



Air Quality Related Values (AQRVs) for Upper Columbia Basin Network (UCBN) Parks

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

Natural Resource Report NPS/UCBN/NRR—2016/1205



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 Upper Columbia Basin Network (UCBN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The UCBN includes nine parks in Idaho, Montana, eastern Oregon and eastern Washington. The UCBN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument and Preserve (CRMO), Hagerman Fossil Beds National Monument (HAFO), John Day Fossil Beds National Monument (JODA), Lake Roosevelt National Recreation Area (LARO), Minidoka National Historic Site (MIIN), Nez Perce National Historical Park (NEPE), and Whitman Mission National Historic Site (WHMI). CRMO is designated as Class I, giving it a heightened level of protection against harm caused by poor air quality under the Clean Air Act.

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

Air quality in the UCBN is generally very good. Levels of air pollution, including exposure to O_3 and atmospheric deposition of N, S, and particulates, in most cases are low.

Sulfur and N pollutants can acidify streams, lakes, and soils. A coarse screening risk assessment by Sullivan et al. (2011b) suggested that resources in UCBN parks appear to be moderately sensitive to acidification relative to other networks in the NPS I&M Program. However, because UCBN parks are exposed to low levels of air pollution, acidification effects are unlikely.

Nitrogen pollutants can cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species diversity and soil nutrient cycling. Several of the UCBN parks were ranked as highly sensitive to N enrichment, including HAFO, JODA, BIHO, CIRO, and NEPE. Estimated N deposition at some of the parks exceeded levels known to affect plant and lichen diversity.

Ozone pollution can harm human health, reduce plant growth and cause visible injury to foliage. However, O_3 exposure at parks within the UCBN is generally low. Particulate pollution can cause haze, reducing visibility. Nevertheless, visibility in the UCBN is generally good compared to the rest of the United States. For example, visibility monitoring conducted at or near BIHO, CRMO, and NEPE indicated relatively low levels of haze. The largest contributors to haze in those parks were organics, SO_4^{2-} and NO_3^- .

Background

There are nine parks in the Upper Columbia Basin Network (UCBN): Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument and Preserve (CRMO), Hagerman Fossil Beds National Monument (HAFO), John Day Fossil Beds National Monument (JODA) National Monuments, Lake Roosevelt National Recreation Area (LARO), Minidoka National Historic Site (MIIN), Nez Perce National Historical Park (NEPE), and Whitman Mission National Historic Site (WHMI). Two of the parks, CRMO and LARO, are larger than 100 square miles. Larger parks generally have more available data with which to evaluate air pollution sensitivities and effects. In addition, the larger parks generally contain more extensive resources in need of protection against the adverse impacts of air pollution. Most of the analyses reported here do not include MIIN because it did not become a designated NPS site until near the completion of this assessment.

There are only two cities larger than 100,000 people in the UCBN region (Boise, Spokane) and none larger than 500,000 people. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people.

The predominant vegetation cover types within the network region are generally quite varied. They include mainly forest and row crops in the north, and shrubland and grassland/herbaceous plant communities in the south. Forest plant associations include Douglas-fir (*Pseudotsuga menziesii*)/mountain snowberry (*Symphoricarpos oreophilus*), limber pine (*Pinus flexilis*)/antelope bitterbush (*Purshia tridentata*), and quaking aspen (*Populus tremuloides*).

