canyon of the Gunnison National Park (BLCA), Bryce Canyon National Park (BRCA), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), Cedar Breaks National Monument (CEBR), Colorado National Monument (COLM), Curecanti National Recreation Area (CURE), Dinosaur National Monument (DINO), Fossil Butte National Monument (FOBU), Golden Spike National Historic Site (GOSP), Hovenweep National Monument (HOVE), Natural Bridges National Monument (NABR), Pipe Spring National Monument (PISP), Timpanogos Cave National Monument (TICA), and Zion National Park (ZION). ARCH, BLCA, BRCA, CANY, CARE, and ZION are designated as Class I parks, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA).

Sullivan et al. (2011a, 2011b) and Kohut (2007a) conducted risk assessments for acidification, eutrophication, and O₃ for all of the NCPN parks; their results are described in this report. This report also describes air pollutant emissions and air quality, and their effects on AQRVs in SCPN parks. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO₃⁻], ammonium [NH₄⁺], and sulfate [SO₄²⁻]); ground-level O₃; haze-causing particles; and airborne toxics. Background for this section can be found in Chapter 1 of “Air Quality Related Values (AQRVs) in National Parks: Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics” (Sullivan 2016).

Atmospheric N and S pollutants can cause acidification of streams, lakes, and soils. Nevertheless, emissions and deposition of S and N in and around the NCPN region are low. In general, county-level S and N emissions were both less than 5 tons per square mile per year in most counties within the NCPN. Total S deposition estimated by Sullivan et al. (2011b) within the NCPN region was generally less than 2 kg S/ha/yr in 2002. Throughout most of the network region, the estimated total N deposition was less than 5 kg N/ha/yr. Given the relatively low levels of acidic deposition, the risk of acidification to soils and streams in this network is considered low.

In addition to contributing to acidification, N deposition can also cause undesirable enrichment of natural ecosystems, leading to changes in aquatic and terrestrial plant species diversity and soil nutrient cycling. Terrestrial resources in the parks in the NCPN are likely highly sensitive to nutrient N enrichment from atmospheric N deposition, given the widespread distribution of arid and semi-arid plant communities. In several NCPN parks, N deposition is exceeding or close to exceeding levels known to affect natural diversity of plant and lichen communities. Potential future increases in local N emissions from agriculture and oil and gas (O&G) development near some of the parks in the NCPN is cause for concern (Sullivan and McDonnell 2014).

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to plant foliage. Ozone levels are relatively low in the NCPN region, but in recent years have increased in

some areas, including DINO. Recent increases in wintertime O₃ in and near DINO appear to be associated with emissions related to O&G development in the Uintah Basin of northeastern Utah, and could pose a health risk to visitors and park staff. Summertime O₃ levels are generally not considered high enough to harm plants, and O₃ uptake is often limited by dry soil conditions. Plants in riparian areas may be at greater risk because their uptake of O₃ is less likely to be limited by dry soil conditions.

Ozone precursors are emitted within and upwind from the NCPN region from a variety of NO_x source types, including power plants, industry, motor vehicles, oil and gas development, and others. Forest fires contribute to these emissions. They emit considerable quantities of NO_x and hydrocarbons, and therefore can contribute to O₃ formation. The concentration of O₃ in the atmosphere in the nonurban western United States has increased since the late 1980s by about 5 ppbv (Jaffe and Ray 2007). Jaffe et al. (2008) investigated the role of forest fire in this trend. The summer burned area was significantly correlated with O₃ concentration at CASTNET and NPS atmospheric chemistry monitoring sites, including sites within CANY. For mean and maximum fire years, the concentration of O₃ in the atmosphere was increased by fire by an average of 3.5 and 8.8 ppbv, respectively. The estimated amount of biomass consumed was a slightly better predictor of O₃ concentration than burned area. This relationship between atmospheric O₃ concentration and burned area or biomass consumed is especially important because the frequency of extreme fire years in the western United States appears to be increasing (Jaffe et al. 2004) due to increased spring and summer temperature, earlier snowmelt, and dryer conditions (Cook et al. 2004, Westerling et al. 2006). Jaffe et al. (2008) concluded that the increase in fires in the western United States has largely been responsible for the observed increase in summer O₃ concentrations reported by Jaffe and Ray (2007). Increasing temperature in the future will likely further influence the effects of fire on O₃ formation, mainly during summer and fall months. High wintertime O₃ episodes are associated with elevated levels of emissions from other source types and occur when the ground is covered with snow and weather conditions promote the formation of a strong temperature inversion.

Particulate pollution can cause haze, reducing visibility. Visibility is a source of concern for all parks in the northern Colorado Plateau because of the magnificent vistas viewed from within and looking into and out of these parks. However, some of the best visibility in the conterminous United States typically occurs in the Colorado Plateau, and effects of haze are limited and mostly stable or improving.

Other airborne contaminants, including mercury (Hg) and other heavy metals and also semi-volatile organic compounds (SOCs), can accumulate in food webs, reaching toxic levels in top predators. Some fish at CARE have been found to have elevated levels of Hg in their tissues; whether the source of the Hg is atmospheric or runoff from mine contamination is undetermined. Information on SOCs in the NCPN is not available.

Background

There are five parks in the NCPN that are larger than 100 square miles: Arches National Park (ARCH), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), Dinosaur National Monument (DINO), and Zion National Park (ZION). There are also 11 smaller parks: Black Canyon of the Gunnison National Park (BLCA), Bryce Canyon National Park (BRCA), Cedar Breaks National Monument (CEBR), Colorado National Monument (COLM), Curecanti National Recreation Area (CURE), Fossil Butte National Monument (FOBU), Golden Spike National Historic Site (GOSP), Hovenweep National Monument (HOVE), Natural Bridges National Monument (NABR), Pipe Spring National Monument (PISP) and Timpanogos Cave National Monument (TICA). 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.

All population centers of considerable magnitude (larger than 25,000 people) in this network region are found near the Great Salt Lake. The remainder of the network region is sparsely populated. Map 1 shows the network boundary, the location of each park, and population centers around the network having more than 100,000 people.

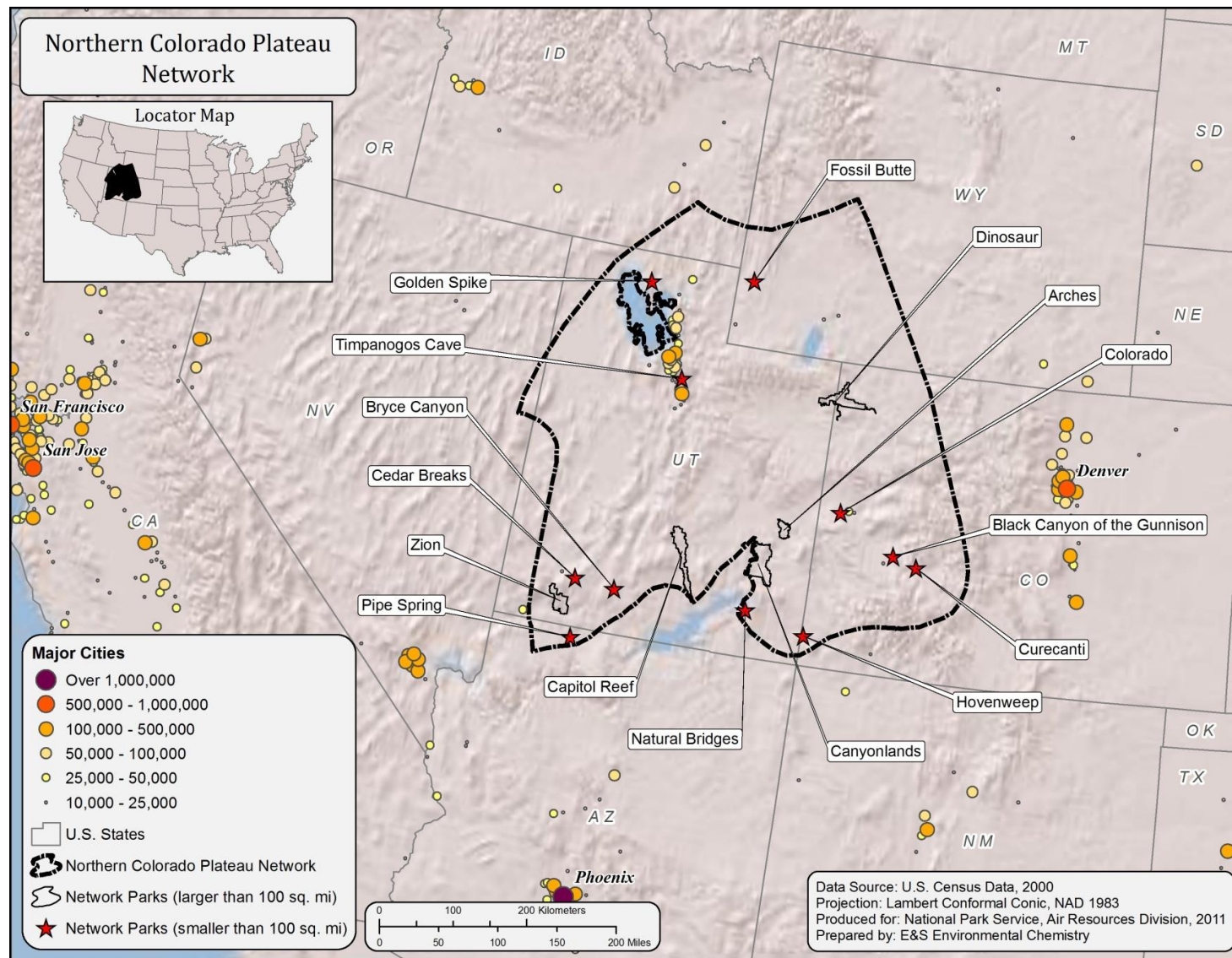
Atmospheric Emissions and Deposition

Annual county-level sulfur (S) emissions in the NCPN region ranged from less than 1 ton per square mile of sulfur dioxide (SO₂) to between 1 and 5 tons per square mile in 2002. In general, county-level S and nitrogen (N) emissions were both less than 5 tons per square mile per year at most locations within the network region. There were scattered SO₂ point sources in the network; most were relatively small and emitted less than 5,000 tons per year.

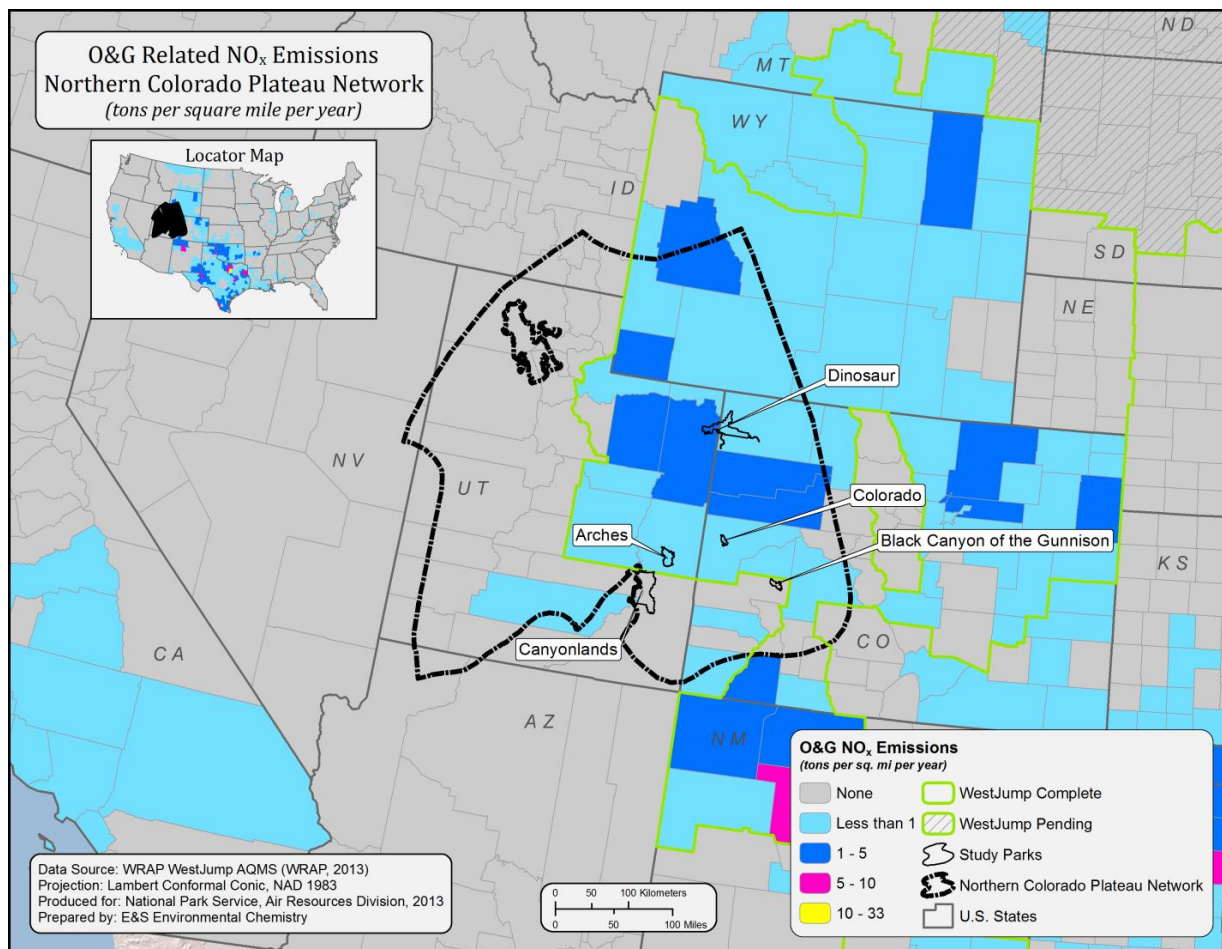
Annual county-level N emissions within the network ranged from less than 1 ton per square mile to between 5 and 20 tons per square mile in 2002. There were several relatively large (larger than about 4,000 tons per year) point sources of oxidized N in and around this network; point source emissions of reduced N were much lower.

Oil and gas (O&G) emissions of N per unit land area in 2008 were relatively high near DINO (Map 2). Furthermore, there has been a continuing increase in O&G development since 2008. Emissions levels are undoubtedly higher, perhaps substantially higher, now than they were in 2008. In some counties in the NCPN, O&G N emissions represented a substantial percentage of the overall N emissions from all sources in 2008 (Map 3).

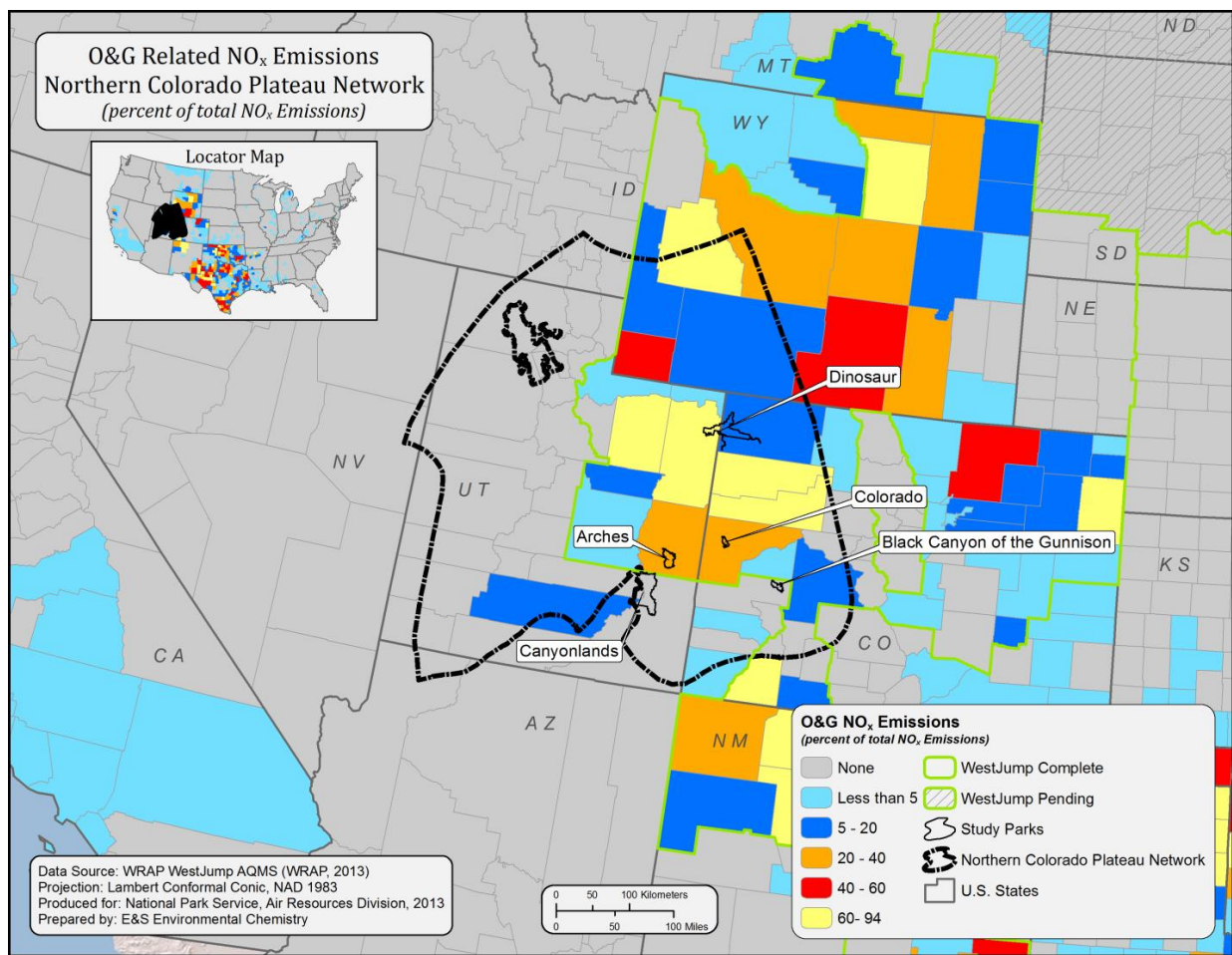
County-level emissions near NCPN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 4 through 6 for SO₂, oxidized N (NO_x), and reduced N (NH₃), respectively. Many counties to the north and west of NCPN parks had relatively high SO₂ emissions (> 5 tons/mi²/yr; Map 4). Spatial patterns in NO_x emissions were generally similar, with highest values to the northwest of NCPN parks (Map 5). Emissions of NH₃ near NCPN parks were somewhat lower, with most counties showing emissions levels below 2 tons/mi²/yr (Map 6).



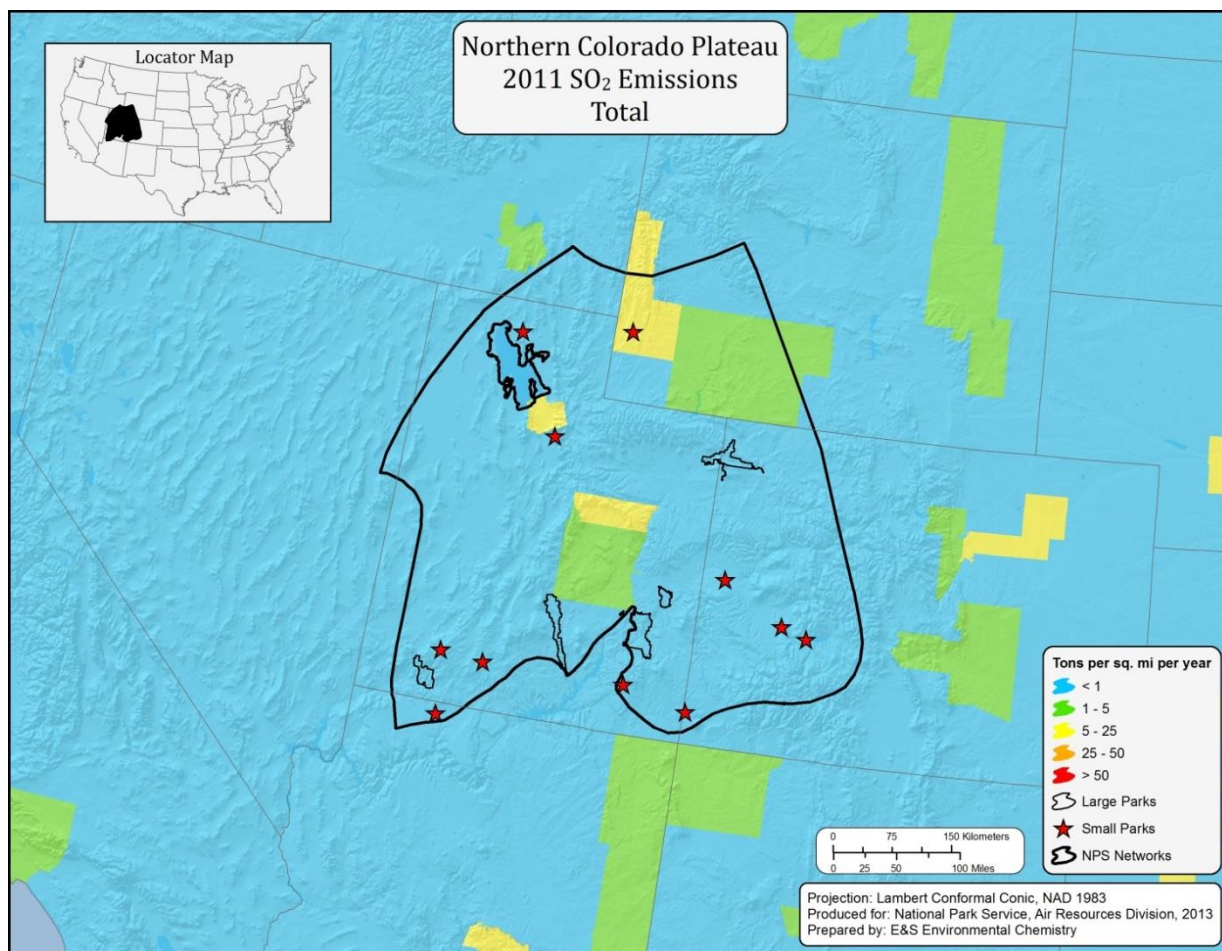
Map 1. Network boundary and locations of parks and population centers with more than 10,000 people near the NCPN.



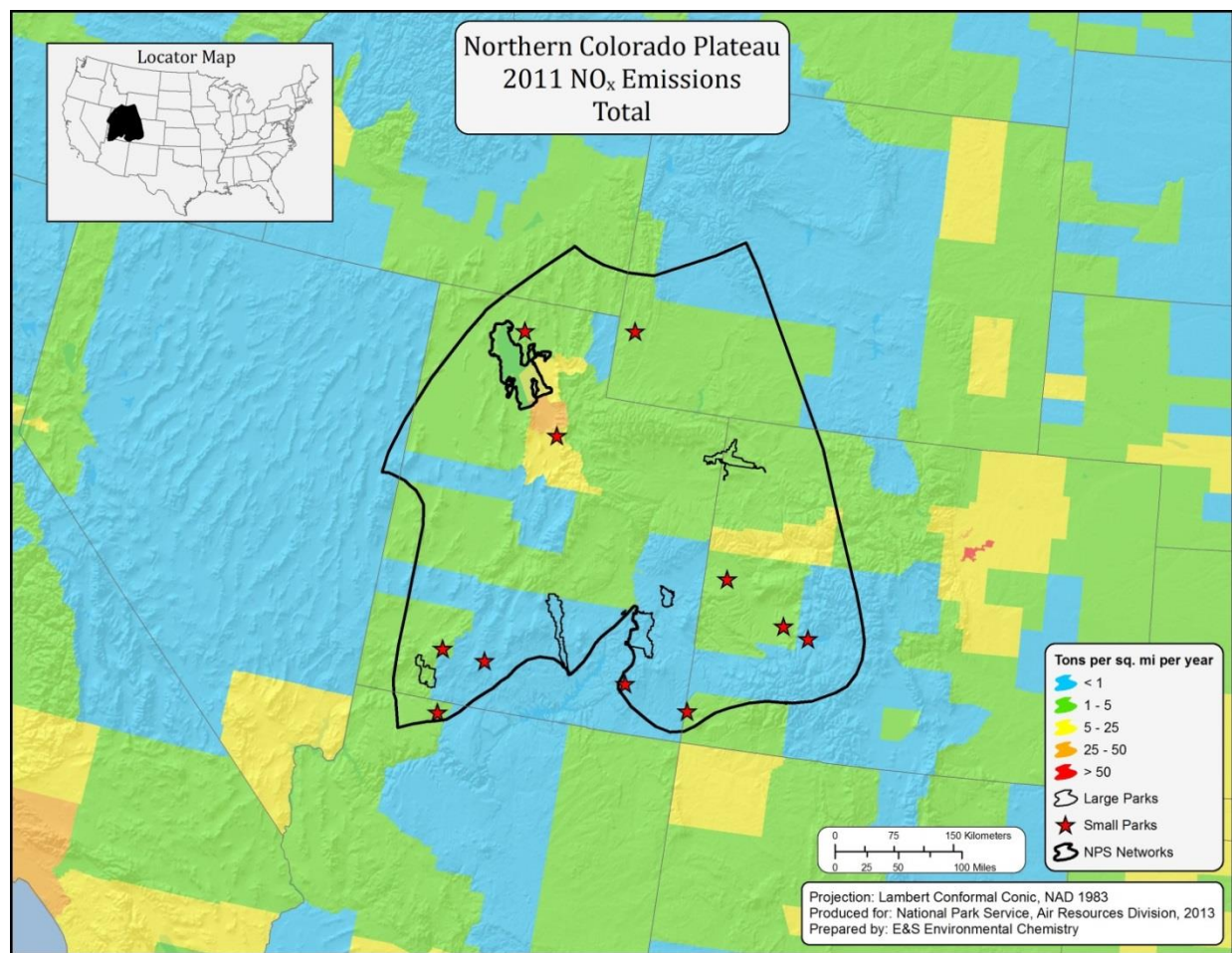
Map 2. Estimated oil and gas (O&G) NO_x emissions per unit land area (tons/mi²/yr) in the Northern Colorado Plateau Network for the year 2008.



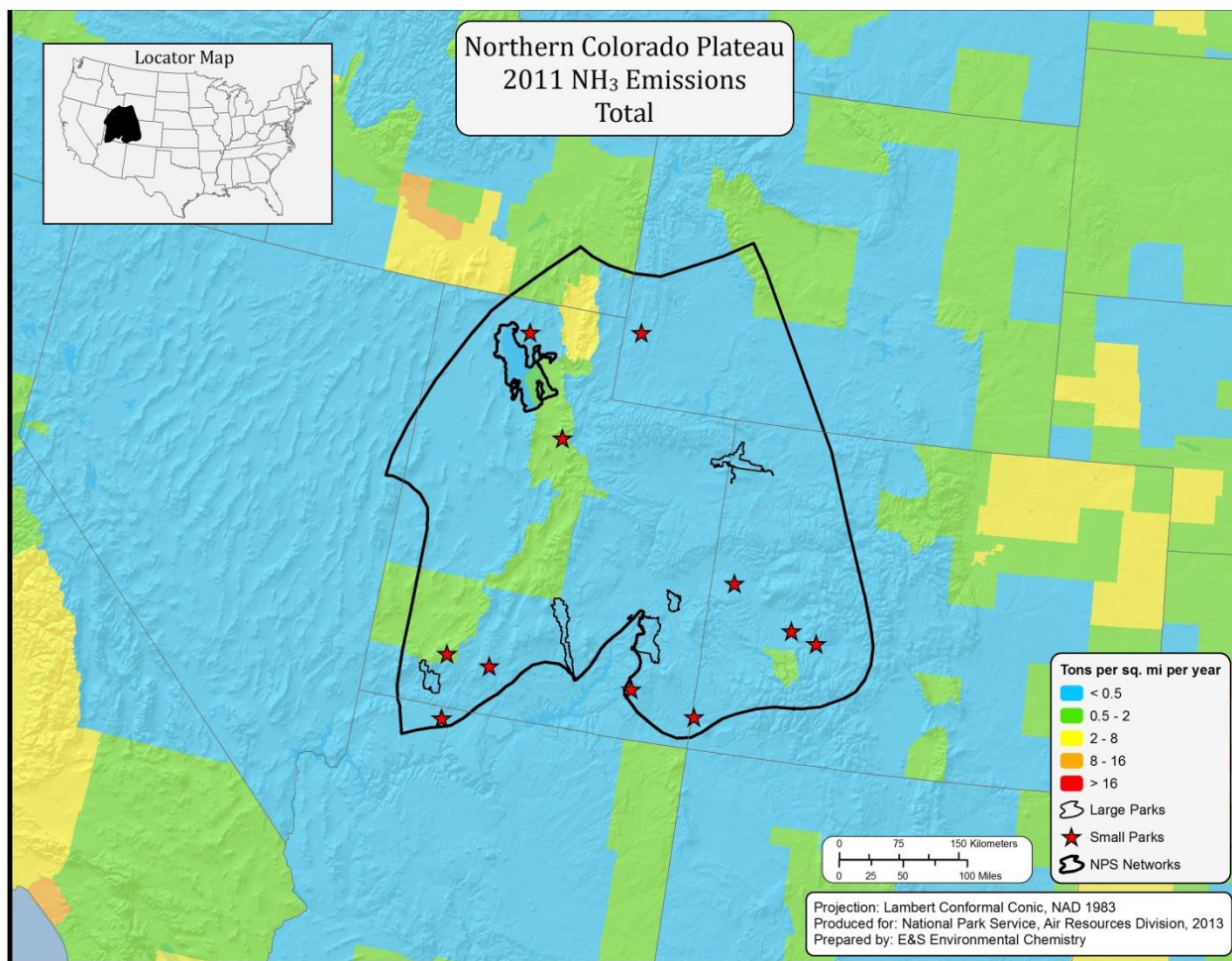
Map 3. Estimated oil and gas (O&G) NO_x emissions in the Northern Colorado Plateau Network as a percentage of total NO_x emissions for the year 2008.



Map 4. Total SO₂ emissions, by county, near NCPN for the year 2011. Data from EPA's National Emissions Inventory.



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



Map 6. Total NH_3 emissions, by county, near NCPN for the year 2011. Data from EPA's National Emissions Inventory.

Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data.

Modeling was accomplished using the Community Multiscale Air Quality (CMAQ) model (Byun and Schere 2006). Priority was given to measured data near the locations of the monitors and to modeled data where monitoring data were not available. In addition, CMAQ data were used for N species that are not routinely measured in the monitoring programs: peroxyacetyl nitrate (PAN), N_2O_5 , NO, NO_2 , HONO, and organic NO_3 . The total deposition estimates are considered to be dynamic, with updates planned as new information becomes available. TDEP data reported here were developed in late 2013 and are designated version 2013.02.

Atmospheric S deposition levels have declined at most NCPN parks since 2001, based on TDEP estimates (Table 1). Estimated total N deposition showed variable responses. At almost all parks in the NCPN, reduced N deposition increased, in many cases by sizeable amounts. Oxidized N deposition decreased in nearly all parks in the network.

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

Park Code	Park Name	Parameter	2001	2011	Absolute	Percent Change	2011	2011	2011
			Average (kg/ha/yr)	Average (kg/ha/yr)	Change (kg/ha/yr)		Minimum (kg/ha/yr)	Maximum (kg/ha/yr)	Range (kg/ha/yr)
ARCH	Arches	Total S	1.01	0.68	-0.33	-32.3%	0.62	0.78	0.16
		Total N	3.11	2.29	-0.82	-26.2%	2.13	2.65	0.52
		Oxidized N	2.31	1.51	-0.79	-34.4%	1.40	1.71	0.31
		Reduced N	0.80	0.78	-0.02	-2.6%	0.70	0.94	0.24
BLCA	Black Canyon of the Gunnison	Total S	0.76	0.74	-0.02	-2.6%	0.59	0.85	0.26
		Total N	2.39	2.46	0.06	2.7%	2.10	2.71	0.61
		Oxidized N	1.61	1.32	-0.30	-18.6%	1.11	1.48	0.37
		Reduced N	0.78	1.14	0.36	46.9%	0.99	1.42	0.43
BRCA	Bryce Canyon	Total S	1.11	0.93	-0.18	-16.4%	0.75	1.29	0.54
		Total N	3.46	3.28	-0.18	-5.5%	2.74	4.31	1.57
		Oxidized N	2.49	1.97	-0.51	-20.8%	1.64	2.60	0.96
		Reduced N	0.98	1.31	0.33	33.8%	1.08	1.72	0.64
CANY	Canyonlands	Total S	0.97	0.68	-0.29	-29.7%	0.59	0.92	0.33
		Total N	2.85	2.22	-0.63	-22.2%	1.94	3.10	1.16
		Oxidized N	2.20	1.50	-0.70	-31.7%	1.31	2.09	0.78
		Reduced N	0.65	0.72	0.06	9.7%	0.63	1.01	0.38
CARE	Capitol Reef	Total S	0.82	0.70	-0.11	-14.0%	0.48	1.19	0.71
		Total N	2.75	2.69	-0.06	-2.7%	1.70	4.58	2.88
		Oxidized N	2.02	1.61	-0.41	-20.5%	1.15	2.54	1.38
		Reduced N	0.73	1.08	0.35	47.1%	0.55	2.04	1.49
CEBR	Cedar Breaks	Total S	1.99	1.69	-0.30	-14.8%	1.54	1.77	0.23
		Total N	5.47	5.86	0.39	7.0%	5.18	6.54	1.36
		Oxidized N	3.66	3.05	-0.61	-16.6%	2.83	3.19	0.36
		Reduced N	1.81	2.81	1.00	53.8%	2.23	3.52	1.29

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

Park Code	Park Name	Parameter	2001	2011	Absolute	Percent Change	2011	2011	2011
			Average (kg/ha/yr)	Average (kg/ha/yr)	Change (kg/ha/yr)		Minimum (kg/ha/yr)	Maximum (kg/ha/yr)	Range (kg/ha/yr)
CEBR	Cedar Breaks	Total S	1.99	1.69	-0.30	-14.8%	1.54	1.77	0.23
		Total N	5.47	5.86	0.39	7.0%	5.18	6.54	1.36
		Oxidized N	3.66	3.05	-0.61	-16.6%	2.83	3.19	0.36
		Reduced N	1.81	2.81	1.00	53.8%	2.23	3.52	1.29
COLM	Colorado	Total S	0.96	0.66	-0.29	-30.4%	0.61	0.75	0.15
		Total N	2.92	2.85	-0.08	-2.4%	2.40	3.05	0.65
		Oxidized N	2.08	1.44	-0.64	-30.7%	1.25	1.64	0.39
		Reduced N	0.85	1.41	0.56	67.4%	0.92	1.56	0.64
CURE	Curecanti	Total S	0.61	0.65	0.04	7.9%	0.44	0.85	0.41
		Total N	1.78	1.95	0.17	10.2%	1.50	2.63	1.13
		Oxidized N	1.24	1.14	-0.10	-7.6%	0.78	1.52	0.74
		Reduced N	0.54	0.81	0.27	52.2%	0.64	1.11	0.47
DINO	Dinosaur	Total S	0.66	0.81	0.15	23.2%	0.58	1.02	0.43
		Total N	2.20	2.39	0.19	8.9%	1.86	2.74	0.87
		Oxidized N	1.61	1.56	-0.05	-2.6%	1.17	1.81	0.63
		Reduced N	0.59	0.82	0.23	40.6%	0.65	1.34	0.69
FOBU	Fossil Butte	Total S	0.87	4.41	3.54	430.8%	1.65	12.55	10.90
		Total N	2.83	3.26	0.43	15.3%	3.01	3.60	0.60
		Oxidized N	1.73	1.50	-0.23	-13.2%	1.31	2.01	0.70
		Reduced N	1.10	1.76	0.66	59.8%	1.36	2.22	0.86
GOSP	Golden Spike	Total S	1.06	0.78	-0.29	-27.1%	0.72	0.91	0.18
		Total N	4.76	5.64	0.88	18.4%	4.60	6.45	1.85
		Oxidized N	2.33	1.27	-1.07	-45.6%	1.22	1.35	0.13
		Reduced N	2.42	4.37	1.95	80.7%	3.37	5.17	1.79

Table 1 (continued). Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCPN parks. Deposition estimates were determined by the U.S. EPA's 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)
HOVE	Hovenweep	Total S	1.21	0.95	-0.26	-21.0%	0.75	1.15	0.40
		Total N	3.09	2.88	-0.21	-7.3%	2.23	3.62	1.39
		Oxidized N	2.46	1.99	-0.47	-19.3%	1.61	2.20	0.59
		Reduced N	0.63	0.89	0.26	38.8%	0.62	1.46	0.84
NABR	Natural Bridges	Total S	1.09	1.06	-0.03	-2.3%	0.89	1.21	0.33
		Total N	3.07	3.50	0.44	14.3%	3.00	3.92	0.92
		Oxidized N	2.35	2.49	0.14	5.8%	2.14	2.74	0.60
		Reduced N	0.71	1.02	0.30	42.3%	0.86	1.18	0.32
PISP	Pipe Spring	Total S	0.82	0.62	-0.20	-24.2%	0.62	0.62	0.00
		Total N	2.97	2.35	-0.62	-20.8%	2.35	2.35	0.00
		Oxidized N	2.28	1.45	-0.83	-36.4%	1.45	1.45	0.00
		Reduced N	0.69	0.90	0.21	31.2%	0.90	0.90	0.00
TICA	Timpanogos Cave	Total S	1.81	2.06	0.25	14.1%	2.06	2.06	0.00
		Total N	6.27	8.43	2.16	34.5%	8.43	8.43	0.00
		Oxidized N	3.51	3.40	-0.11	-3.2%	3.40	3.40	0.00
		Reduced N	2.76	5.03	2.28	82.5%	5.03	5.03	0.00
ZION	Zion	Total S	1.10	0.98	-0.12	-10.7%	0.74	1.35	0.62
		Total N	3.71	3.71	0.00	-0.3%	2.89	5.16	2.27
		Oxidized N	2.73	2.11	-0.62	-22.7%	1.72	2.61	0.90
		Reduced N	0.98	1.60	0.61	61.8%	1.16	2.62	0.00

Dry deposition predominates in arid ecosystems, such as are prevalent in the NCPN. It is difficult to quantify, however, in large part because the deposition flux is influenced by a multitude of factors, including the mix of air pollutants present, surface characteristics of soil and vegetation, and meteorological conditions (Weathers et al. 2006). Because the vegetation is sparse in arid ecosystems, soil surfaces are potentially exposed to substantial direct dry deposition of atmospheric pollutants. Padgett et al. (1999) found that inorganic N can accumulate on the soil surface of coastal sage scrub vegetation communities in southern California during dry smoggy periods. Upon onset of the rainy season, the concentration of NO_3^- in the surface soil decreased and NO_3^- was leached down the soil profile (Padgett et al. 1999, Padgett and Bytnerowicz 2001). This can supply a pulse of N to plant roots.

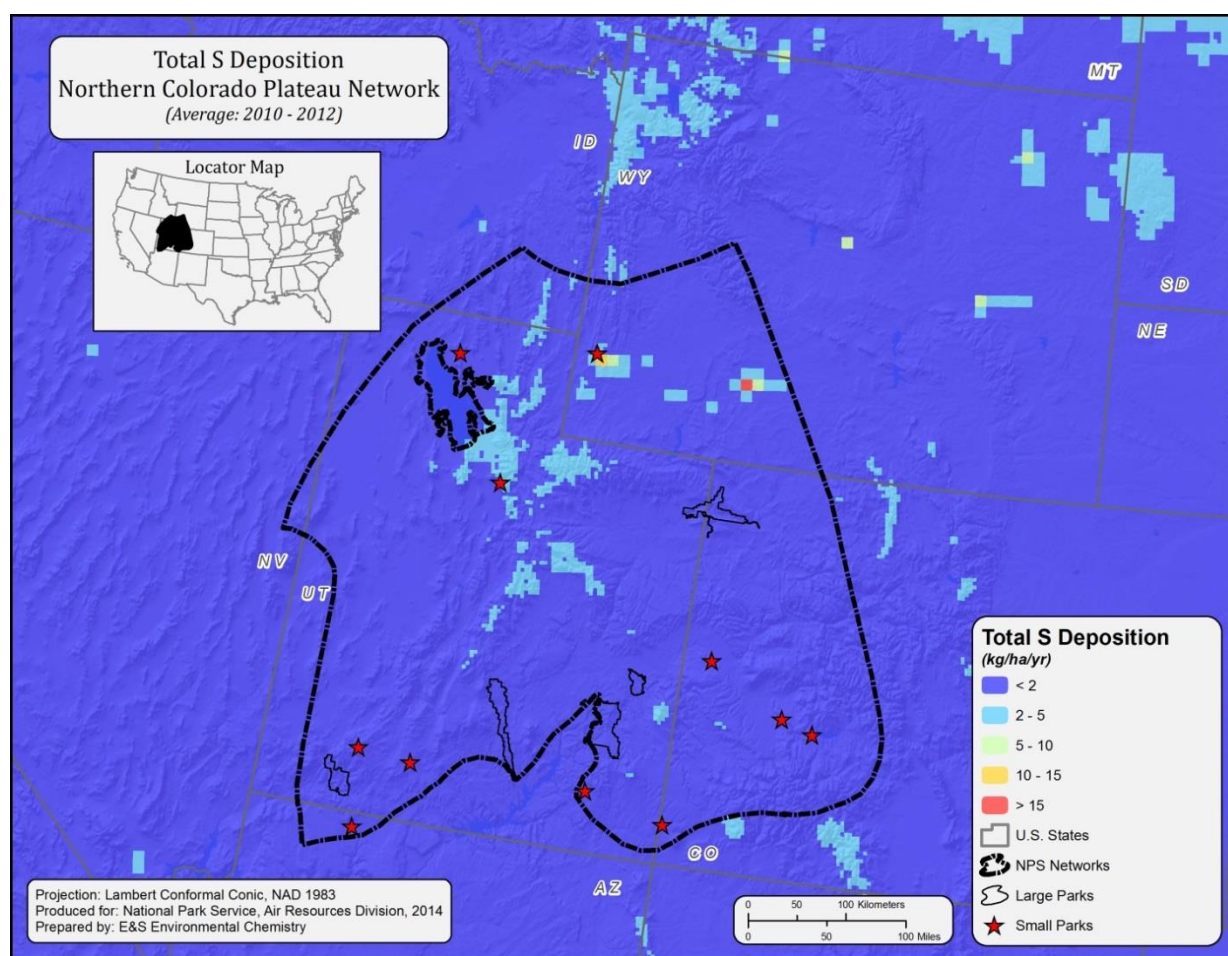
Total S deposition estimated by Sullivan et al. (2011b) within the NCPN was generally less than 2 kg S/ha/yr in 2002; there were only a few scattered locations where it was slightly higher. Total N deposition within the network in 2002 ranged from less than 2 kg N/ha/yr to as high as 5 to 10 kg N/ha/yr. Throughout most of the network, the estimated total N deposition was less than 5 kg N/ha/yr. The highest estimated N deposition within the network occurs around the Great Salt Lake where much of the human development is concentrated.

Total S deposition in and around the NCPN for the period 2010-2012 was generally highest (> 5 kg S/ha/yr) in the northcentral portion of the network region and lowest (< 2 kg S/ha/yr) in the southern portion of the network area (Map 7). Oxidized inorganic N deposition for the period 2010-2012 was less 5 kg N/ha/yr throughout the park land within the NCPN (Map 8). Most park areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 9); a few areas received higher amounts. Total N deposition was less than 10 kg N/ha/yr at most park locations (Map 10).