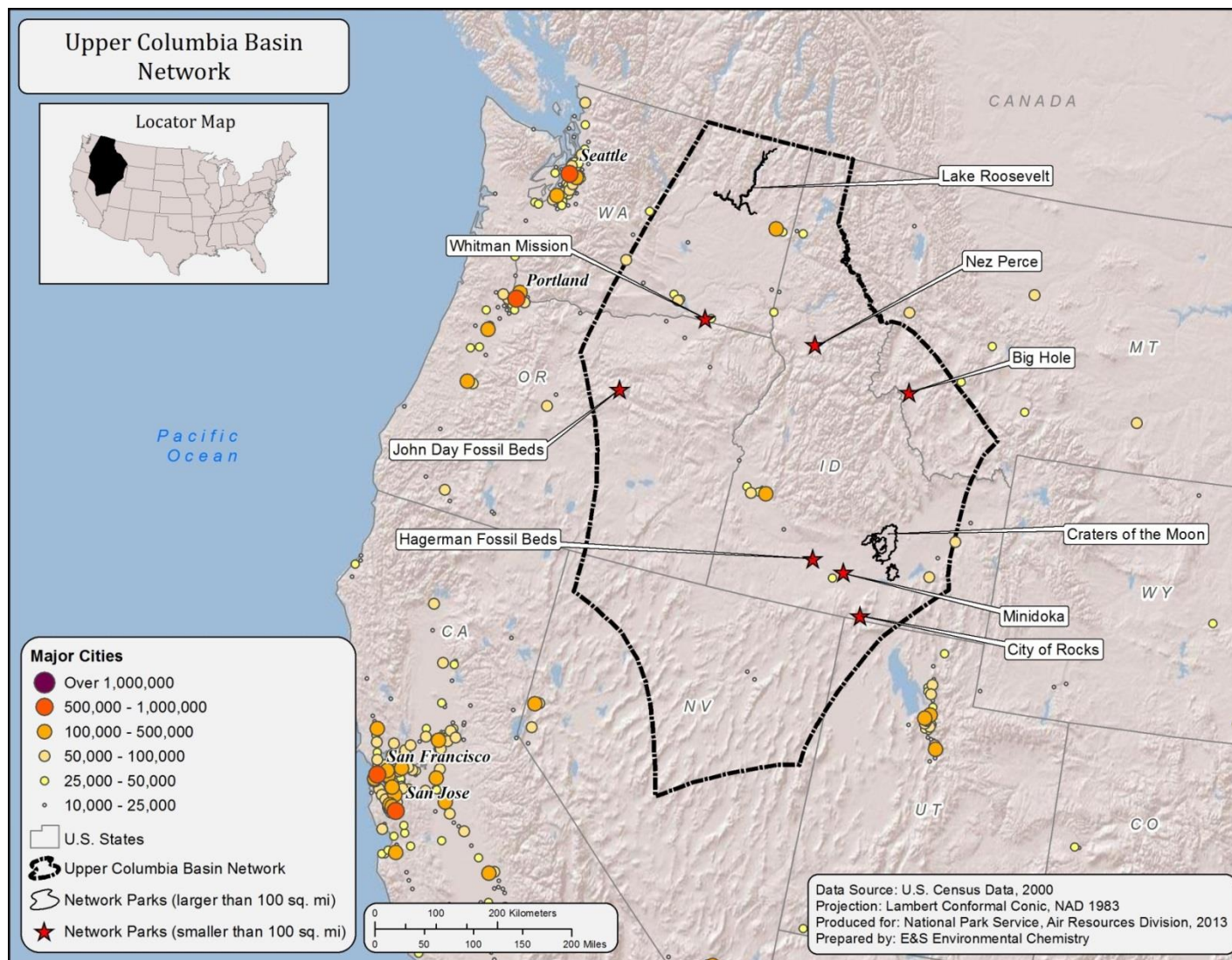
Atmospheric Emissions and Deposition

Air quality in the UCBN is generally very good compared to other areas of the United States (Eilers et al. 1994). The principal air masses that affect the UCBN are derived from the atmosphere over the Pacific Ocean and emissions of air pollutants in Oregon and Washington upwind of the UCBN are low relative to most other regions. Pollutant concentrations in precipitation are low at most locations throughout the network.

County level sulfur dioxide (SO₂) emissions in the UCBN region were low in 2002, mostly less than 1 ton per square mile per year (ton/mi²/yr), with a few areas having emissions between 1 and 5 tons/mi²/yr (Sullivan et al. 2011b). There were few point sources of SO₂ emissions in the region, and those sources were relatively small; all but one emitted less than 5,000 tons of SO₂ per year.

County-level N emissions in 2002 within the UCBN region ranged from less than 1 ton/mi²/yr to more than 5 tons/mi²/yr. In general, annual county N emissions were less than 5 tons/mi²/yr. There were few N point sources of any magnitude in this region.

Total N emissions, the sum from both point and non-point sources, can be underestimated by the emissions inventories because emissions of reduced N (ammonia, NH₃) from agriculture are highly variable both spatially and temporally and are difficult to quantify. Clarisse et al. (2009) mapped global atmospheric NH₃ concentrations using satellite data and identified a “hotspot” of NH₃ over the



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

Snake River Valley in south-central Idaho. Concentrations of NH_3 in this region were much higher than those predicted by commonly used atmospheric models. The researchers concluded that NH_3 emissions could be significantly underestimated in regions of high intensity agricultural activity.