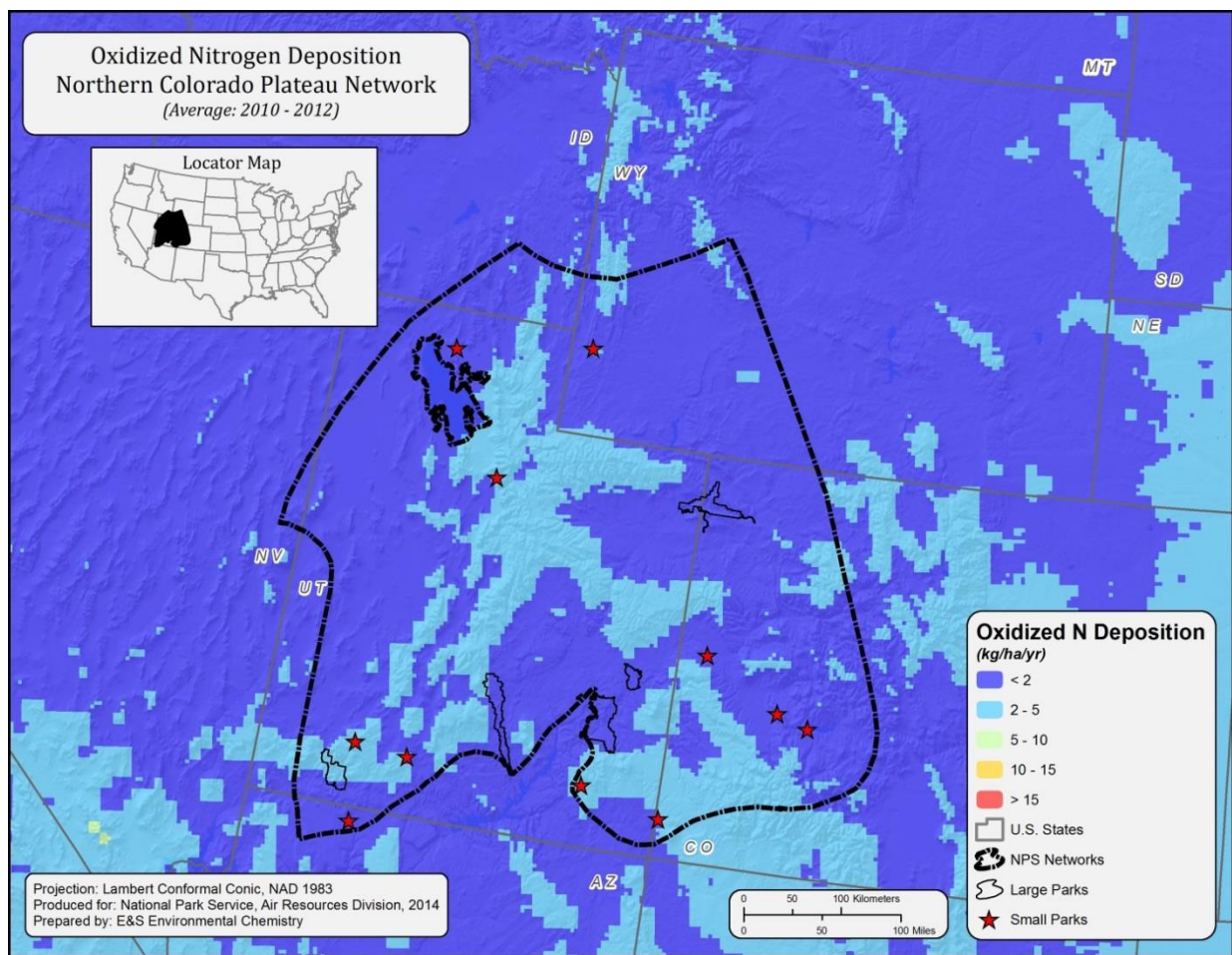
Acidification

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 the NCPN that was near the middle of the distribution among all networks. The overall level of concern for acidification effects on Inventory and Monitoring (I&M) parks within this network was considered by Sullivan et al. (2011b) to be Moderate. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

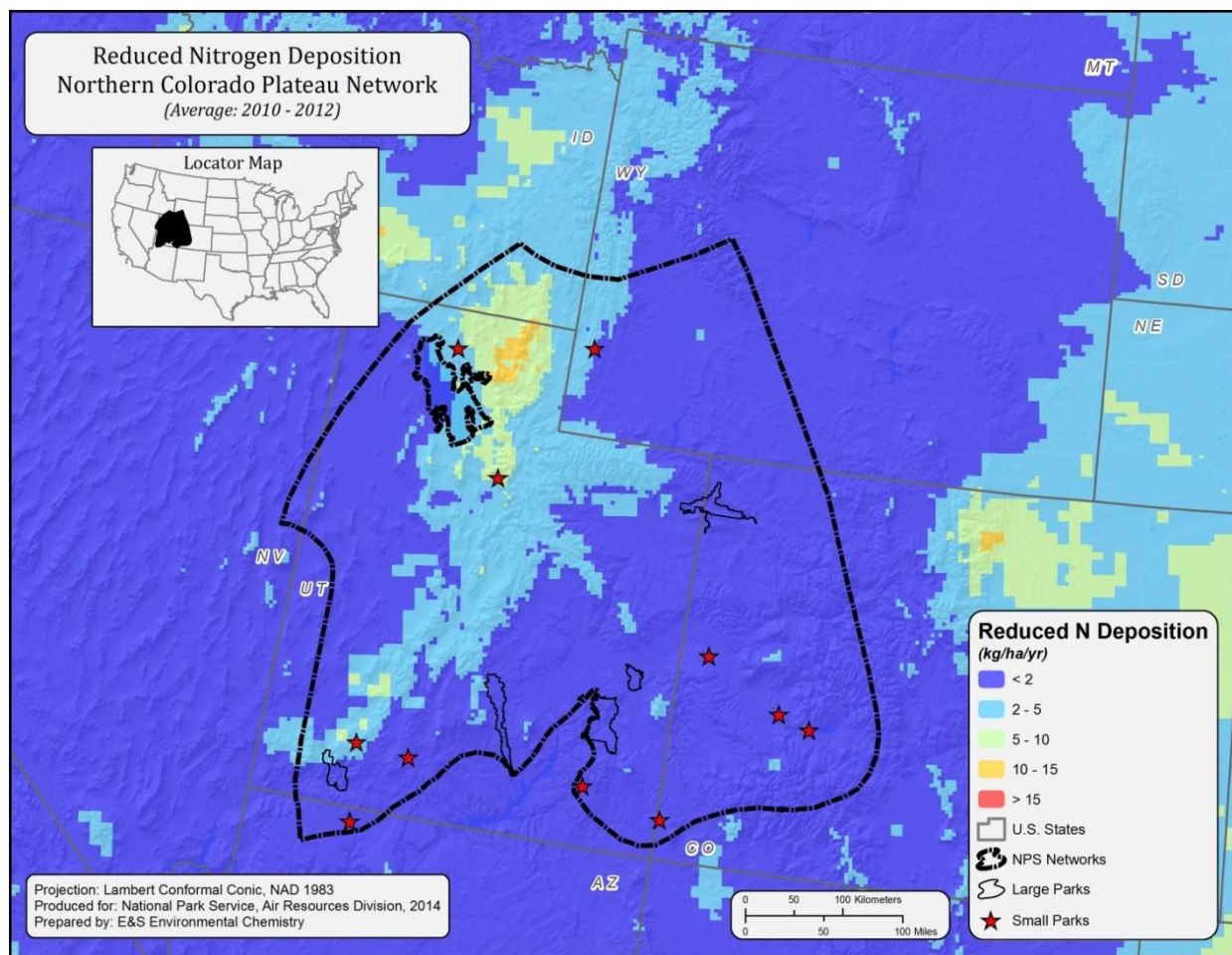
The five I&M parks in the Northern Colorado Plateau Network that are larger than 100 square miles were all in the lowest (four parks) or second lowest (DINO) quintile in acid Pollutant Exposure (Sullivan et al. 2011b). Among the smaller parks, TICA and HOVE were ranked in the middle quintile and the remaining parks were ranked in the second lowest or lowest quintile for this theme.



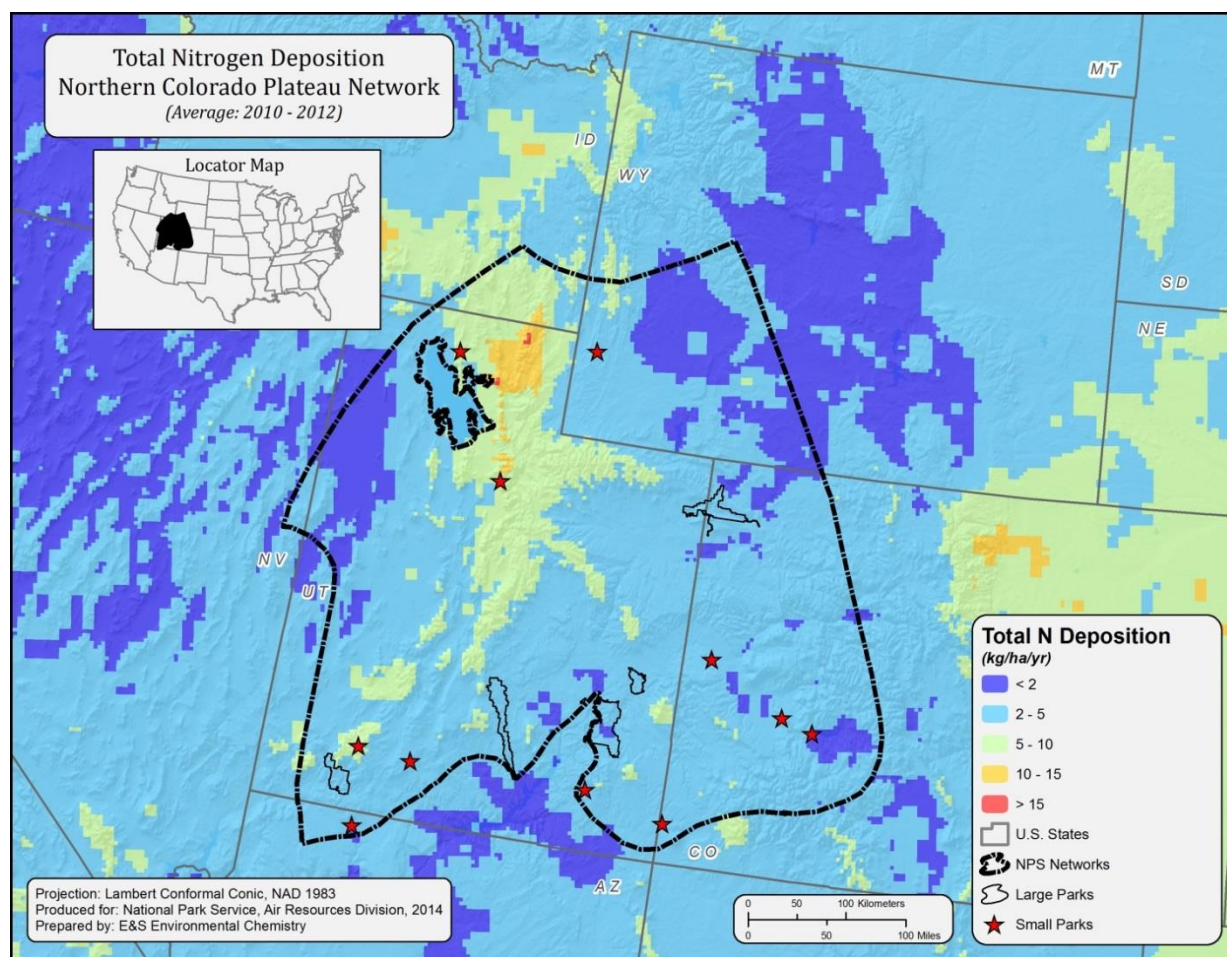
Map 7. Total S deposition for the three-year period centered on 2011 in and around the NCPN. (Source: Schwede and Lear 2014)



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



Map 9. Reduced inorganic N deposition for the three-year period centered on 2011 in and around the NCPN. (Source: Schwede and Lear 2014)



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

The ranking system for Ecosystem Sensitivity to acidification applied by Sullivan et al. (2011b) was based on generalized coarse-scale data. The suggestion that some of the parks in this network might be acid-sensitive is not supported by park-specific data. In general, surface waters of the NCPN are considered resistant to acidification due to the nature of the hydrogeology of the region (Binkley et al. 1997). Data are not available that document substantial sensitivity of aquatic or terrestrial resources to acidification. Given the relatively low levels of acidic deposition (especially of S), acidification effects are unlikely in this network at the present time.

Nutrient Nitrogen Enrichment

The network rankings developed by Sullivan et al. (2011a) for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient enrichment, and Park Protection yielded an overall network nutrient enrichment Summary Risk ranking for the NCPN that was in the second highest quintile among all networks. The overall level of concern for nutrient N enrichment effects on I&M parks within this network was judged by Sullivan et al. (2011a) to be High. Because the NCPN contains substantial arid and semi-arid vegetation, the network is presumed to be highly sensitive to nutrient N enrichment effects. Additions of N to grasslands in this network may favor the spread of non-native invasive grass and herbaceous species. 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 five I&M parks in the NCPN that are larger than 100 square miles were all in the lowest quintile (very low) in nutrient N Pollutant Exposure (Table 2). Among the smaller parks, TICA was ranked in the middle quintile (moderate) and three parks (FOBU, GOSP, and HOVE) were ranked in the second lowest quintile (low) for nutrient N Pollutant Exposure. Other small parks were ranked Very Low. Pollutant exposure rankings may change as more is learned about the extent of O&G emissions in the NCPN region.

Ecosystem Sensitivity to nutrient N enrichment was ranked in the highest (ARCH, CANY, DINO) or second highest (CARE, ZION) quintile for all of the large parks (Table 2). The smaller parks exhibited variable rankings, from the lowest quintile (TICA) to the highest quintile (CURE, FOBU, GOSP, HOVE) for this theme (Table 2).

Historically, ecosystems in the arid Southwest derived much of their N from N-fixation in biological soil crusts (Schwinning et al. 2005). Atmospheric N deposition now constitutes an additional important source of N input to these systems. Biological crusts are active mainly during the cooler months, from autumn to spring (Belnap 2003), when the native plant N requirement is highest. While active, these crusts release N to the soil as NH_4^+ , which is then transformed to NO_3^- . This close coupling between N release to the soil by crusts and peak N demand by native plants may have been important in maintaining native grasslands. The simultaneous decline of soil crust cover and increase in atmospheric N deposition may have decreased ecosystem resilience to environmental change and increased the risk of invasion by weedy summer annuals (Schwinning et al. 2005). For example, a fertilization experiment in an arid grassland on the Colorado Plateau demonstrated a large difference in the response of native and non-native plants to added N (Schwinning et al. 2005). For two years, plots were treated with 0, 10, 20, or 40 kg N/ha/yr as a KNO_3 solution. Galleta (*Hilaria jamesii*) and Indian ricegrass (*Oryzopsis hymenoides*) showed no increase in leaf photosynthesis or tiller size, but ricegrass showed a 50% increase in tiller density in the second year at the 20 and 40 kg N/ha/yr application levels. For both species, the increased N application hastened the onset of water stress.

Table 2. Estimated park rankings¹ according to risk of nutrient enrichment impacts on sensitive receptors in the NCPN (Source: Sullivan et al. 2011b)

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
<i>Arches</i>	ARCH	Very Low	Very High
Black Canyon of the Gunnison	BLCA	Very Low	Moderate
Bryce Canyon	BRCA	Very Low	Low
<i>Canyonlands</i>	CANY	Very Low	Very High
<i>Capitol Reef</i>	CARE	Very Low	High
Cedar Breaks	CEBR	Very Low	Low
Colorado	COLM	Very Low	Low
Curecanti	CURE	Very Low	Very High
<i>Dinosaur</i>	DINO	Very Low	Very High
Fossil Butte	FOBU	Low	Very High
Golden Spike	GOSP	Low	Very High
Hovenweep	HOVE	Low	Very High
Natural Bridges	NABR	Very Low	Low
Pipe Spring	PISP	Very Low	High
Timpanogos Cave	TICA	Moderate	Very Low
<i>Zion</i>	ZION	Very Low	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.

Unexpectedly, a non-native species, Russian thistle (*Salsola iberica*) showed a rapid growth response to the highest fertilization rate in the first summer, when rainfall was above average. Schwinning et al. (2005) suggested that the timing and amount of N deposition could facilitate noxious weed invasion and thus change community composition in arid grasslands.

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 CL in parks in the NCPN for the two relevant ecoregions here (Northwestern Forested Mountains and North American Deserts) suggest relatively low values (≤ 5 kg N/ha/yr at the lower end of the estimated CL range; Table 3). However, ambient N deposition estimates reported by Pardo et al. (2011) at parks in this network were even lower, in most parks less than 3 kg N/ha/yr. With the exception of nutrient-N CL to protect lichens (for which eight NCPN parks were estimated to be in exceedance of the nutrient-N empirical CL), there were few sensitive resources and parks estimated to be in exceedance (Table 3). The exception was TICA, which was estimated to have ambient N deposition approximately double the deposition estimates for the other parks in the network. At TICA, empirical CL were estimated to be in exceedance for protection of mycorrhizal fungi, lichens, herbaceous plants, and forest vegetation and for the prevention of NO₃⁻ leaching in drainage water. Sullivan and McDonnell (2014) mapped

Table 3. Empirical critical loads for nitrogen in the NCPN, 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	Herbaceous			Nitrate Leaching
				Lichen	Plant	Forest	
Arches NP	North American Deserts	2.8	NA	3	3 - 8.4	NA	NA
Black Canyon of the Gunnison NP	North American Deserts	2.7	NA	3	3 - 8.4	NA	NA
Bryce Canyon NP	North American Deserts	2.7	NA	3	3 - 8.4	NA	NA
Bryce Canyon NP	Northwestern Forested Mountains	2.7	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Canyonlands NP	North American Deserts	2.7	NA	3	3 - 8.4	NA	NA
Capitol Reef NP	North American Deserts	2.7	NA	3	3 - 8.4	NA	NA
Capitol Reef NP	Northwestern Forested Mountains	2.7	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Cedar Breaks NM	Northwestern Forested Mountains	3.1	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Colorado NM	North American Deserts	2.5	NA	3	3 - 8.4	NA	NA
Curecanti NRA	North American Deserts	2.7	NA	3	3 - 8.4	NA	NA
Curecanti NRA	Northwestern Forested Mountains	2.7	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Dinosaur NM	North American Deserts	2.3	NA	3	3 - 8.4	NA	NA
Fossil Butte NM	North American Deserts	2.5	NA	3	3 - 8.4	NA	NA
Golden Spike NHS	North American Deserts	3.3	NA	3	3 - 8.4	NA	NA
Hovenweep NM	North American Deserts	3.1	NA	3	3 - 8.4	NA	NA
Natural Bridges NM	North American Deserts	2.1	NA	3	3 - 8.4	NA	NA
Pipe Spring NM	North American Deserts	2.2	NA	3	3 - 8.4	NA	NA
Timpanogos Cave NM	Northwestern Forested Mountains	5.7	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Zion NP	North American Deserts	3.1	NA	3	3 - 8.4	NA	NA
Zion NP	Northwestern Forested Mountains	3.1	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17

nutrient N CL for selected national parks in the intermountain West, including CANY, DINO, COLM, ARCH, and BLCA in the NCPN. This assessment was based on plant communities within Level I ecoregions for which empirical CL were compiled by Pardo et al. (2011). These parks are largely covered by vegetation types that were found by Pardo et al. (2011) to be highly sensitive to potential nutrient N enrichment. The northern half of BLCA was in exceedance, but there were no areas of nutrient N exceedance in ARCH, DINO, or CANY, and only a small section of COLM was in exceedance. Virtually all of COLM and DINO and the southern half of both ARCH and BLCA received N deposition in 2008 that was below, but within 1 kg N/ha/yr, of exceedance. Thus, any appreciable increase in N deposition from further O&G, agricultural, or other sources may increase the risk of excess nutrient effects throughout most of the park lands in the NCPN (Sullivan and McDonnell 2014).

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or thought to occur within the I&M parks found in the NCPN are listed in Table 4. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O₃ (e.g., dark stipple) are designated in the table by an asterisk. All parks in the network contained at least five sensitive and/or bioindicator species.

The W126 and SUM06 O₃ exposure indices calculated by NPS staff are given in Table 5, along with Kohut's (2007a) O₃ risk ranking. The NPS and Kohut ranking systems differ. The NPS ranking system (NPS 2010) is a quick assessment of O₃ condition that ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of either the W126 or SUM06 index. The former is a measure of cumulative O₃ exposure that preferentially weights higher concentrations; the latter is a measure of cumulative O₃ exposure that includes only hourly concentrations over 60 ppb. Both metrics are calculated over a 3-month period. The W126 was classified as Moderate exposure at values between 7 and 13 ppm-hr, as defined by NPS (2010). Values higher than 13 ppm-hr were classified as High exposure, and values lower than 7 ppm-hr were classified as Low exposure. The SUM06 was classified as Moderate at values between 8 and 15 ppm-hr. Higher and lower values were classified as High and Low, respectively, as defined by NPS (2010).

Kohut's approach constitutes a comprehensive assessment of potential risk to plants. It considers both O₃ exposure and environmental conditions (soil moisture). Kohut also used injury thresholds from the literature, but evaluated a different O₃ metric (after Lefohn et al. 1997), the W126 over a 5-month period in conjunction with the N100 (number of hours over 100 ppb O₃). The rationale for the N100 statistic is that higher O₃ concentrations are most likely to cause plant injury. Kohut examined five individual years of O₃ exposure and soil moisture data and considered the effects of low soil moisture on O₃ uptake each year when assigning risk. 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.

The results of both ranking systems should be considered when evaluating the potential for O₃ injury to park vegetation. The Kohut approach considered environmental conditions that significantly affect plant response to O₃, but exposures have likely changed since the time of the assessment (1995-1999). The NPS approach considers more recent O₃ conditions (2005-2009), but not environmental conditions.

Within the NCPN, Kohut (2007b) classified only FOBU, GOSP, and TICA as having Moderate risk of foliar injury due to O₃ exposure. All other parks were classified as having Low risk. Low soil moisture can limit O₃ uptake in these parks during some years. However, for the three parks classified as having highest risk of foliar injury, there was not a clear pattern of high O₃ exposure at times of low soil moisture. Such a pattern, which suggests limited O₃ uptake, was found for eight of the parks judged to have Low overall risk.

Table 4. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the NCPN. (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	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION
<i>Ailanthus altissima</i> *	Tree-of-heaven		x			x									x		x
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry		x			x			x	x						x	x
<i>Amelanchier alnifolia</i> var. <i>pumila</i>	Saskatoon serviceberry										x						
<i>Apocynum androsaemifolium</i> var. <i>androsaemifolium</i> *	Spreading dogbane			x													
<i>Apocynum androsaemifolium</i> var. <i>pumilum</i> *	Spreading dogbane															x	
<i>Apocynum androsaemifolium</i> *	Spreading dogbane								x		x						
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp	x	x	x	x	x	x	x	x	x				x	x		x
<i>Artemisia ludoviciana</i> spp. <i>Incompta</i> *	Silver wormwood							x									
<i>Artemisia ludoviciana</i> spp. <i>Ludoviciana</i> *	Silver wormwood		x						x								
<i>Artemisia ludoviciana</i> var. <i>albula</i> *	Silver wormwood	x		x	x	x									x		
<i>Artemisia ludoviciana</i> var. <i>ludoviciana</i> *	Silver wormwood						x			x	x	x					x
<i>Artemisia ludoviciana</i> var. <i>mexicana</i> *	Silver wormwood													x			
<i>Asclepias incarnate</i>	Swamp milkweed				x					x							
<i>Fraxinus americana</i> *	White ash					x											
<i>Fraxinus pennsylvanica</i>	Green ash					x											
<i>Oenothera elata</i> spp. <i>Hirsutissima</i> *	Evening primrose								x								
<i>Oenothera elata</i> *	Evening primrose					x				x				x			
<i>Padus virginiana</i> spp. <i>melanocarpa</i>	Choke cherry		x						x								
<i>Physocarpus malvaceus</i> *	Pacific ninebark															x	
<i>Pinus ponderosa</i> spp. <i>Scopulorum</i> *	Ponderosa pine				x	x	x	x		x				x			x
<i>Pinus ponderosa</i> var. <i>scopulorum</i> *	Ponderosa pine			x	x	x	x			x				x			x
<i>Platanus occidentalis</i> *	American sycamore																x
<i>Populus tremuloides</i> *	Quaking aspen		x	x		x	x	x	x	x	x						x
<i>Prunus virginiana</i> var. <i>melanocarpa</i>	Choke cherry			x	x					x	x	x	x	x		x	x
<i>Rhus aromatica</i> var. <i>trilobata</i> *	Skunkbush			x	x	x				x			x	x	x	x	
<i>Robinia pseudoacacia</i>	Black locust	x				x									x		x
<i>Salix gooddingii</i>	Gooding's willow	x			x	x		x						x			
<i>Salix gooddingii</i> var. <i>variabilis</i>	Gooding's willow																x
<i>Salix scouleriana</i> *	Scouler's willow						x		x	x	x						x
<i>Sambucus racemosa</i> var. <i>melanocarpa</i> *	Red elderberry										x						
<i>Sambucus racemosa</i> var. <i>microbotrys</i> *	Red elderberry						x										x
<i>Solidago canadensis</i> var. <i>salebrosa</i>	Goldenrod	x															
<i>Vitis labrusca</i> *	Northern fox grape					x											
<i>Vitis vinifera</i> *	European wine grape																x

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

* Bioindicator species

Table 5. Ozone assessment results for I&M parks in the NCPN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007a) ozone risk ranking for the period 1995-1999¹.

Park Name ²	Park Code	W126		Sum06		Kohut O ₃ Risk Ranking
		Value (ppm-hr)	Ranking	Value (ppm-hr)	Ranking	
<i>Arches</i>	ARCH	13.97	High	18.98	High	Low
Black Canyon of the Gunnison	BLCA	13.09	High	17.37	High	Low
Bryce Canyon	BRCA	17.37	High	25.74	High	Low
<i>Canyonlands</i>	CANY	14.70	High	20.35	High	Low
<i>Capitol Reef</i>	CARE	16.16	High	22.82	High	Low
Cedar Breaks	CEBR	17.96	High	27.08	High	Low
Colorado	COLM	11.37	Moderate	14.56	Moderate	Low
Curecanti	CURE	13.60	High	18.15	High	Low
<i>Dinosaur</i>	DINO	10.81	Moderate	12.62	Moderate	Low
Fossil Butte	FOBU	12.99	Moderate	16.85	High	Moderate
Golden Spike	GOSP	17.66	High	25.01	High	Moderate
Hovenweep	HOVE	14.46	High	20.48	High	Low
Natural Bridges	NABR	14.40	High	20.16	High	Low
Pipe Spring	PISP	18.09	High	27.29	High	Low
Timpanogos Cave	TICA	18.28	High	25.41	High	Moderate
<i>Zion</i>	ZION	18.16	High	27.62	High	Low

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

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

NPS (2010) evaluated the fourth-highest 8-hour O₃ concentrations for national parks that have consistently been at or above the standard of 75 ppb, based on 11-20 years of monitoring data running through 2008. There were six parks that routinely had such high concentrations, and six additional parks had O₃ levels that were typically below the 75 ppb standard, but were within the EPA's proposed range for a possible new standard (60-70 ppb; NPS 2010). These latter parks included CANY within the NCPN.

Visibility Impairment

Natural Background and Ambient Visibility Conditions

Visibility is a source of concern for all parks in the northern Colorado Plateau because of the magnificent vistas viewed from within and looking into and out of the parks. In general, the best visibility in the conterminous United States typically occurs in the Great Basin, Colorado Plateau, and Rocky Mountains. Regional and local pollution sources that cause haze and contribute to visibility impairment¹ throughout the NCPN include automobiles, coal- and oil-fired power plants, smelters, wildfires, and urban emissions (Peterson et al. 1998), and recently oil and gas development (Sullivan and McDonnell 2014).

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 Regional Haze Rule, which requires each state to develop a plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions by 2064. Six of the NCPN parks are classified as Class I under the Clean Air Act: ARCH, BLCA, BRCA, CANY, CARE, and ZION. The other SCPN parks are classified as Class II. Natural background visibility, or natural haze, 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. IMPROVE samplers use filters to collect the fine particles of pollution that cause haze and impair visibility. Visibility conditions are estimated based on the types and amounts of fine particles and typically reported using the haze index deciview (dv)².

IMPROVE monitors are located in BRCA (BRCA1), CANY (CANY1), CARE (CAPI1), and ZION (ZICA1; ZION1 operated from 2001-2003, at which time the sampler was moved to a new location and the site was renamed ZICA1). Data are also available that are considered to be representative of visibility conditions in five of the other parks. A monitoring site is considered by IMPROVE to be representative of an area if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area.

Current visibility estimates reflect current pollution levels and provide park managers with information on spatial differences in visibility and air pollution. Data from IMPROVE show that visibility impairment caused by air pollution occurs virtually all the time at most national park and

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

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

wilderness area monitoring stations (Regional Haze Rule 1999). To evaluate visibility conditions over time and space, IMPROVE compares conditions on two groups of days, the 20% clearest and the 20% haziest days. Table SCPN-6 gives the estimated natural (i.e., no man-made impairment) conditions and degree of impairment on the average of the 20% clearest and 20% haziest days.

In addition to the IMPROVE samplers, cameras have been used to illustrate visibility conditions. Representative photos of selected vistas under three different visibility conditions are shown in Figure 1a-b for BRCA and CANY. In addition to expressing visibility in dv , visibility is expressed in terms of light extinction (B_{ext}) in inverse megameters (Mm^{-1}) and visual range in kilometers (km). Deciview and b_{ext} are most closely related to the amounts and types of fine pollution particles in the air, whereas visual range can be influenced by meteorological conditions. Photos were selected to correspond with the clearest 20% of visibility conditions, haziest 20% of visibility conditions, and annual average visibility conditions at each location. This series of photos provides a graphic illustration of the visual effect of these differences in haze level at a representative vista in each of these parks.

IMPROVE data allow estimation of visual range (VR), a measurement more easily understood by many park visitors than dv or light extinction. Available data indicate that at the BRCA site (BRCA1; also representative of CEBR), air pollution has reduced average VR from 170 to 110 miles (274 to 177 km). On the haziest days, VR has been reduced from 120 to 70 miles (193 to 113 km). Severe haze episodes occasionally reduce visibility to 16 miles (26 km). At the CANY site (CANY1; also representative of ARCH and NABR), air pollution has reduced average VR from 170 to 110 miles (274 to 177 km). On the haziest days, VR has been reduced from 130 to 75 miles (209 to 121 km). Severe haze episodes occasionally reduce visibility to 26 miles (42 km). At the CARE site (CAPI1), air pollution has reduced average VR from 170 to 110 miles (274 to 177 km). On the haziest days, VR has been reduced from 130 to 80 miles (209 to 129 km). Severe haze episodes occasionally reduce visibility to 21 miles (34 km). At the ZION site (ZICA1), air pollution has reduced average VR from 160 to 100 miles (258 to 161 km). On the haziest days, VR has been reduced from 120 to 70 miles (193 to 113 km). Severe haze episodes occasionally reduce visibility to 21 miles (34 km). At the Weminuche Wilderness site (WEMI1, also representative of BLCA and CURE), air pollution has reduced average VR from 170 to 120 (274 to 193 km) miles. On the haziest days, VR has been reduced from 130 to 80 miles (209 to 129 km). Severe haze episodes occasionally reduce visibility to 13 miles (21 km).

Table 6. Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008¹. Four parks have on-site monitors. In addition, the BRCA1 monitor represents CEBR; CANY1 represents ARCH and NABR; WEMI1, at Weminuche Wilderness represents BLCA and CURE. The ZION1 site was discontinued in 2004; the ZICA1 site has operated from 2003 to the present.

Park Name ²	Park Code	Site ID	Estimated Natural Haze		
			20% Clearest Days	20% Hazeiest Days	Average Days
			dv	dv	dv
<i>Arches</i> ³	ARCH	CANY1	1.05	6.43	3.37
Black Canyon of the Gunnison ³	BLCA	WEMI1	0.98	6.21	3.22
Bryce Canyon	BRCA	BRCA1	0.57	6.80	3.22
<i>Canyonlands</i>	CANY	CANY1	1.05	6.43	3.37
<i>Capitol Reef</i>	CARE	CAPI1	1.25	6.03	3.31
Cedar Breaks ³	CEBR	BRCA1	0.57	6.80	3.22
Curecanti ³	CURE	WEMI1	0.98	6.21	3.22
Natural Bridges ³	NABR	CANY1	1.05	6.43	3.37
<i>Zion</i>	ZION	ZICA1	1.80	6.70	4.06

Park Name	Park Code	Site ID	Measured Ambient Haze (For Years 2004 through 2008)		
			20% Clearest Days	20% Hazeiest Days	Average Days
			dv	dv	dv
<i>Arches</i> ³	ARCH	CANY1	2.86	10.64	6.64
Black Canyon of the Gunnison ³	BLCA	WEMI1	2.60	9.90	6.12
Bryce Canyon	BRCA	BRCA1	2.22	11.59	6.62
<i>Canyonlands</i>	CANY	CANY1	2.86	10.64	6.64
<i>Capitol Reef</i>	CARE	CAPI1	3.08	11.37	6.95
Cedar Breaks ³	CEBR	BRCA1	2.22	11.59	6.62
Curecanti ³	CURE	WEMI1	2.60	9.90	6.12
Natural Bridges ³	NABR	CANY1	2.86	10.64	6.64
<i>Zion</i>	ZION	ZICA1	4.39	12.60	8.20

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

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

Bryce Canyon

20% Clearest Days

Taken: 3:00 PM

Haze = 2 dv

$B_{\text{ext}} = 12 \text{ Mm}^{-1}$

VR = 320 km



20% Haziest Days

Taken: 3:00 PM

Haze = 10 dv

$B_{\text{ext}} = 26 \text{ Mm}^{-1}$

VR = 150 km



Average Days

Taken: 3:00 PM

Haze = 7 dv

$B_{\text{ext}} = 21 \text{ Mm}^{-1}$

VR = 190 km



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

Canyonlands

20% Clearest Days

Taken: 3:00 PM

Haze = 3 dv

$B_{\text{ext}} = 13 \text{ Mm}^{-1}$

VR = 290 km



20% Haziest Days

Taken: 3:00 PM

Haze = 11 dv

$B_{\text{ext}} = 30 \text{ Mm}^{-1}$

VR = 190 km



Average Days

Taken: 3:00 PM

Haze = 7 dv

$B_{\text{ext}} = 21 \text{ Mm}^{-1}$

VR = 190 km



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

Composition of Haze

Ammonium SO_4^{2-} , ammonium NO_3^- , elemental carbon (C), coarse mass, organic mass, sea salt, and soil make up the haze that causes visibility degradation. Sulfates form in the atmosphere from SO_2 emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, power plants, industry, O&G development, and fire. Organic compounds are emitted from a variety of both natural (biogenic) and anthropogenic sources, including agriculture, industry, and fire. Soil can enter the atmosphere through both natural processes and human disturbance.

Figure 2a- shows estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze and its composition for the monitored parks in the NCPN. For more information on these data, see http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm.

Sources of Visibility Impairment in the NCPN

Analyses conducted by the Western Regional Air Partnership (WRAP) indicated that a variety of sources contribute to visibility impairment throughout the western United States, including within the NCPN (Figures 3 to 10). In addition to many sources in the U.S., air pollution sources outside the western U.S., 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).

The WRAP has provided technical assistance for Western states in developing their plans to meet the requirements of the Regional Haze Rule. As part of this, the WRAP has conducted regional modeling to identify what type of pollution sources are affecting visibility in Class I areas, and where that pollution is coming from. Source regions include WRAP (AZ, CA, CO, ID, MT, ND, NM, NV, OR, SD, UT, WA, and WY), Pacific Offshore (PO), CENRAP (AL, AR, IA, KS, MN, MO, NE, OK, and TX), Eastern U.S., Canada, Mexico, and Outside Domain (OD-outside the modeling domain). Source types identified include Outside Domain (OD-undefined), Point (e.g., power plants, smelters), Area (e.g., oil and gas development), Mobile (e.g., vehicles), Anthropogenic Fires (prescribed burns), and Natural Fires and Biogenic Sources. The following sections show regional contributions to atmospheric sulfate and nitrate, two of the primary controllable anthropogenic pollutant species responsible for visibility impairment, on the worst 20% visibility days for each of the Class I areas in the NCPN, for the base year 2002 and projected contributions for the year 2018. Also shown are the contributions, by region and source type, to sulfate and nitrate on the worst 20% visibility days for 2002 and 2018. Although WRAP also modeled contributions for the best 20% visibility days, this analysis focuses on the worst days when visibility is most impaired by human activities. Projections for 2018 were modeled using 2008 and earlier data. Projections therefore do not include emissions changes unforeseen at the time of the modeling, including reductions at some point sources and increases due to activities like oil and gas exploration, development, and production. Updates to emissions inventories are underway and will be used to improve current estimates and to improve modeled projections of future conditions.

CANY (also representing ARCH and NABR)

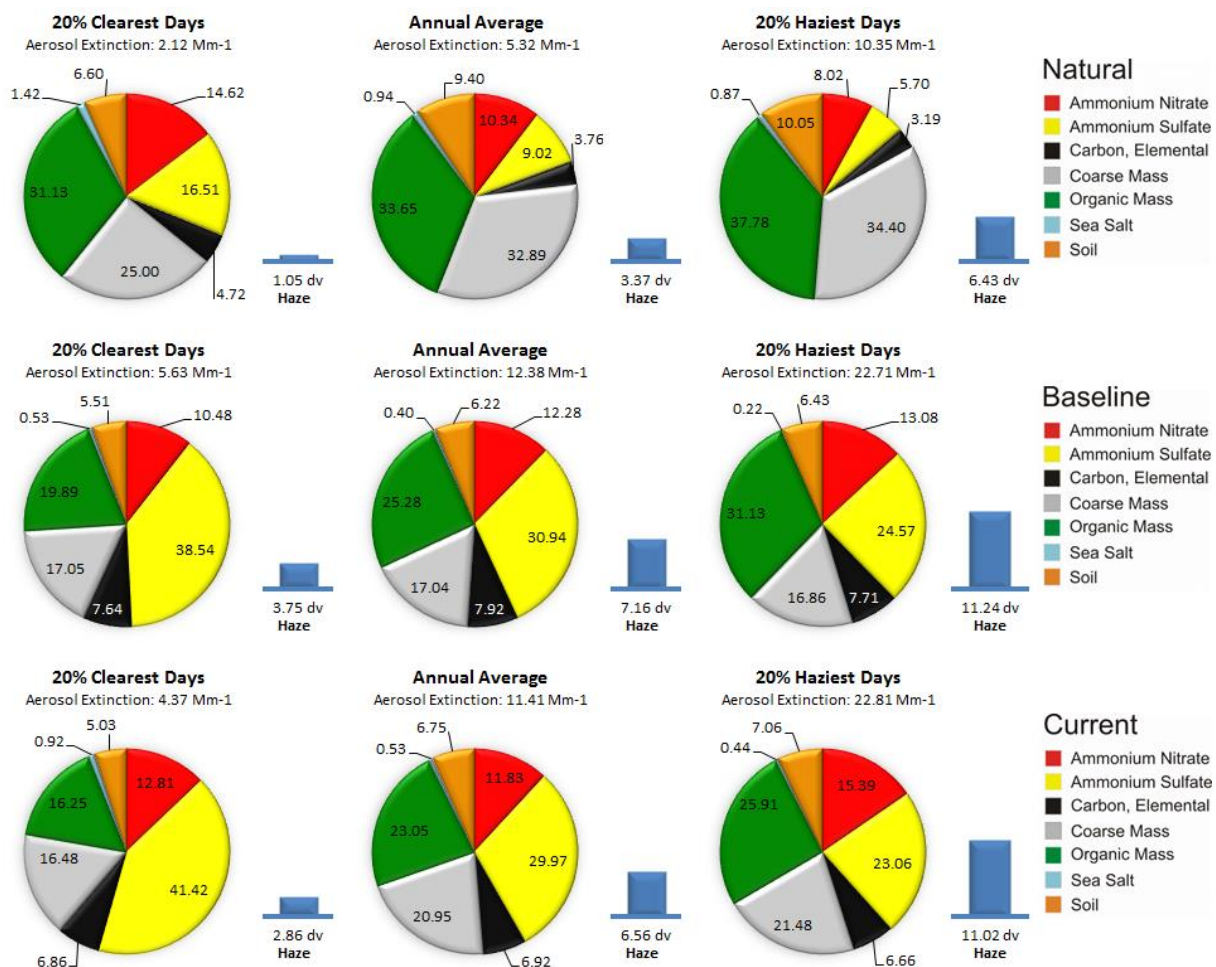


Figure 2a. Composition of haze at CANY (also representing ARCH and NABR). Estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze in deciviews (blue columns) and light extinction (aerosol extinction) in inverse megameters (Mm⁻¹) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for the parks in the NCPN. Data for ARCH, BLCA, CEBR, CURE, and NABR were taken from representative sites (see Table 6). Data Source: NPS-ARD.

WEMI1 (also representing BLCA and CURE)

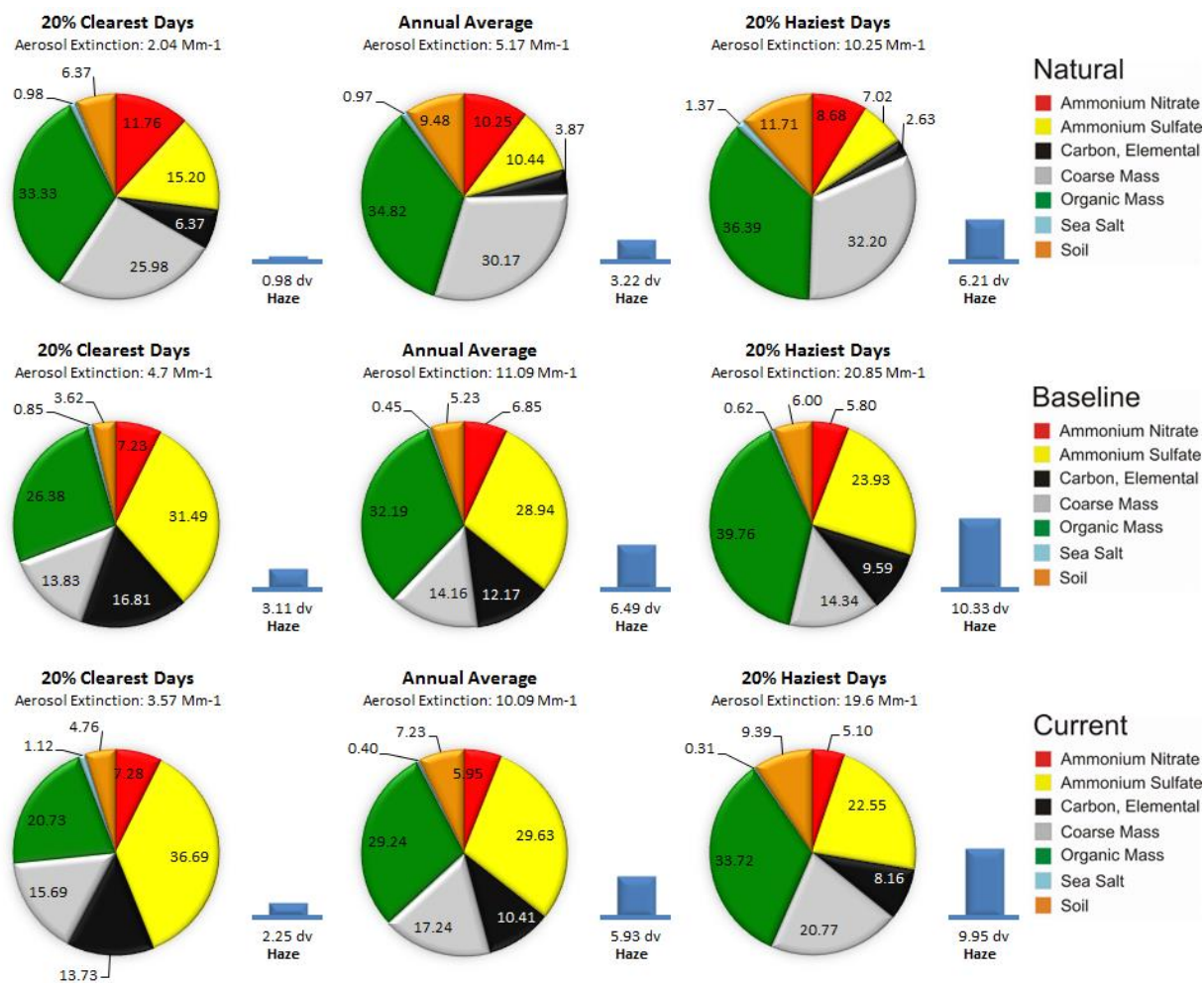


Figure 2b. Composition of haze at WEMI1 (also representing BLCA and CURE). Estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze in deciviews (blue columns) and light extinction (aerosol extinction) in inverse megameters (Mm⁻¹) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for the parks in the NCPN. Data for ARCH, BLCA, CEBR, CURE, and NABR were taken from representative sites (see Table 6). Data Source: NPS-ARD.