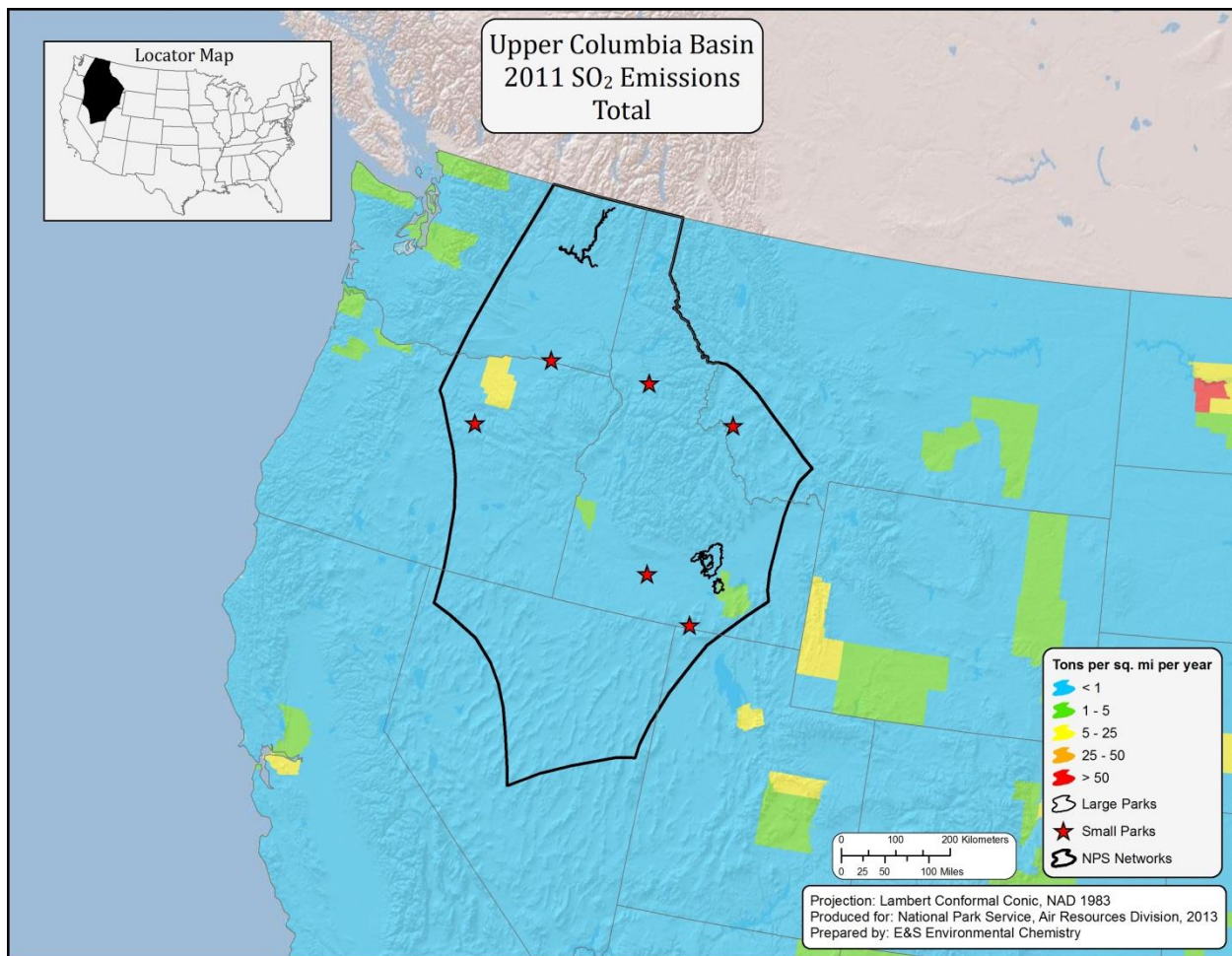
County-level emissions near the UCBN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO_2 , oxidized N (NO_x), and NH_3 , respectively. Most counties near the UCBN parks had low SO_2 emissions ($< 1 \text{ ton/mi}^2/\text{yr}$; Map 2). Spatial patterns in NO_x emissions showed somewhat higher values (Map 3). Emissions of NH_3 near UCBN parks were variable (Map 4).

Data from passive NH_3 samplers deployed in several UCBN parks in 2010 and 2011 found a gradient of atmospheric NH_3 concentrations from CRMO (2-4 micrograms per cubic meter [$\mu\text{g}/\text{m}^3$]) to HAFO (9-10 $\mu\text{g}/\text{m}^3$). Nitrogen deposition also increased along the gradient, reaching estimated levels of 8-9 kilograms/hectare/year ($\text{kg}/\text{ha}/\text{yr}$) and greatly exceeding modeled levels (Dr. Edith Allen, personal communication, August, 2013).

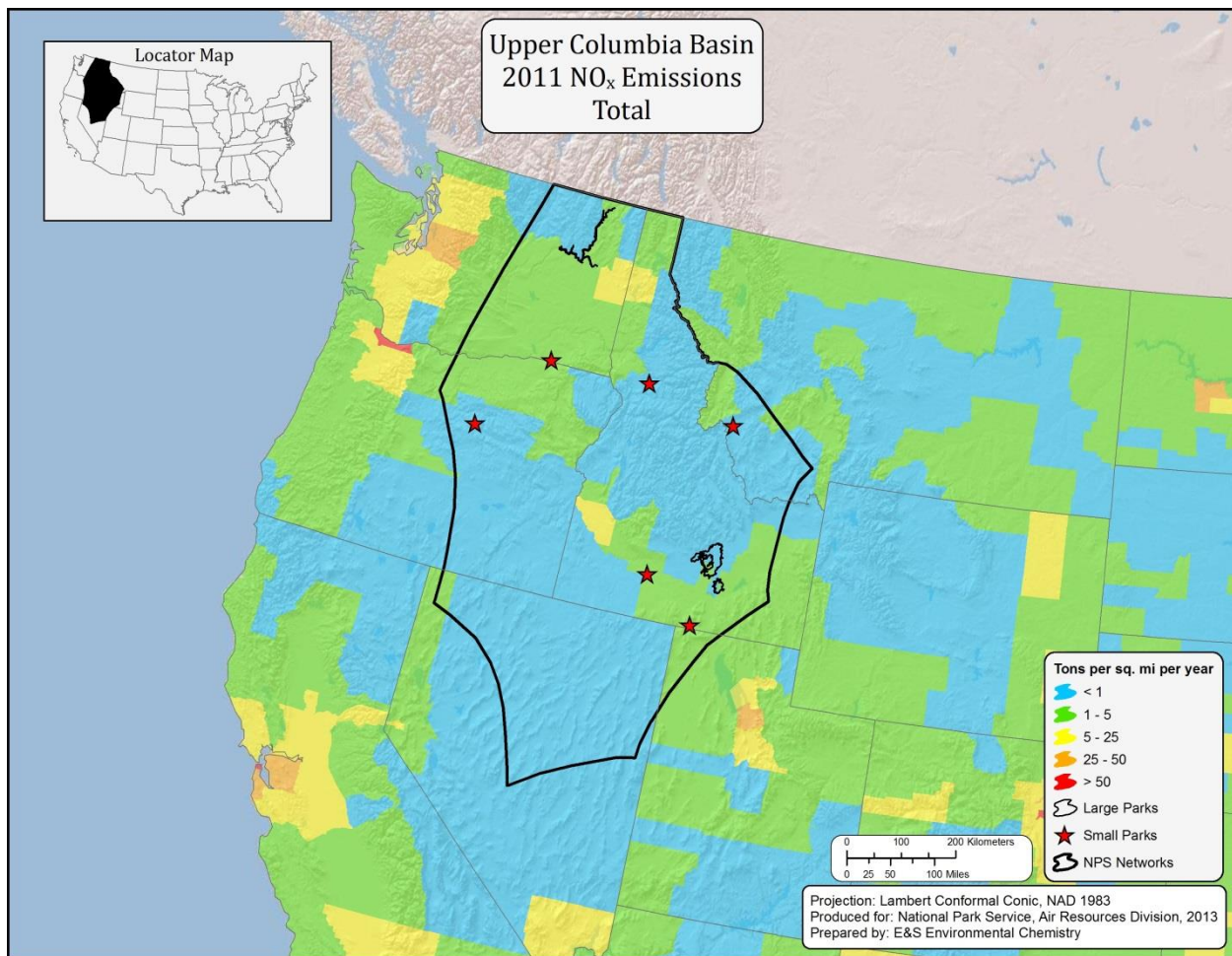
Geiser et al. (2008) sampled atmospheric deposition of S and oxidized (mainly from fuel combustion) and reduced (mainly from agriculture) N in Hells Canyon National Recreation Area (NRA), along the border between Oregon and Idaho. In addition, they analyzed O_3 and atmospheric particulate data from monitoring sites in Hells Canyon. Despite its remote location, Geiser et al. (2008) found that Hells Canyon NRA experiences higher rates of N deposition than most other remote northwestern locations. Relatively high concentrations of N in precipitation at CRMO, located to the southeast of Hells Canyon, are derived regionally from fertilized fields and animal feeding operations (Eilers et al. 2000). The channeling of winds from the Snake River Valley transports air pollutants into Hells Canyon NRA. Thus, back trajectory model analyses by Geiser et al. (2008) suggested that poor air quality in Hells Canyon occurs on days when air masses pass through the upper and lower Snake River basins *en route* to Hells Canyon.