BRCA (also representing CEBR)

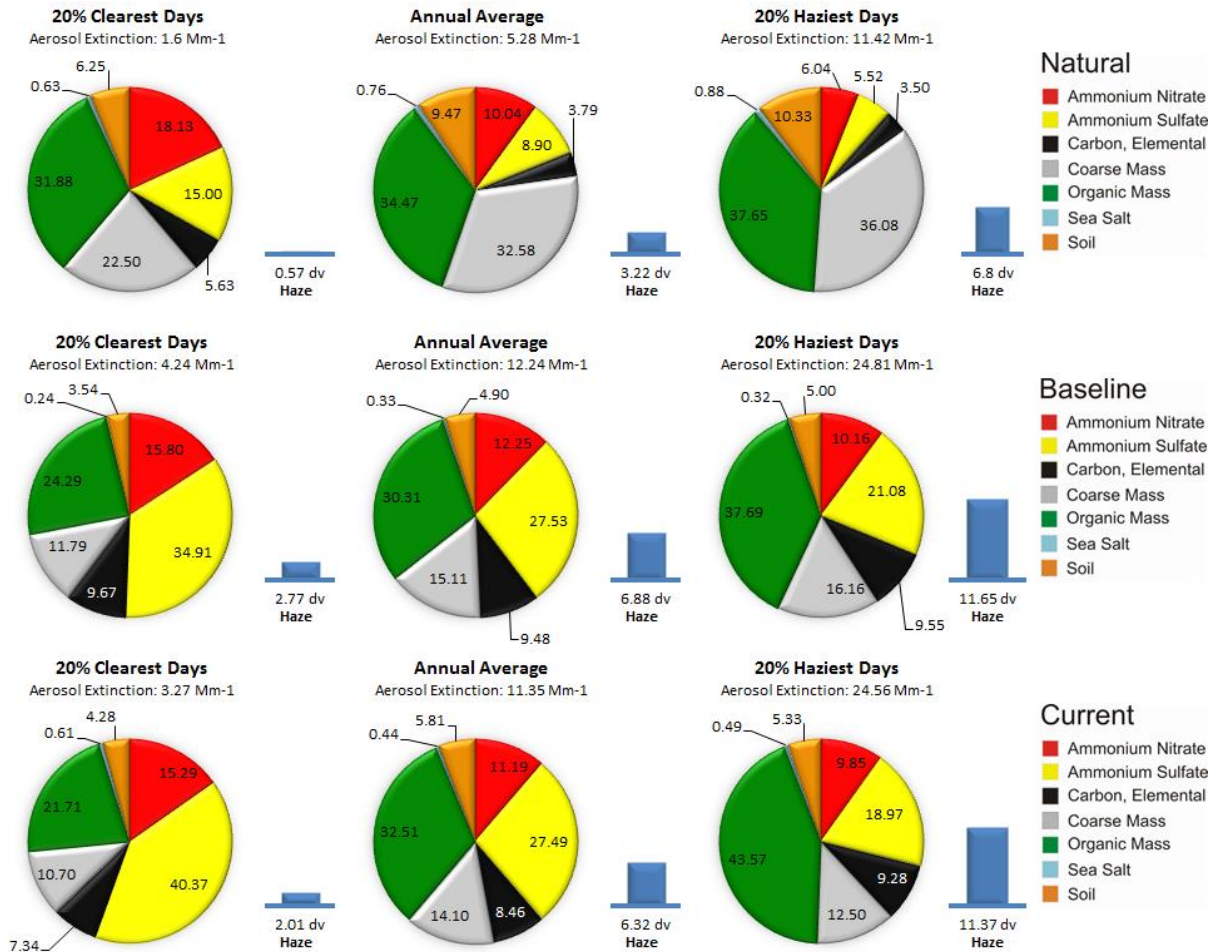


Figure 2c. Composition of haze at BRCA (also representing CEBR). Estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze in deciviews (blue columns) and light extinction (aerosol extinction) in inverse megameters (Mm⁻¹) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for the parks in the NCPN. Data for ARCH, BLCA, CEBR, CURE, and NABR were taken from representative sites (see Table 6). Data Source: NPS-ARD.

CARE

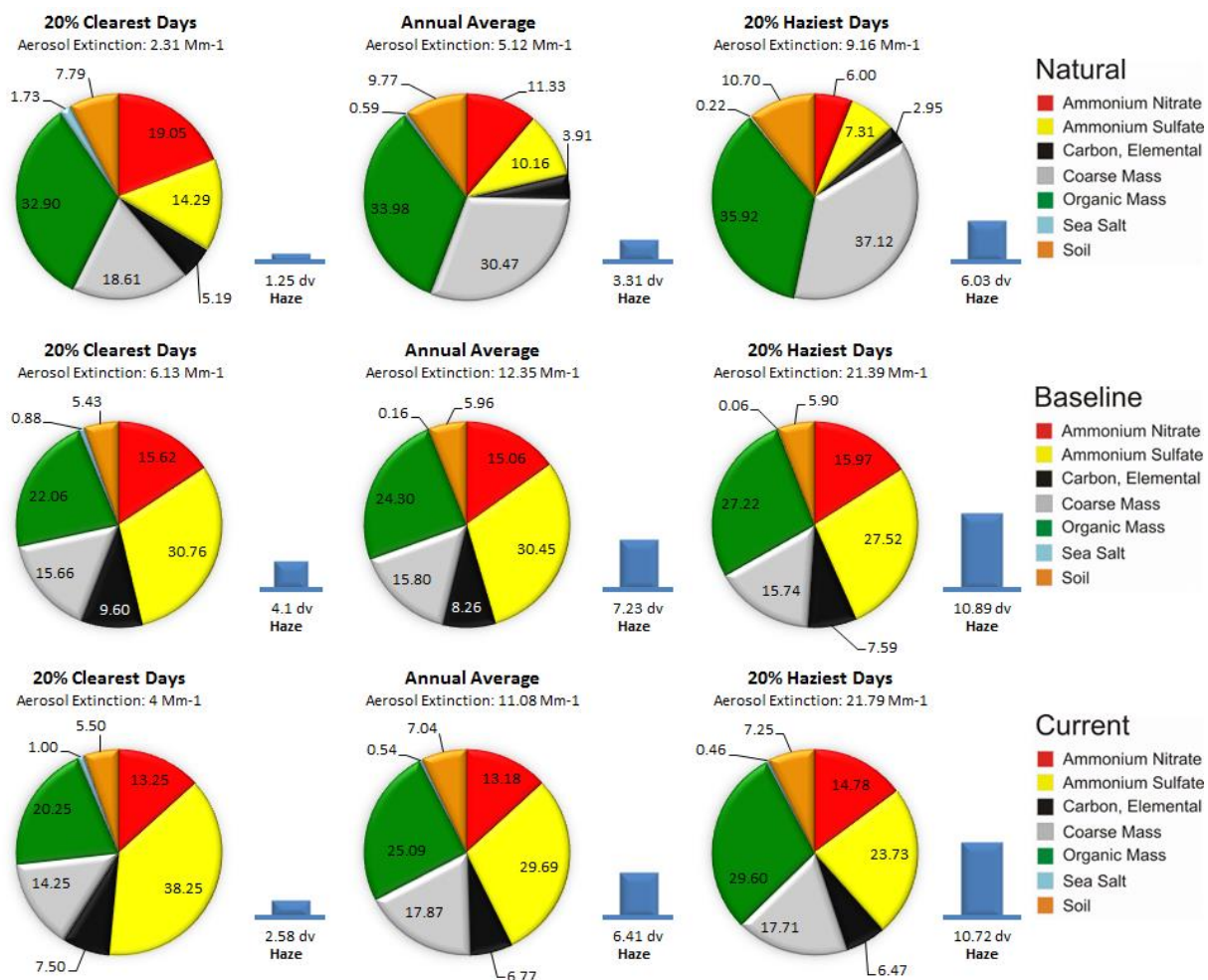


Figure 2d. Composition of haze at CARE. Estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze in deciviews (blue columns) and light extinction (aerosol extinction) in inverse megameters (Mm^{-1}) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for the parks in the NCPN. Data for ARCH, BLCA, CEBR, CURE, and NABR were taken from representative sites (see Table 6). Data Source: NPS-ARD.

ZICA1

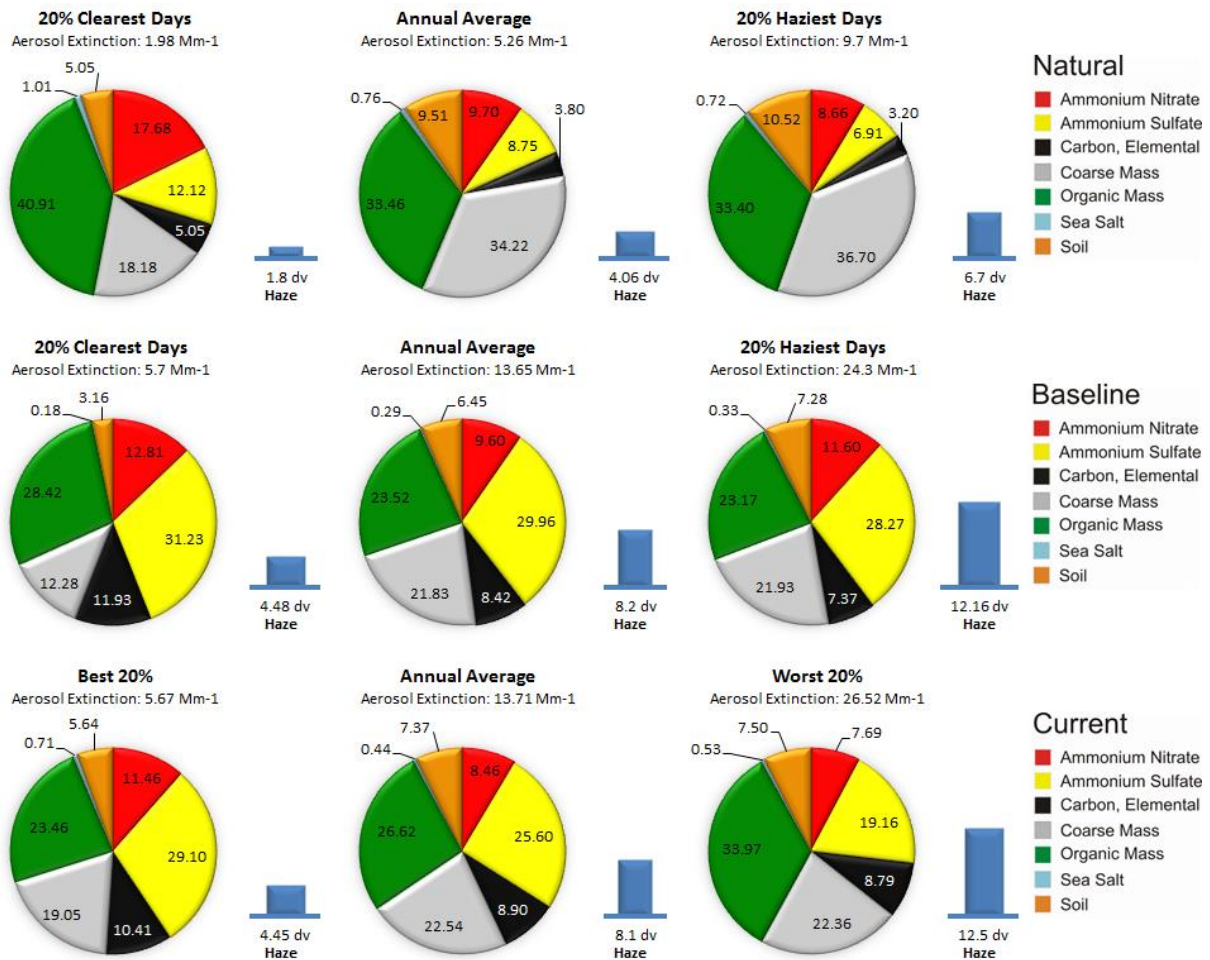


Figure 2e. Composition of haze at ZICA1. Estimated natural (pre-industrial), baseline (2000-2004), and more recent (2006-2010) levels of haze in deciviews (blue columns) and light extinction (aerosol extinction) in inverse megameters (Mm^{-1}) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for the parks in the NCPN. Data for ARCH, BLCA, CEBR, CURE, and NABR were taken from representative sites (see Table 6). Data Source: NPS-ARD.

The West-Wide Jump-Start Air Quality Modeling Study (WestJump) updated the WRAP work with emissions inventories for the year 2008 (ENVIRON et al. 2013, Appendix O). The WestJump results for NO_3^- and sulfate are described and compared to the WRAP data in the following sections.

WestJump data have some of the same limitations as the WRAP data in that they do not include recent emissions reductions and increases occurring since 2008. The WestJump data agree with the WRAP data in that they also show that organic and elemental C from prescribed burns and other anthropogenic sources are significant, and in some cases major, contributors to haze and visibility impairment in the NCPN parks at times. Ongoing work continues to improve emissions inventories, particularly for fires (both wildfires and prescribed burns) through the WRAP and the Joint Fire Science Program (JFSP 2014). Carbon from prescribed burns is, at present, considered controllable by EPA. This can be problematic for States and Federal Land Managers because prescribed burns, while contributing to visibility impairment, are needed to improve and maintain forest health and to avoid catastrophic wildfires.

Arches and Canyonlands NPs

Figure 3a shows regional contributions to atmospheric sulfate on the worst 20% of days at ARCH and CANY in the base year of 2002 and the projected contributions in 2018. Sulfate concentrations were projected to remain relatively unchanged to 2018, with sources from both within the WRAP region and outside the modeling area (Outside Domain – OD) significantly contributing to sulfate at ARCH and CANY.

Figure 3b shows source type by region, including each of the WRAP States. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018. Point sources (e.g., power plants) within the WRAP region, Mexico, and the Pacific Offshore regions are important contributors to sulfate at ARCH and CANY.

Figure 4a shows that nitrate concentrations are projected to remain steady from 2002 to 2018 at ARCH and CANY, and that sources in the WRAP region are primarily responsible for nitrate at those parks. Figure NCPN 4b shows that point, mobile, and area sources from UT, NM, and other WRAP states are primary contributors to nitrate at ARCH and CANY. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018.

Data from the 2008 WestJump emissions inventory found that 70 percent of the pollutants that reduced visibility in ARCH and CANY came from sources within the WRAP region, mainly UT. Nitrate was a larger contributor to haze than SO_4^{2-} , but organic and elemental C from prescribed fires and other sources were the major controllable pollutants reducing visibility in ARCH and CANY (ENVIRON et al. 2013, Appendix O).

Bryce Canyon NP

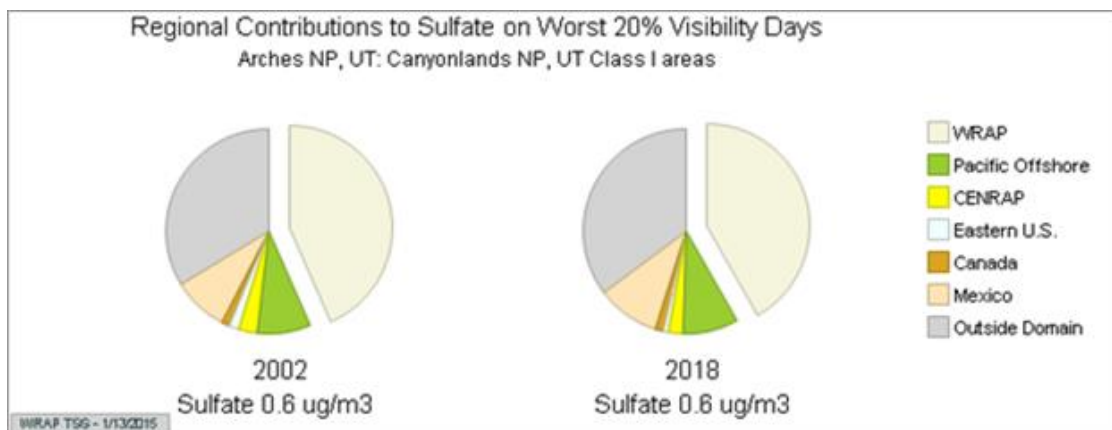
Figure 5a shows regional contributions to sulfate on the worst 20% of days at BRCA in the base year of 2002 and the projected contributions in 2018. Sulfate concentrations are projected to decrease somewhat by 2018, and the regional contribution profile remains similar, with the WRAP region as the dominant source area within the modeling domain.

Figure 5b shows source type by region, including each of the WRAP States. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018. Point sources (e.g., power plants) contribute most to sulfate at BRCA, but area sources and fires also contribute. The Pacific Offshore region (e.g., shipping), Mexico, CA, NV, and UT are significant source regions.

Figure NCPN -6a shows that nitrate concentrations are projected to remain steady from 2002 to 2018 at BRCA, and that sources in the WRAP region are primarily responsible for nitrate at BRCA. Figure 6b shows that mobile, point, and area, sources all contribute to nitrate at BRCA, with sources in CA dominating. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018.

Data from the WestJump emissions inventory found that about two-thirds of the pollutants that reduced visibility in BRCA in 2008 came from sources within the WRAP region, mainly UT and CA. Nitrate was a somewhat larger contributor to haze than SO_4^{2-} , but organic and elemental carbon from prescribed fires and other sources, primarily in UT and CA, were the major controllable pollutants reducing visibility in BRCA (ENVIRON et al. 2013, Appendix O).

a)



b)

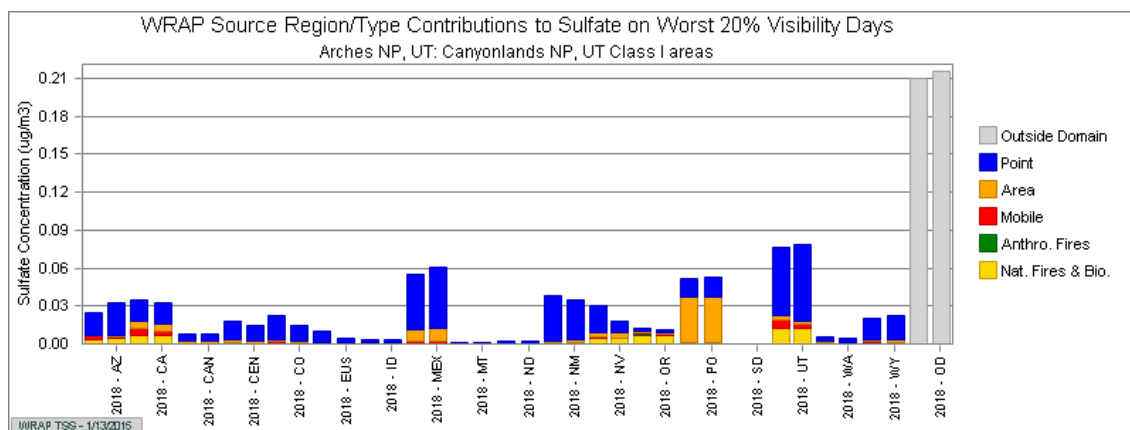


Figure 3. Regional contributions to sulfate on worst 20% visibility days (a) and WRAP source region/type contributions to sulfate on worst 20% visibility days (b) for ARCH and CANY.

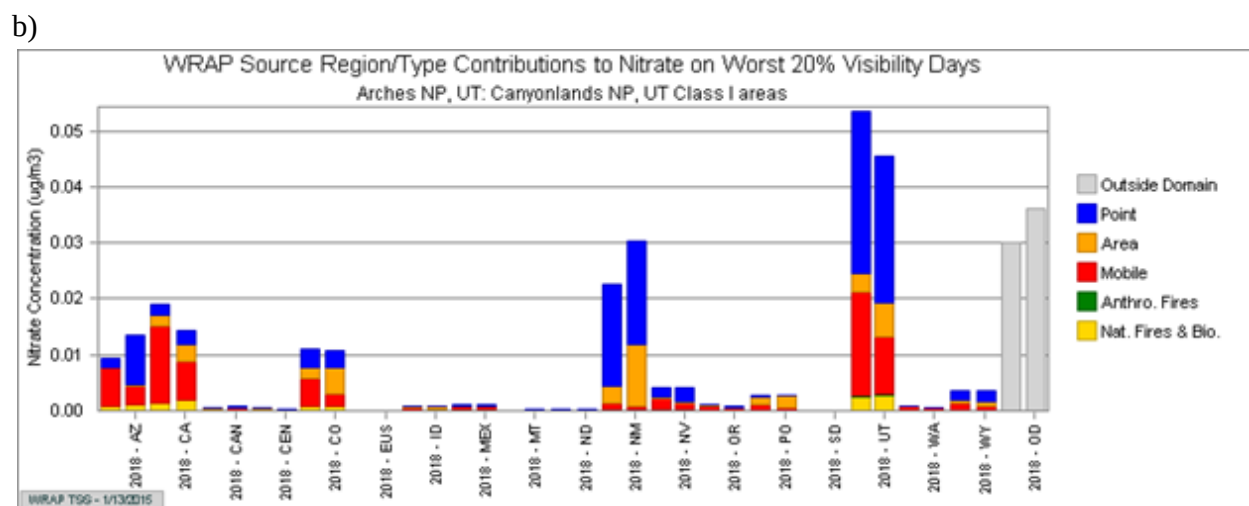
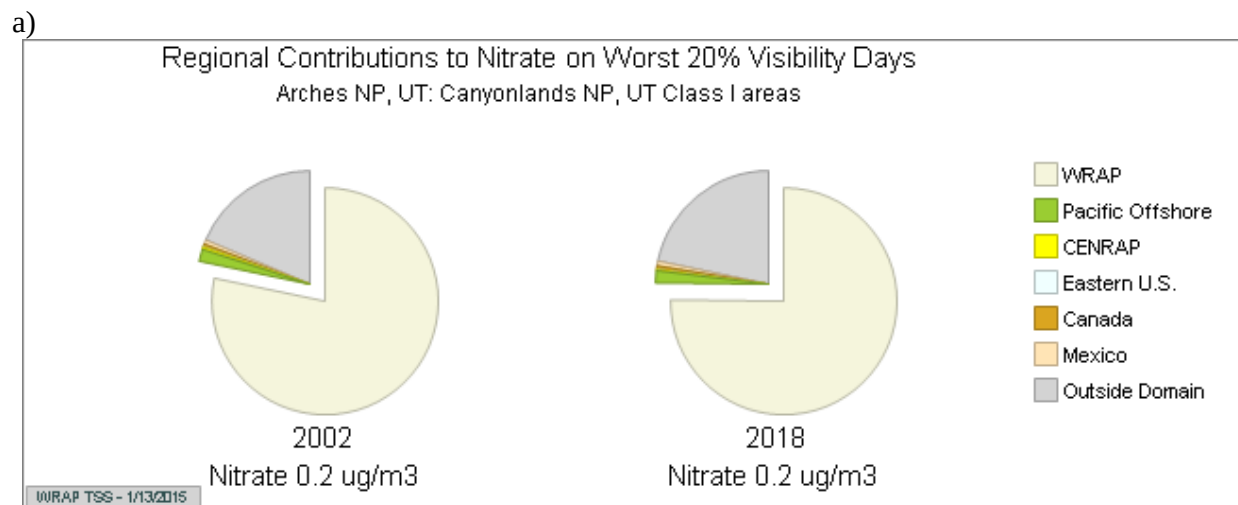


Figure 4. Regional contributions to nitrate on worst 20% visibility days (a) and WRAP source region/type contributions to nitrate on worst 20% visibility days (b) for ARCH and CANY.

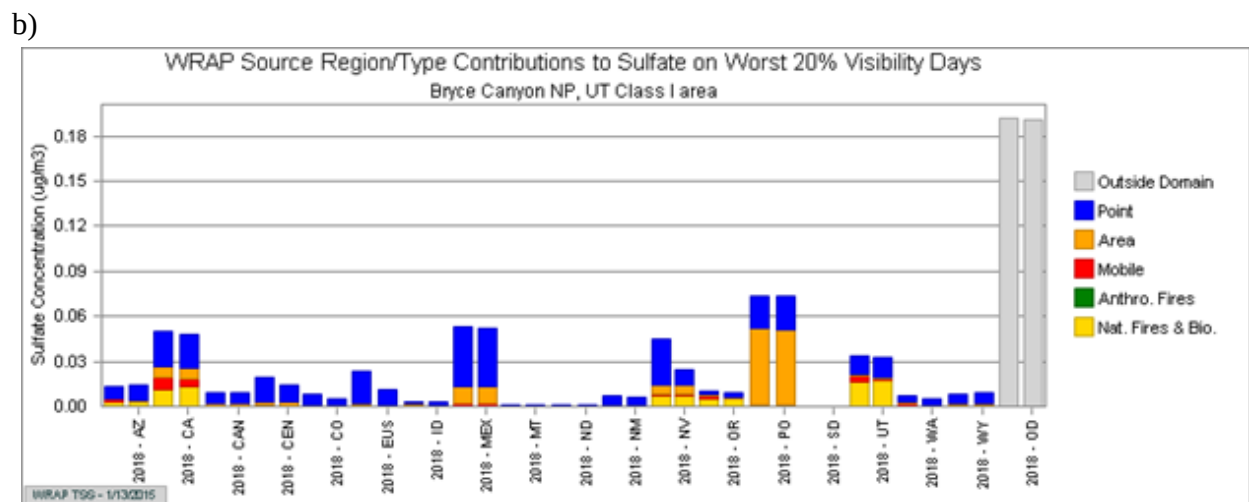
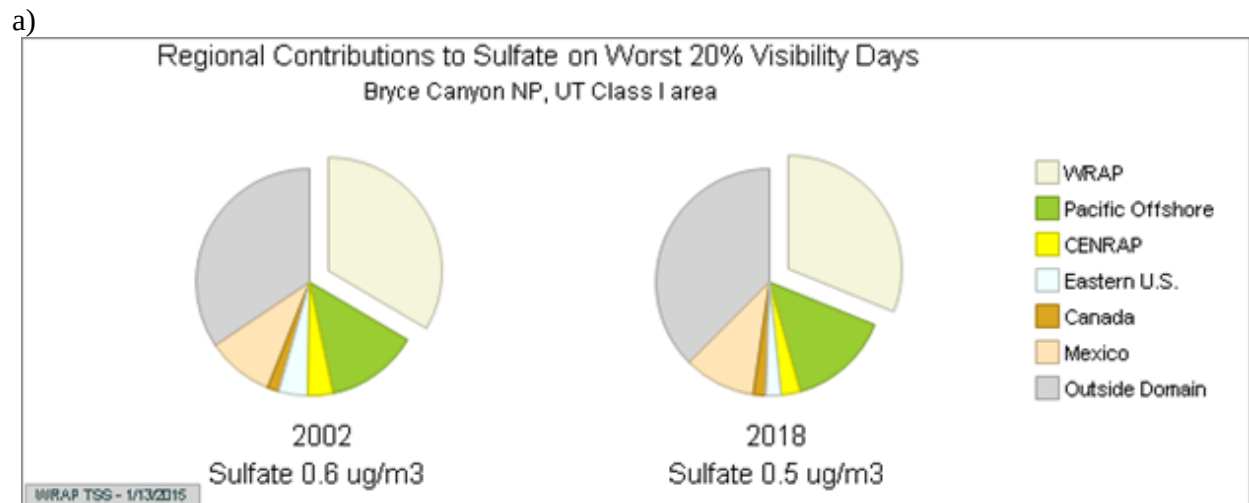


Figure 5. Regional contributions to sulfate on worst 20% visibility days (a) and WRAP source region/type contributions to sulfate on worst 20% visibility days (b) for BRCA.

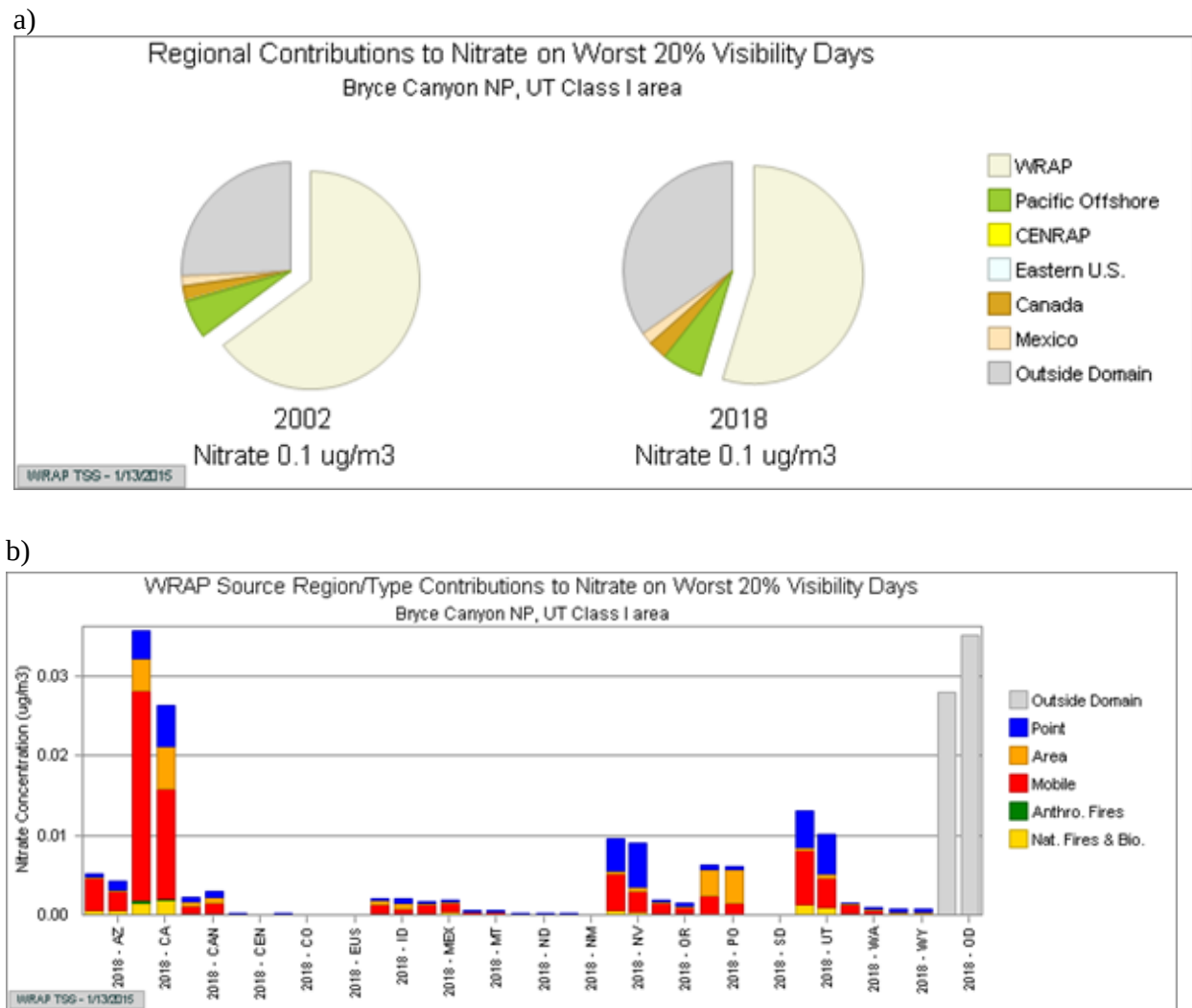


Figure 6. Regional contributions to nitrate on worst 20% visibility days (a) and WRAP source region/type contributions to nitrate on worst 20% visibility days (b) for BRCA.

Capitol Reef NP

Figure 7a shows regional contributions to sulfate on the worst 20% of days at CARE in the base year of 2002 and the projected contributions in 2018. Sulfate concentrations are projected to remain relatively unchanged 2018, with emissions from both the WRAP region and from outside the modeling area (Outside Domain – OD) significantly contributing to sulfate at CARE.

Figure 7b shows source type by region, including each of the WRAP States. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018. Point sources (e.g., power plants) from WRAP states and Mexico are important contributors to sulfate at CARE.

Figure 8a shows that nitrate concentrations are projected to remain steady from 2002 to 2018 at CARE, and that sources in the WRAP region are primarily responsible for nitrate at CARE. Figure 8b shows that point and mobile sources, primarily from UT, are primary contributors to nitrate at

CARE. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018.

Data from the 2008 WestJump emissions inventory found that about two-thirds of the pollutants that reduced visibility in CARE came from sources within the WRAP region, mainly UT and CA. Nitrate was a larger contributor to haze than SO_4^{2-} . For controllable pollutants, nitrate and sulfate were the primary contributors to visibility impairment in CARE, with organic and elemental carbon from prescribed fires and other sources also contributing significantly (WRAP 2013).

Zion NP

Figure 9a shows regional contributions to sulfate on the worst 20% of days at ZION in the base year of 2002 and the projected contributions in 2018. Sulfate concentrations are projected to decrease somewhat by 2018, and the regional contribution profile remains similar, with the WRAP region as the dominant source area within the modeling domain.

Figure 9b shows source type by region, including each of the WRAP States. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018. Point sources (e.g., power plants) contribute most to sulfate at ZION. The WRAP states, Mexico, and the Pacific Offshore region (e.g., shipping) are significant source regions.

Figure 10a shows that nitrate concentrations are projected to remain steady from 2002 to 2018 at ZION, and that sources in the WRAP region are primarily responsible for nitrate at ZION. Figure 10b shows that mobile, point, and area sources all contribute to nitrate at ZION, with sources in UT and CA dominating. Each region is represented by two columns, one for 2002 (unlabeled) followed by one for 2018.

Data from the WestJump emissions inventory found that about 70 percent of the pollutants that reduced visibility in ZION in 2008 came from sources within the WRAP region, mainly UT and CA.

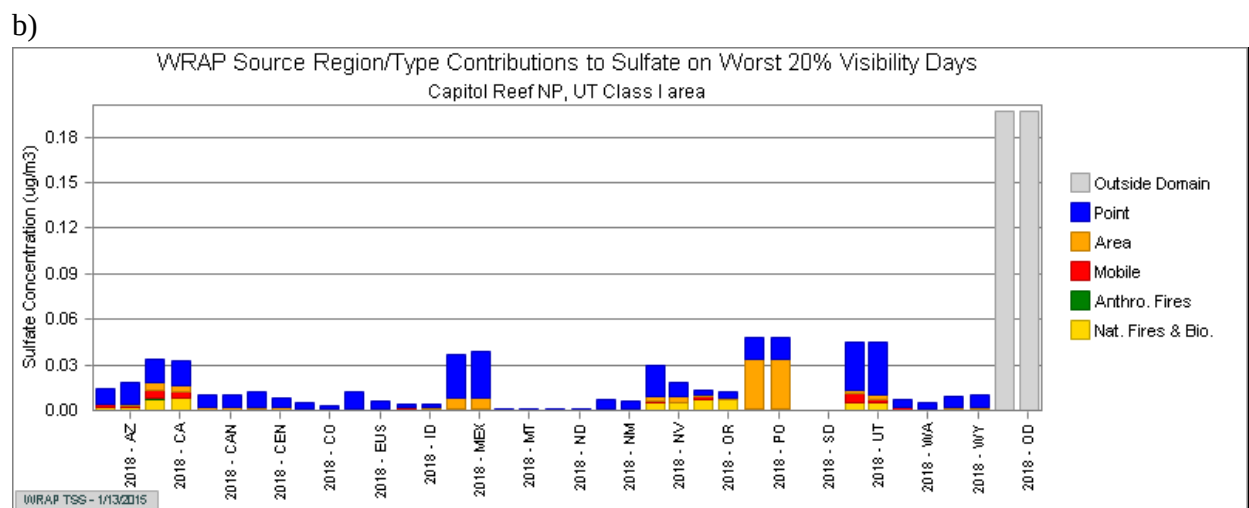
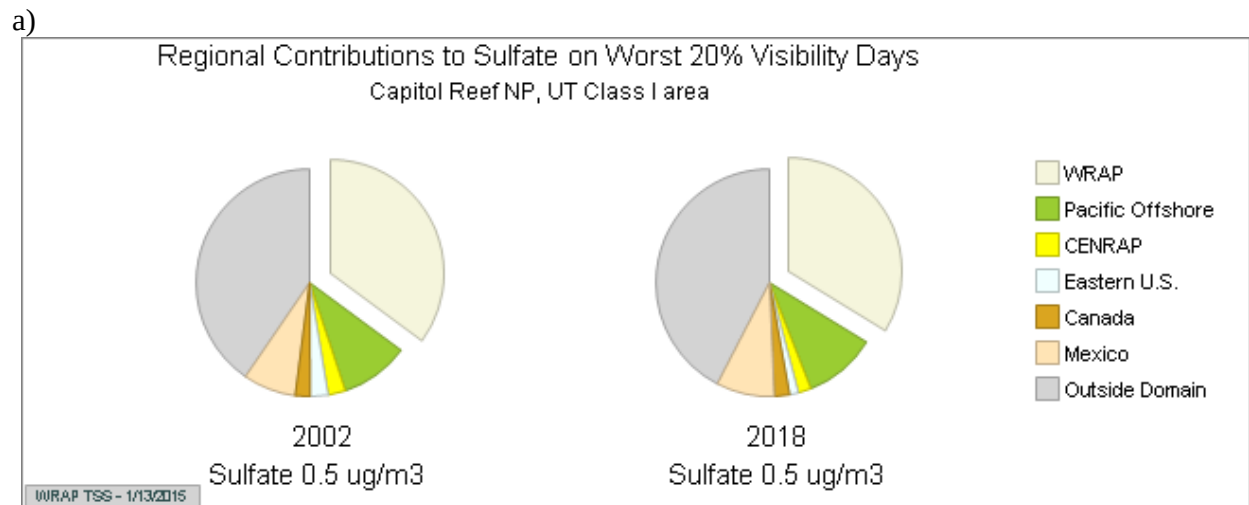


Figure 7. Regional contributions to sulfate on worst 20% visibility days (a) and WRAP source region/type contributions to sulfate on worst 20% visibility days (b) for CARE.

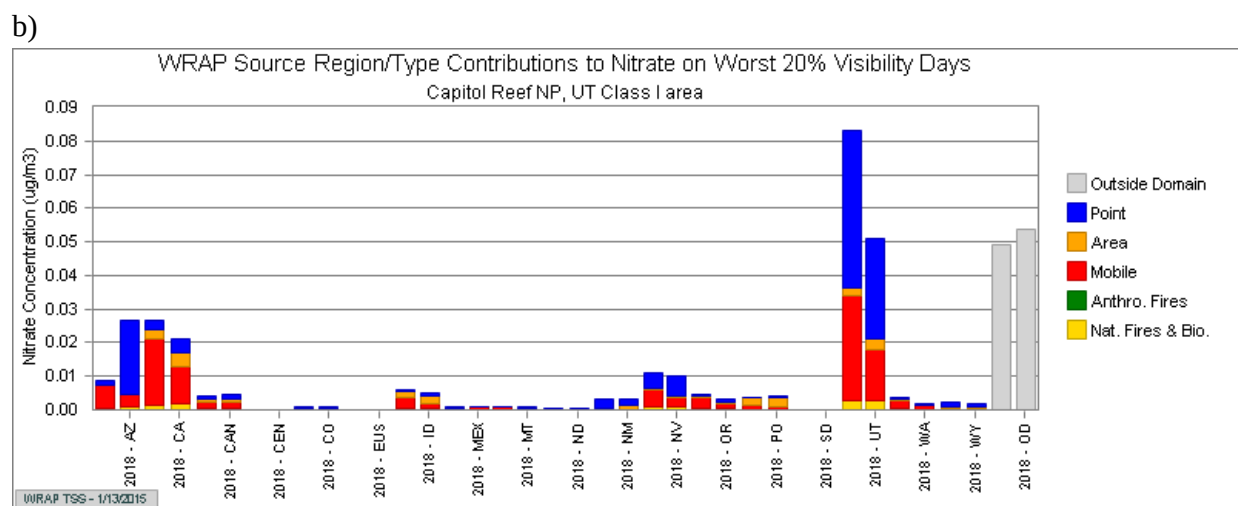
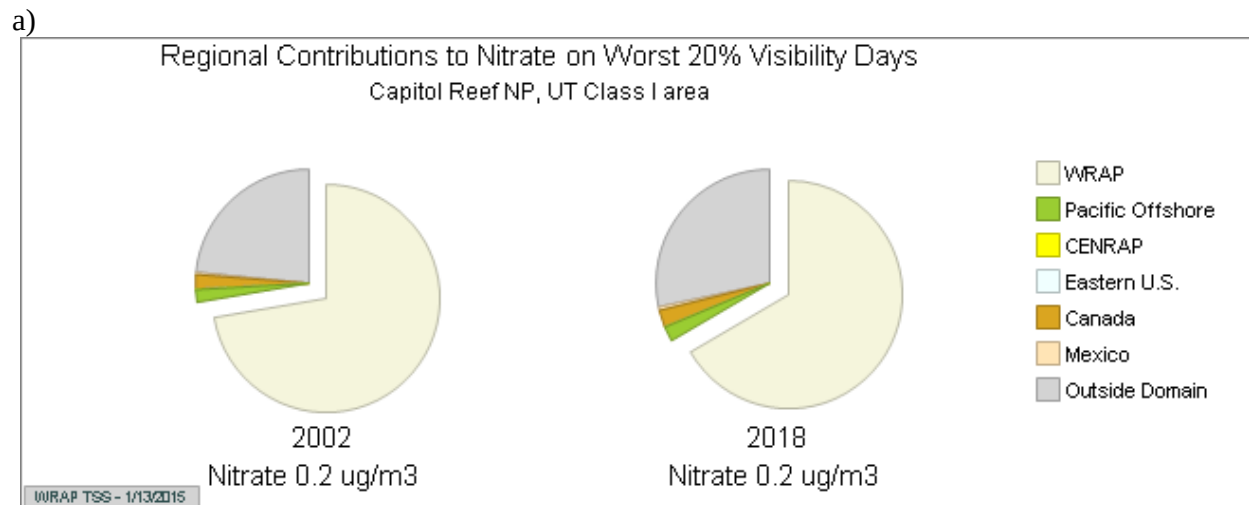


Figure 8. Regional contributions to nitrate on worst 20% visibility days (a) and WRAP source region/type contributions to nitrate on worst 20% visibility days (b) for CARE.