MIIN is located downwind of confined animal feeding operations (CAFOs) in the Snake River Valley. These CAFOs produce NH_3 and other air pollutants. Gomez-Moreno et al. (2010) reported results of model simulations of air pollution levels near a proposed CAFO, using the CALPUF model. Results suggested the potential for intermittent effects at MIIN during both winter and summer conditions.

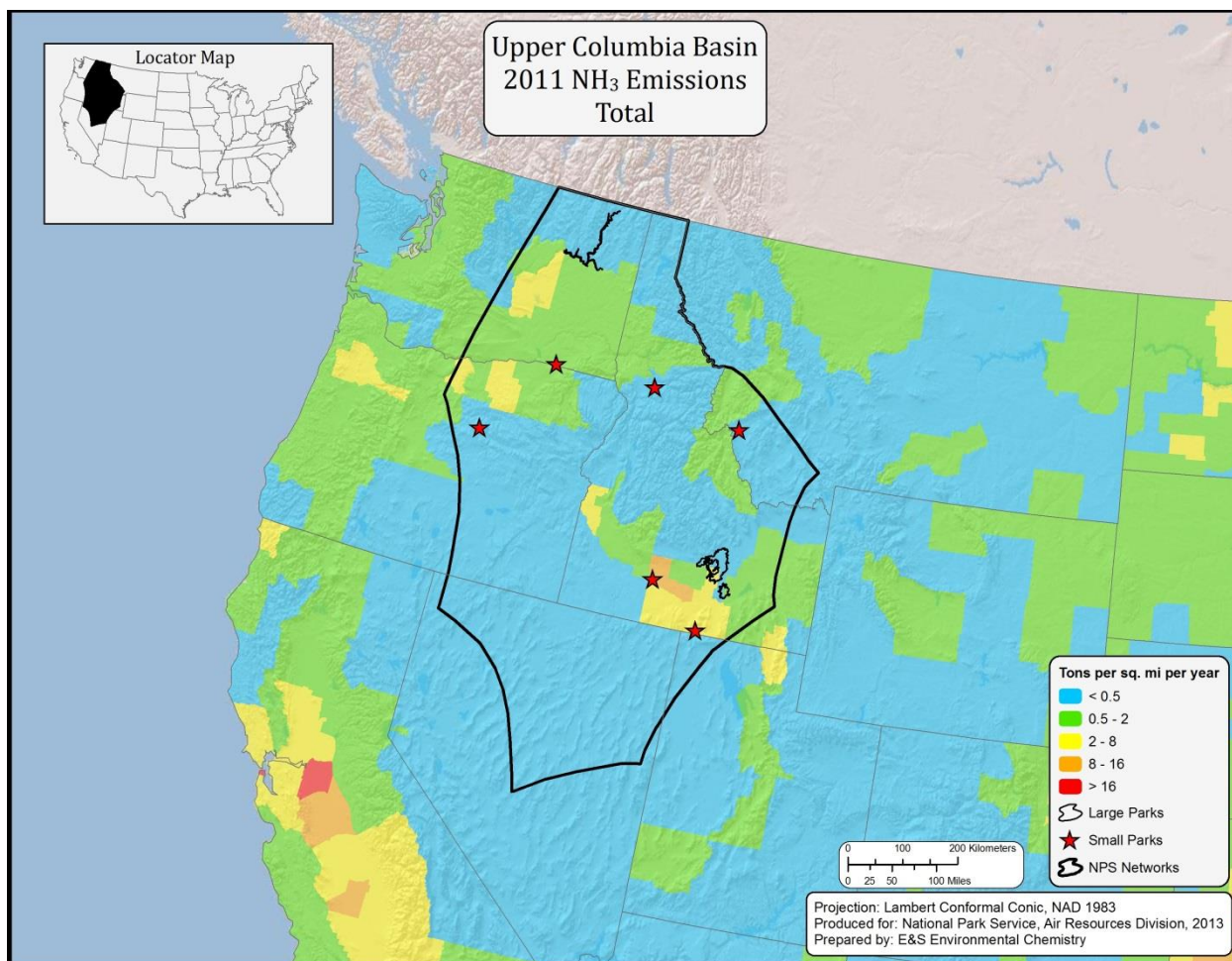
Dry deposition, rather than wet deposition, of S and N predominates in arid ecosystems, such as are prevalent in the UCBN. Dry deposition is difficult to quantify, in large part because the deposition is influenced by a multitude of factors, including the mix of air pollutants present, surface characteristics 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 semi-arid 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 N was leached down the soil profile (Padgett et al. 1999, Padgett and Bytnerowicz 2001). Similar processes may occur in the UCBN.