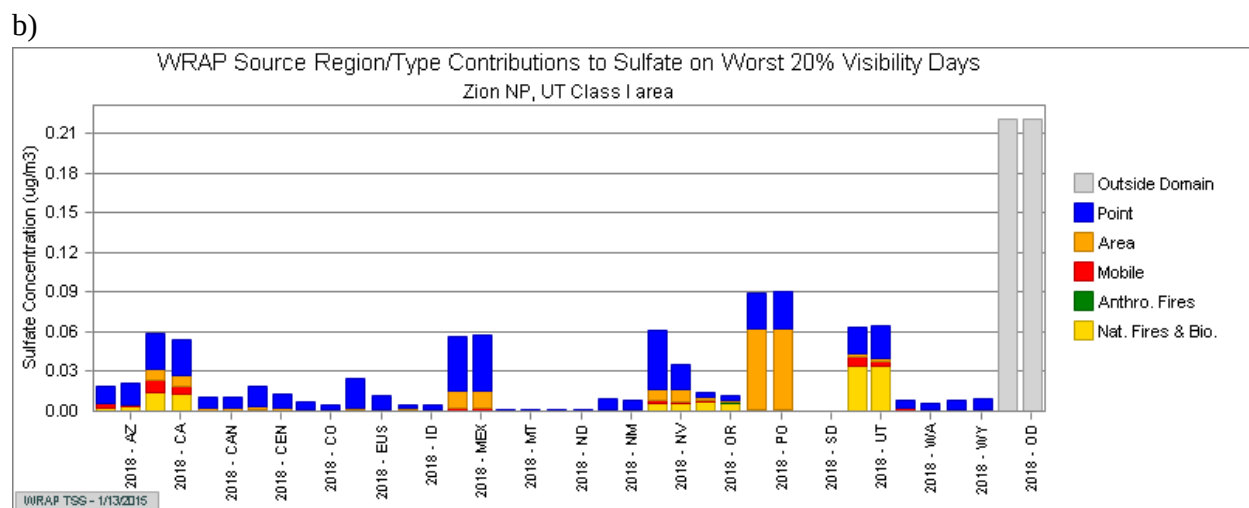
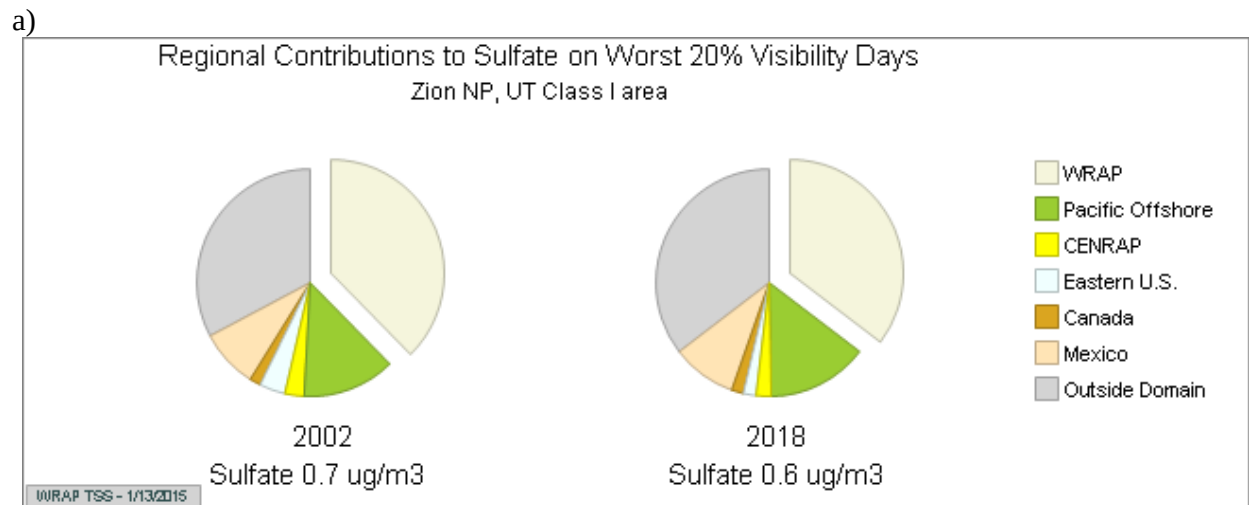


Figure 9. Regional contributions to sulfate on worst 20% visibility days (a) and WRAP source region/type contributions to sulfate on worst 20% visibility days (b) for ZION.

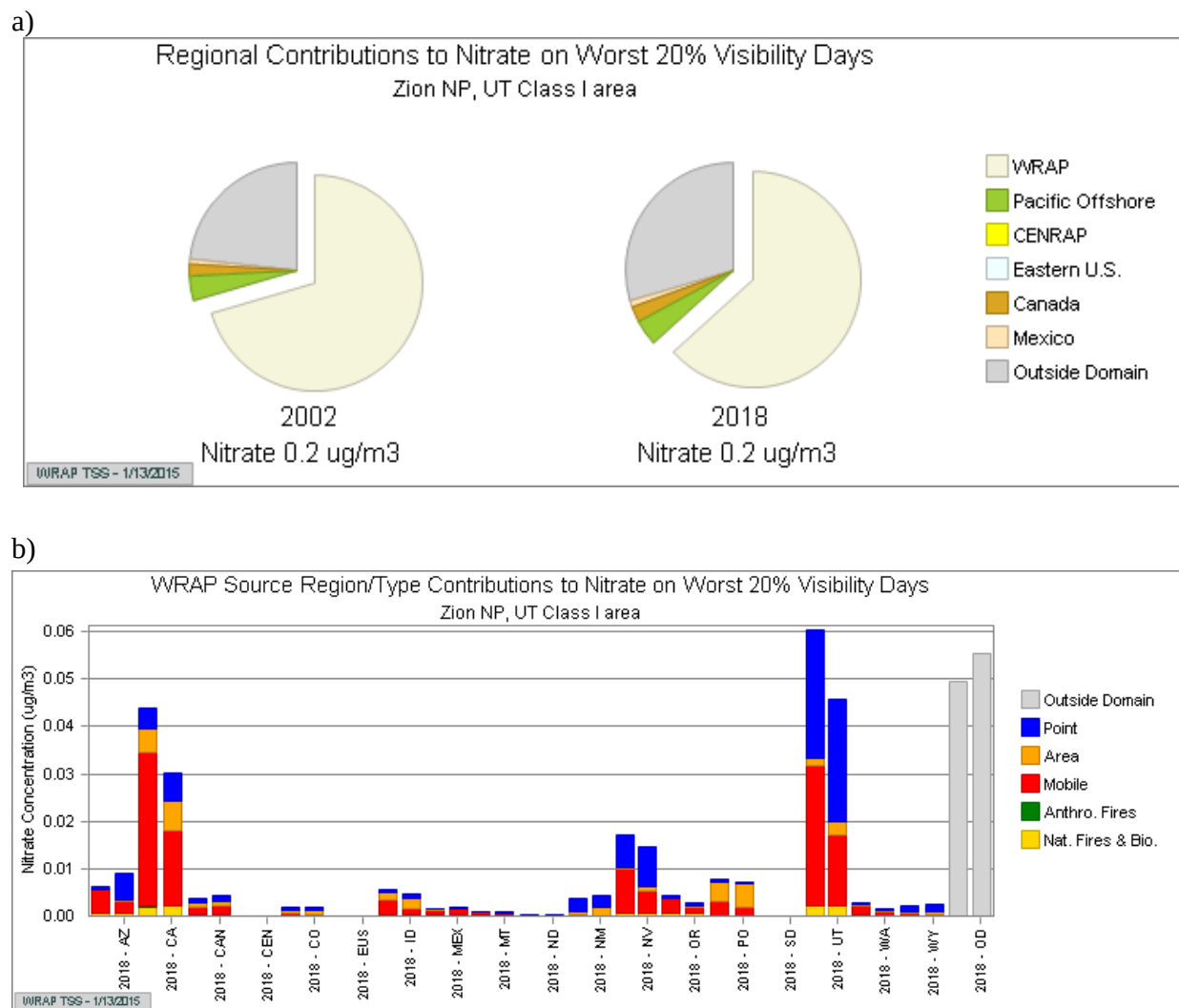


Figure 10. Regional contributions to nitrate on worst 20% visibility days (a) and WRAP source region/type contributions to nitrate on worst 20% visibility days (b) for ZION.

Nitrate was a larger contributor to haze than SO_4^{2-} . Nitrate and SO_4^{2-} , along with organic and elemental carbon from prescribed fires and other sources, were the major controllable pollutants reducing visibility in ZION (WRAP 2013).

Trends in Visibility

IMPROVE long-term trend data are available for ARCN (1990-2013), BRCA (1990-2013), CANY (1990-2013), CARE (2003-2013), and ZION (2004-2013). Trends are shown in Figure 11a-e for the 20 percent clearest and haziest days. Visibility improved significantly on the 20 percent clearest days at ARCN (1990-2013), BRCA (1990-2013), CANY (1990-2013), and CARE (2003-2013), but not at ZION (2004-2013). Data showed no significant trends on haziest days in any of the parks.

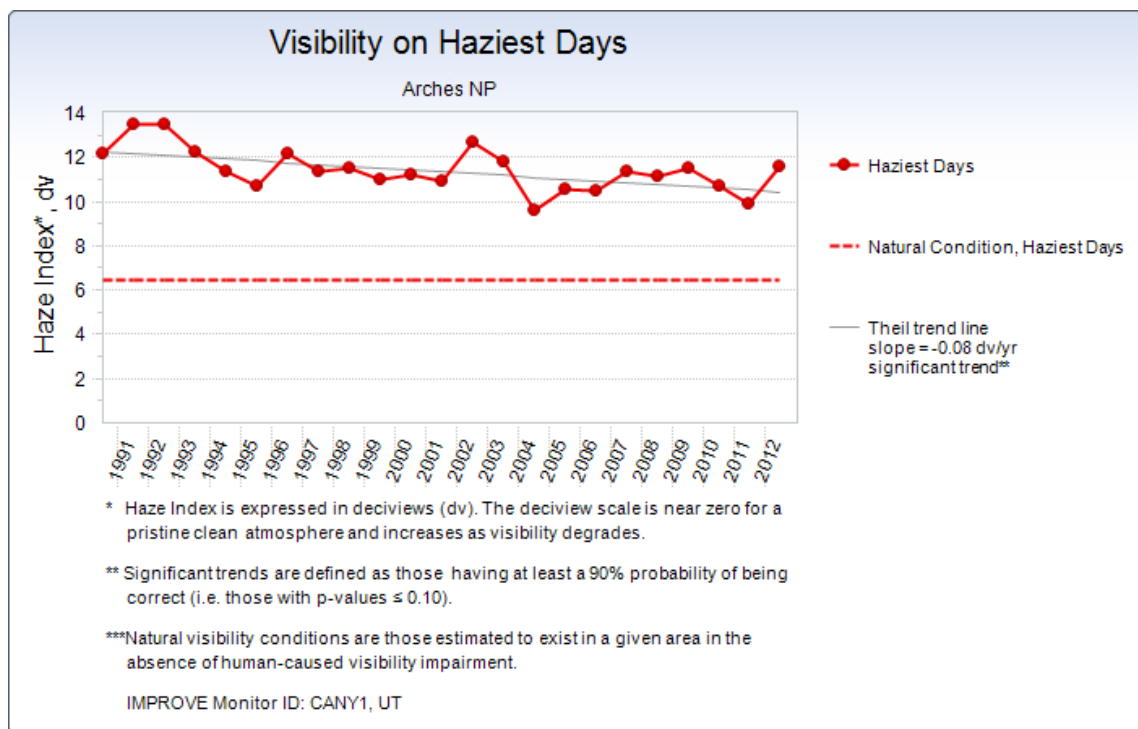
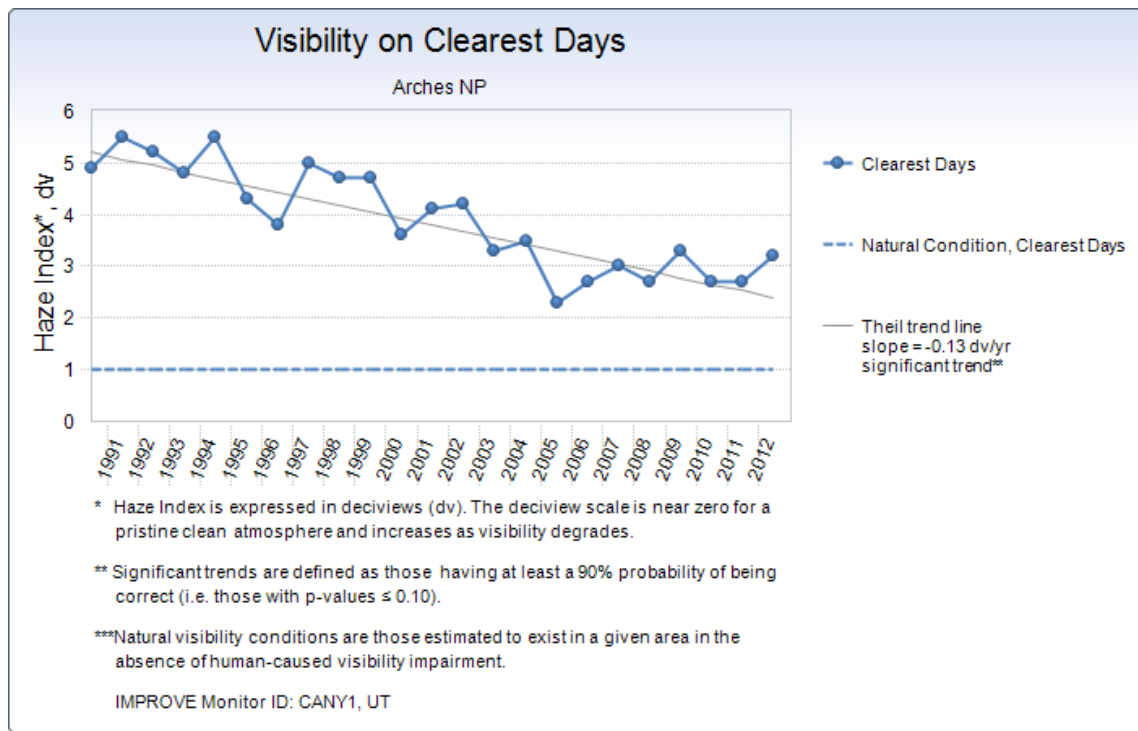


Figure 11a. Trends in ambient haze levels at ARCH based on IMPROVE measurements on the 20% clearest and 20% haziest days over the monitoring period of record. Data Source: WRAP TSS (technical support system) at vista.cira.colostate.edu/tss.

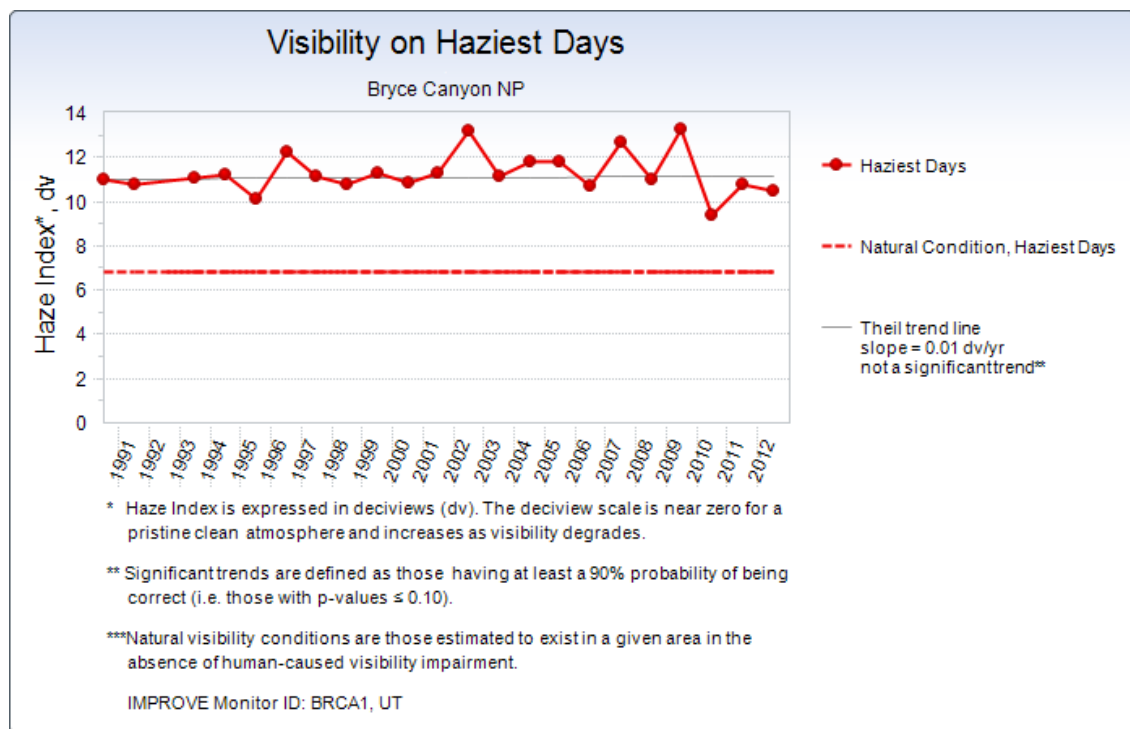
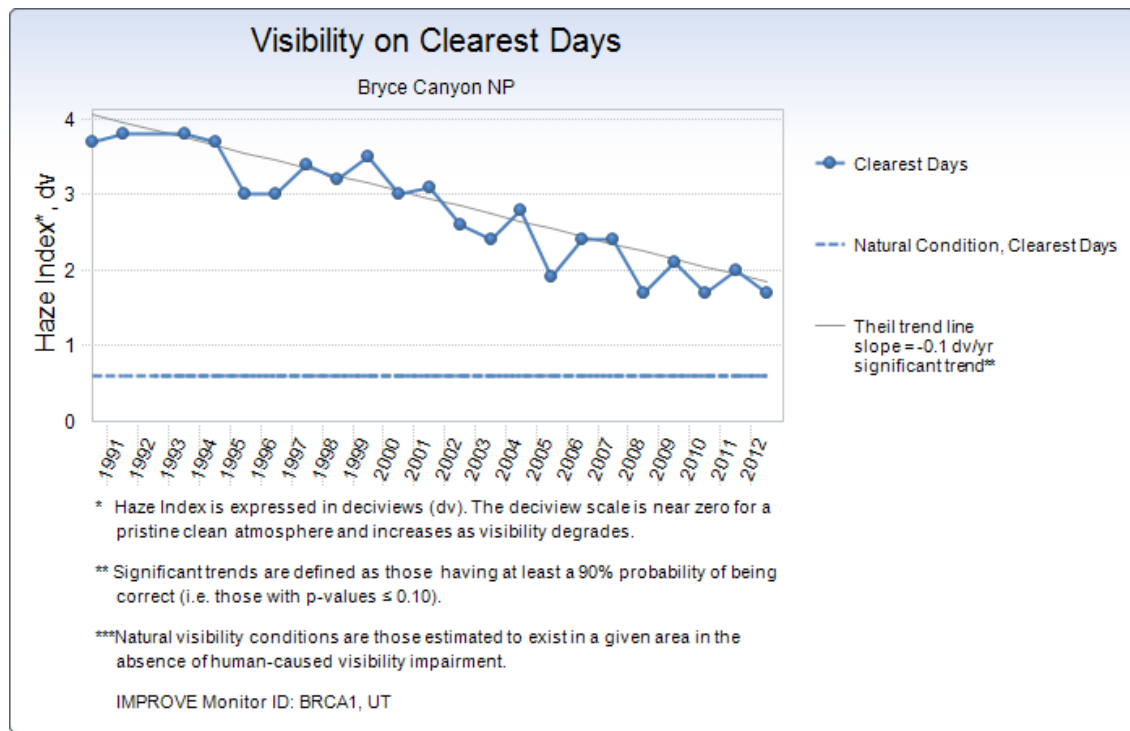


Figure 11b. Trends in ambient haze levels at BRCA based on IMPROVE measurements on the 20% clearest and 20% haziest days over the monitoring period of record. Data Source: WRAP TSS (technical support system) at vista.cira.colostate.edu/tss.

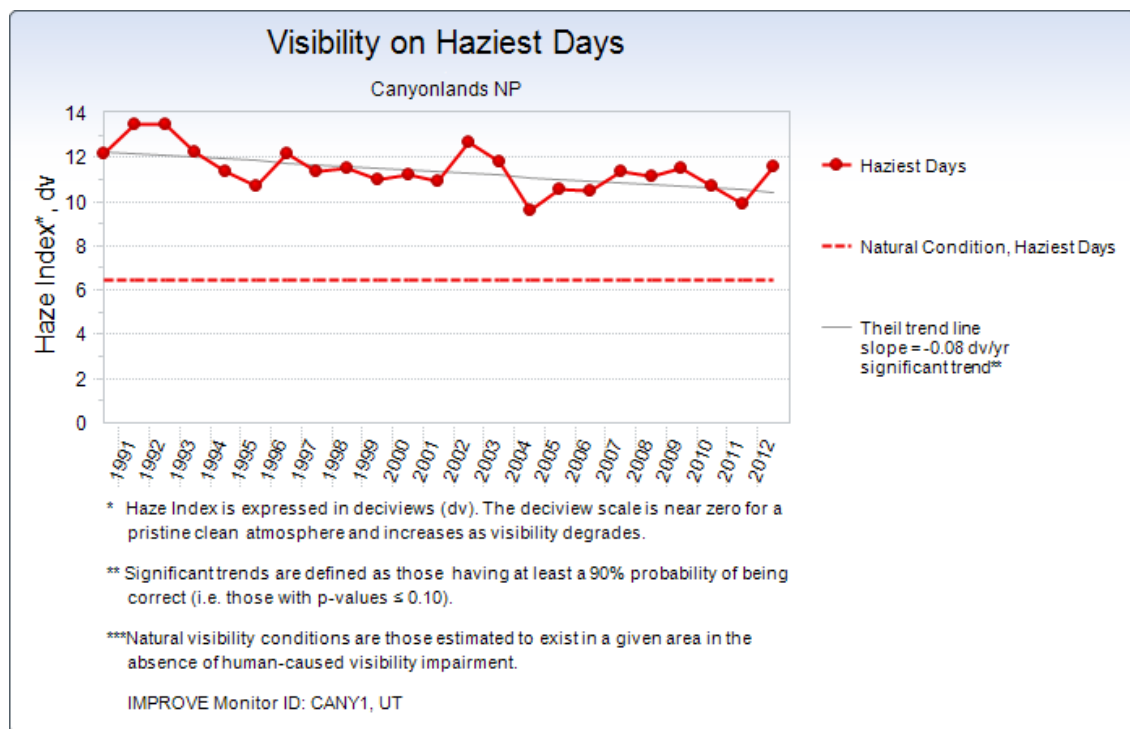
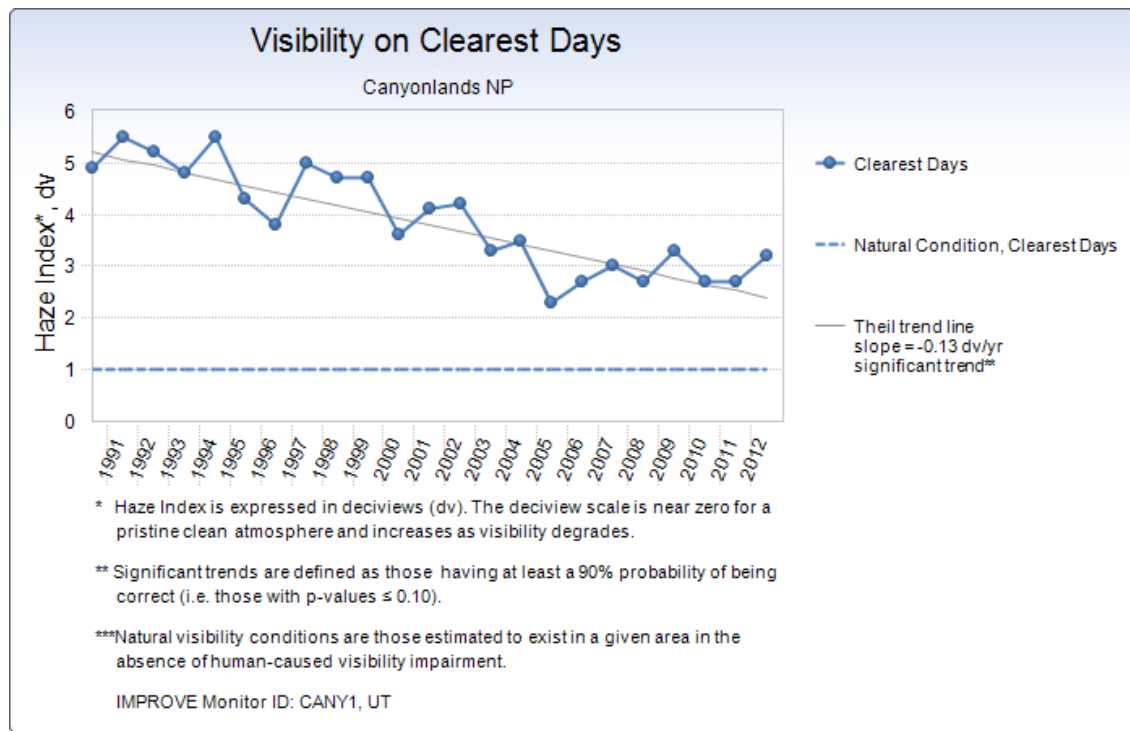


Figure 11c. Trends in ambient haze levels at CANY based on IMPROVE measurements on the 20% clearest and 20% haziest days over the monitoring period of record. Data Source: WRAP TSS (technical support system) at vista.cira.colostate.edu/tss.

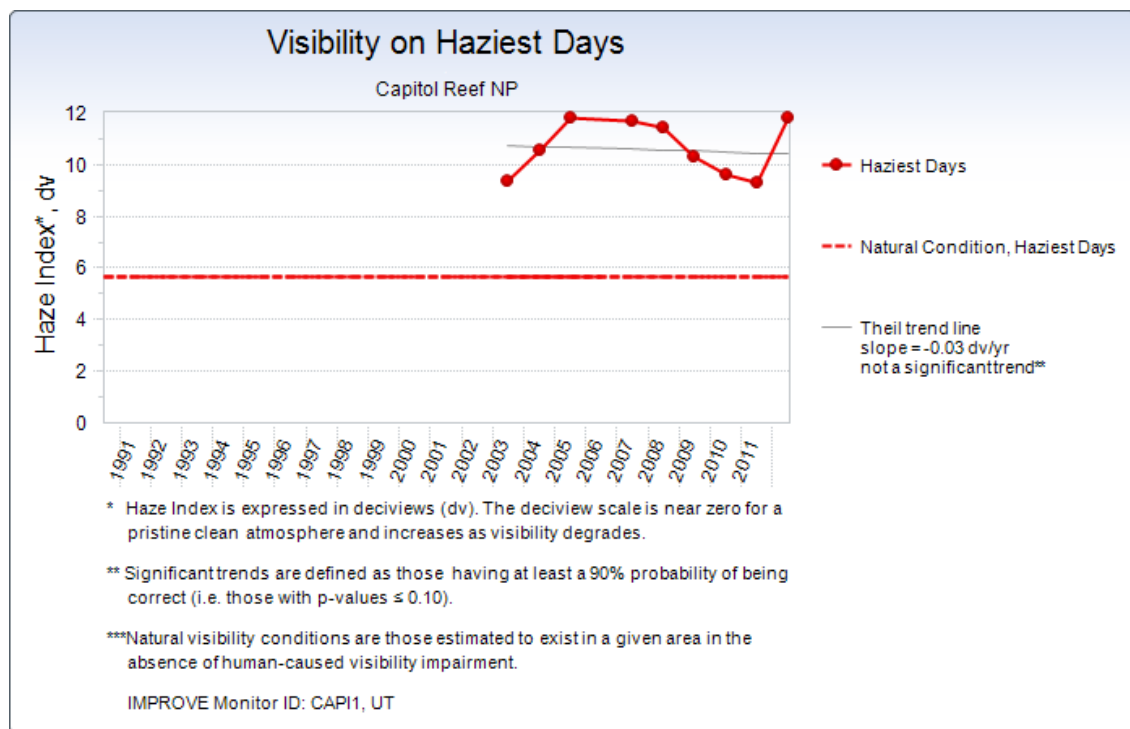
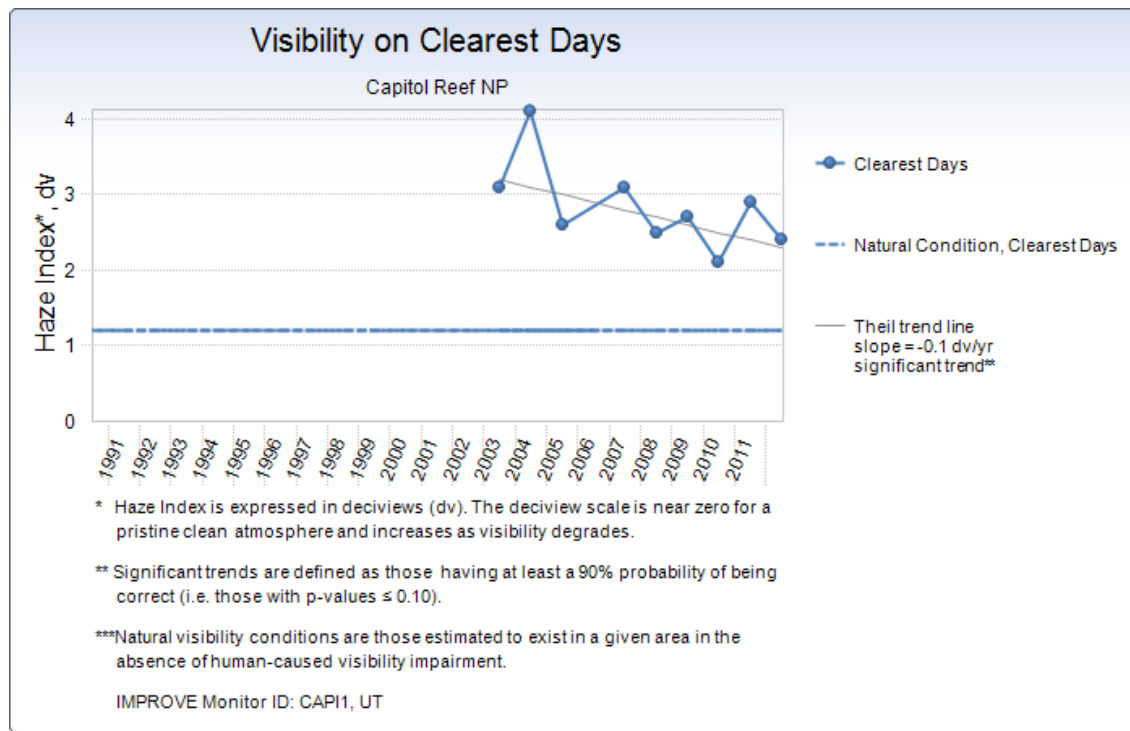


Figure 11d. Trends in ambient haze levels at CARE based on IMPROVE measurements on the 20% clearest and 20% haziest days over the monitoring period of record. Data Source: WRAP TSS (technical support system) at vista.cira.colostate.edu/tss.

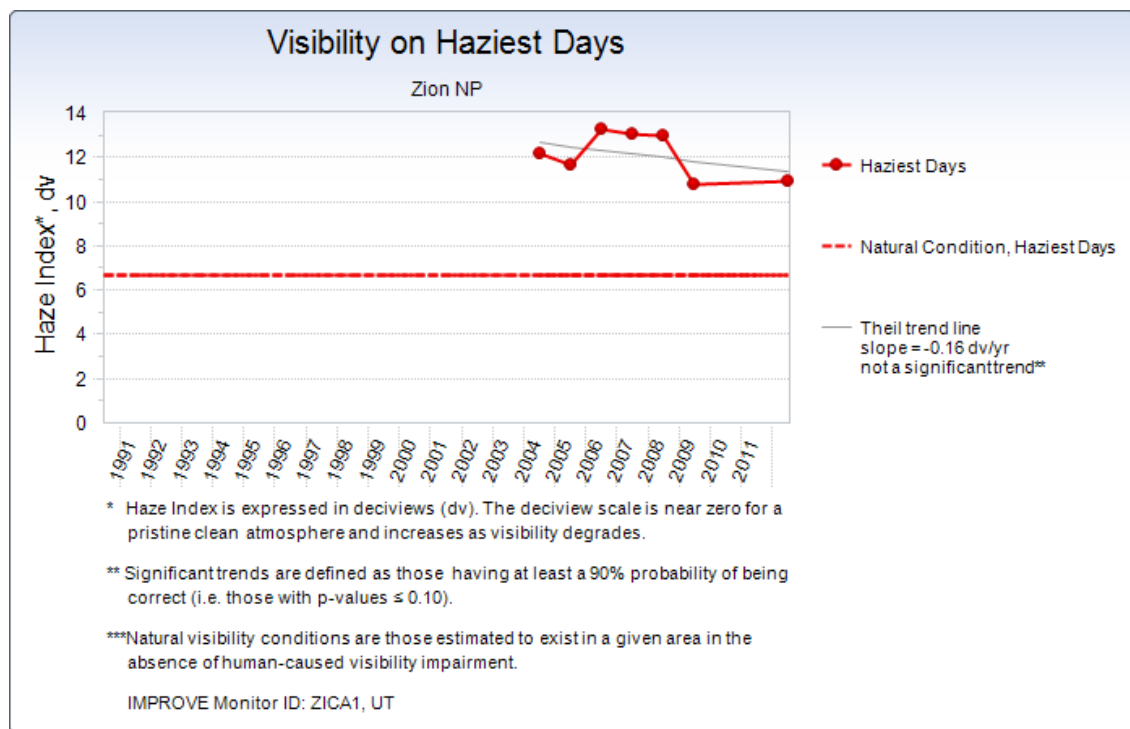
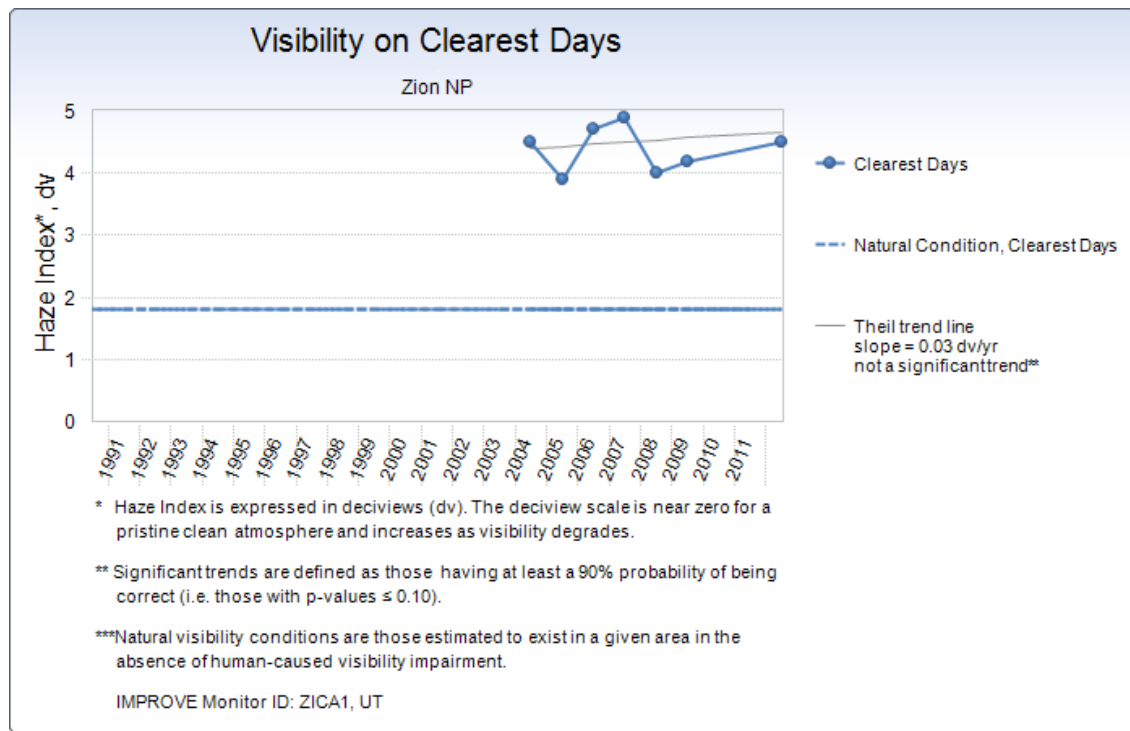


Figure 11e. Trends in ambient haze levels at ZION based on IMPROVE measurements on the 20% clearest and 20% haziest days over the monitoring period of record. Data Source: WRAP TSS (technical support system) at vista.cira.colostate.edu/tss.

Development of State Implementation Plans

According to the Regional Haze Rule, 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 by 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). Strategies for meeting the requirements of the Regional Haze Rule are detailed in State-specific Implementation Plans, which must be approved by the EPA. Included in those Plans are the major emissions reductions achieved or expected as a result of the Best Available Retrofit Technology (BART) requirement of the Regional Haze Rule. Because of this requirement, major emissions reductions have been made by power plants (electric generating units - EGUs), and many more are anticipated from sources impacting the NCPN region. Figure SCPN-12 shows trends in SO₂ and NO_x emissions from EGUs in CO and UT, the states having the largest EGUs affecting visibility at NCPN parks. From 2000-2013, very large emissions reductions occurred in these states. These reductions will result in visibility improvements if other visibility-reducing pollutants do not increase. However, as noted previously, organics and carbon fine particles also are major contributors to visibility impairment in the region.

Table 7 gives estimates of visibility at six NCPN Class I areas on the 20 percent clearest and haziest days. Haze is significantly elevated over natural conditions on both clear and hazy days for both the baseline (2000-2004) period and 2018. Natural conditions on the haziest days are not expected to be achieved by 2064. Estimates for these parks indicate that natural conditions will not be reached for many years (115-217 years), suggesting that reductions in addition to those illustrated by Figure 12 will be needed (pers. comm. Don Shepherd, NPS ARD).

Toxic Airborne Contaminants

Atmospheric deposition of Hg from coal-burning power plants has been identified as a major source of mercury (Hg) to remote ecosystems (Landers et al. 2008). Because of the size and number of coal-burning power plants in the NCPN region, Hg is a potential problem for ecosystems in the parks. Although Hg is not monitored in the NCPN parks, data from Hg monitors in the region, including a monitor near Salt Lake City, UT, suggest that concentrations of Hg in rainfall and snow are relatively high.

Wet Hg deposition to an ecosystem is a function of Hg concentration in precipitation and precipitation amounts. When Hg is deposited to an ecosystem, ecosystem conditions may facilitate methylation of Hg from its inorganic form to the more toxic organic form, methylmercury (MeHg). MeHg readily bioaccumulates in food chains, reaching toxic levels in fish and wildlife. Methylation most commonly occurs in wetlands, reservoirs, and riverine systems. Eagles-Smith et al. (2014) examined fish from 21 national parks in the western U.S., including two NCPN parks, CARE (in the Fremont River) and ZION (Virgin River). In both parks, only speckled dace, a small, invertebrate-

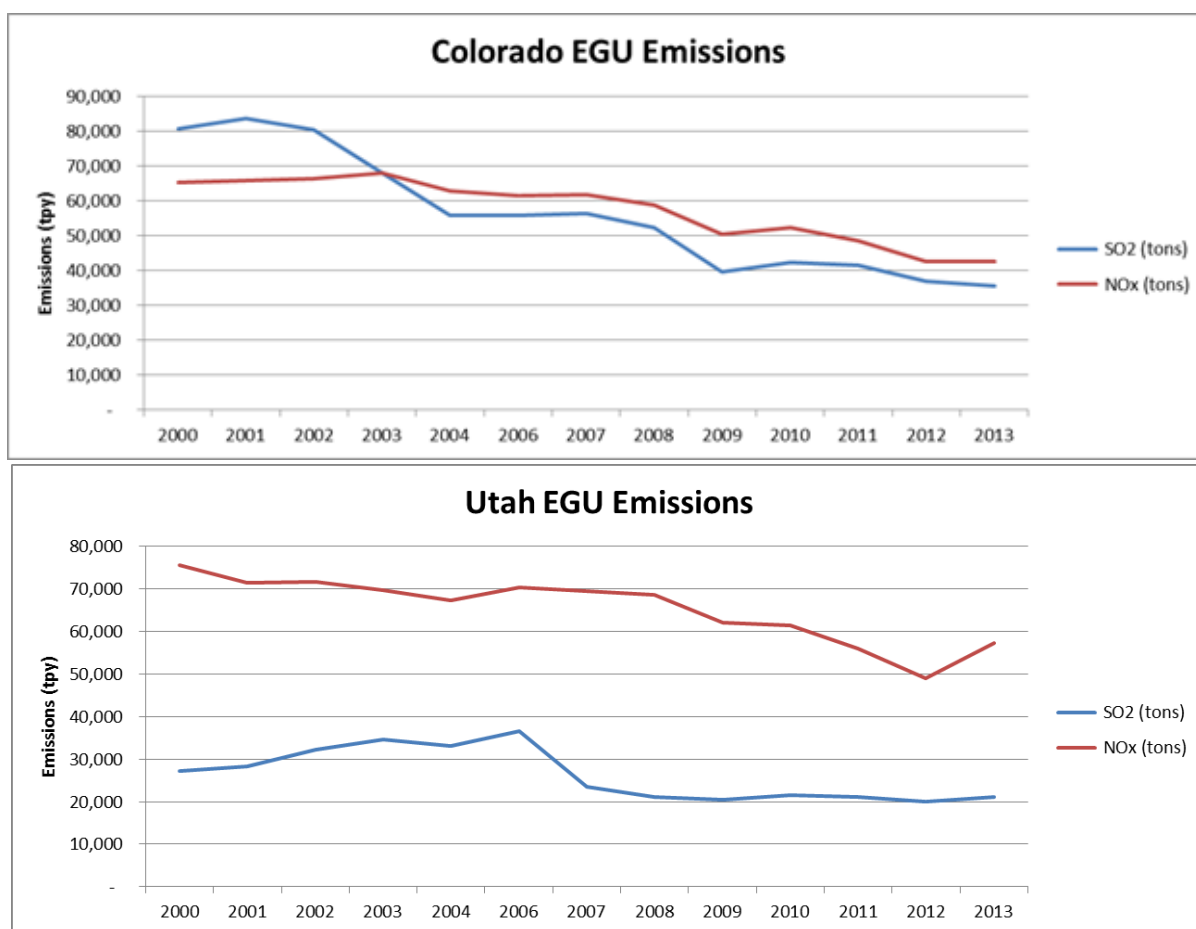


Figure 12. Trends in sulfur dioxide (SO₂) and nitrogen oxides (NO_x) emissions at power plants (electrical generating units - EGUs) in Colorado and Utah from 2000-2013. (Pers. comm. Don Shepherd, NPS ARD 2015).

Table 7. Estimates of natural and baseline (2000-2004) and projected 2018 visibility on the 20% clearest and haziest days at Arches NP, Black Canyon of the Gunnison NM, Bryce Canyon NP, Canyonlands NP, Capitol Reef NP, and Zion NP, as well as the estimated years to natural conditions on the haziest days given actual and anticipated emissions reductions in the region (Data for natural, baseline, and projected 2018 visibility from WRAP at <http://vista.cira.colostate.edu/tss/Results/HazePlanning.aspx>; estimated years to natural conditions from Don Shepherd, NPS ARD).

Park Name	Measured Baseline, Projected 2018, and Estimated Natural Haze						Years to Natural Conditions
	20% Clearest Days (dv)			20% Haziest Days (dv)			
	Baseline	2018	Natural	Baseline	2018	Natural	
Arches	3.8	3.5	1.0	11.2	10.7	6.4	134
Black Canyon of the Gunnison	3.1	2.9	1.0	10.3	9.8	6.2	115
Bryce Canyon	2.8	2.6	0.6	11.6	11.1	6.8	134
Canyonlands	3.8	3.5	1.0	11.2	10.7	6.4	134
Capitol Reef	4.1	3.9	1.2	10.9	10.4	5.7	146
Zion	5.0	4.7	1.9	13.2	12.8	7.0	217

feeding species, were sampled. Because of their small size they are not consumed by humans, so no conclusions can be drawn regarding human toxicity related to their consumption. However, their Hg concentrations were as high or higher than those in the largest, long-lived predatory species, such as lake trout, sampled in other national parks. Speckled dace serve as potential prey items for predatory fishes and piscivorous birds, and concentrations in dace from both parks exceeded levels associated with biochemical and reproductive effects in fish and reproductive impairment in birds (Eagles-Smith et al. 2014).

Other airborne contaminants pose a risk to biota in the NCPN parks. These include persistent organic pollutants and other semi-volatile organic compounds (SOCs) such as pesticides, industrial and urban use compounds, and polycyclic aromatic hydrocarbon combustion products (Landers et al. 2010). Limited information regarding the levels of SOC contaminants in the NCPN parks is available (<http://science.nature.nps.gov/im/units/ncpn/publications.cfm>).

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