Map 2. Total SO₂ emissions, by county, near the UCBN for the year 2011. Data from EPA's National Emissions Inventory.



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



Map 4. Total NH₃ emissions, by county, near the UCBN for the year 2011. Data from EPA's National Emissions Inventory.

Total modeled S deposition in 2002 was low throughout the entire UCBN network at less than 2 kg S/ha/yr (Sullivan et al. 2011b). Total modeled N deposition was in the range of 2 to 5 kg N/ha/yr at most of the UCBN parks. More 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 sulfur (S) deposition. The TDEP 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), 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 generally increased at UCBN parks since 2001, based on TDEP estimates (Table 1). Increases in total S deposition over the previous decade were larger than 20% at many of the parks. Oxidized and reduced N showed opposite patterns, with oxidized N

generally decreasing and reduced N increasing at all of the parks in the network since the monitoring period 2000-2002. Increases in the deposition of reduced N were in many cases larger than 40%.

Mercury (Hg) deposition is an important concern in the UCBN. The contribution from natural Hg sources relative to anthropogenic sources varies geographically. For example, Nevada occurs within a global mercuriferous belt, with area emissions about three times higher than the average value assumed for global modeling (Gustin 2003). In Nevada, natural and anthropogenic Hg emissions are approximately equal (Gustin 2003).

Total S deposition in and around the UCBN for the period 2010-2012 was generally low (< 2 kg S/ha/yr) at park locations within the network area (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was less than 2 kg N/ha/yr throughout the park lands within the UCBN (Map 6). Most areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7); a few areas in the network region received higher amounts. Total N deposition was variable (Map 8).

Acidification

The relative network rankings developed in a coarse screening assessment 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 UCBN that was the lowest of all I&M networks. The overall level of concern for acidification effects on UCBN parks was judged by Sullivan et al. (2011b) to be Very Low.

Two of the parks in the UCBN were ranked by Sullivan et al. (2011b) in the second lowest quintile (Low) for acid Pollutant Exposure: HAFO and WHMI (Table 2). The other parks in the network were ranked in the lowest quintile (Very Low) for this theme (Table 2). Ecosystem Sensitivity to acidification rankings varied, with CRMO and WHMI ranked in the lowest quintile, and CIRO ranked in the second highest. CIRO is located in the Idaho Batholith and may contain low-ANC streams. The other five parks were ranked in the middle quintile for Ecosystem Sensitivity to acidification (Table 2). While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

There is no information about the effects of acidic deposition on terrestrial resources in the UCBN region. In view of the very low levels of S and N air pollutant exposure for the parks in this network, such effects are unlikely.

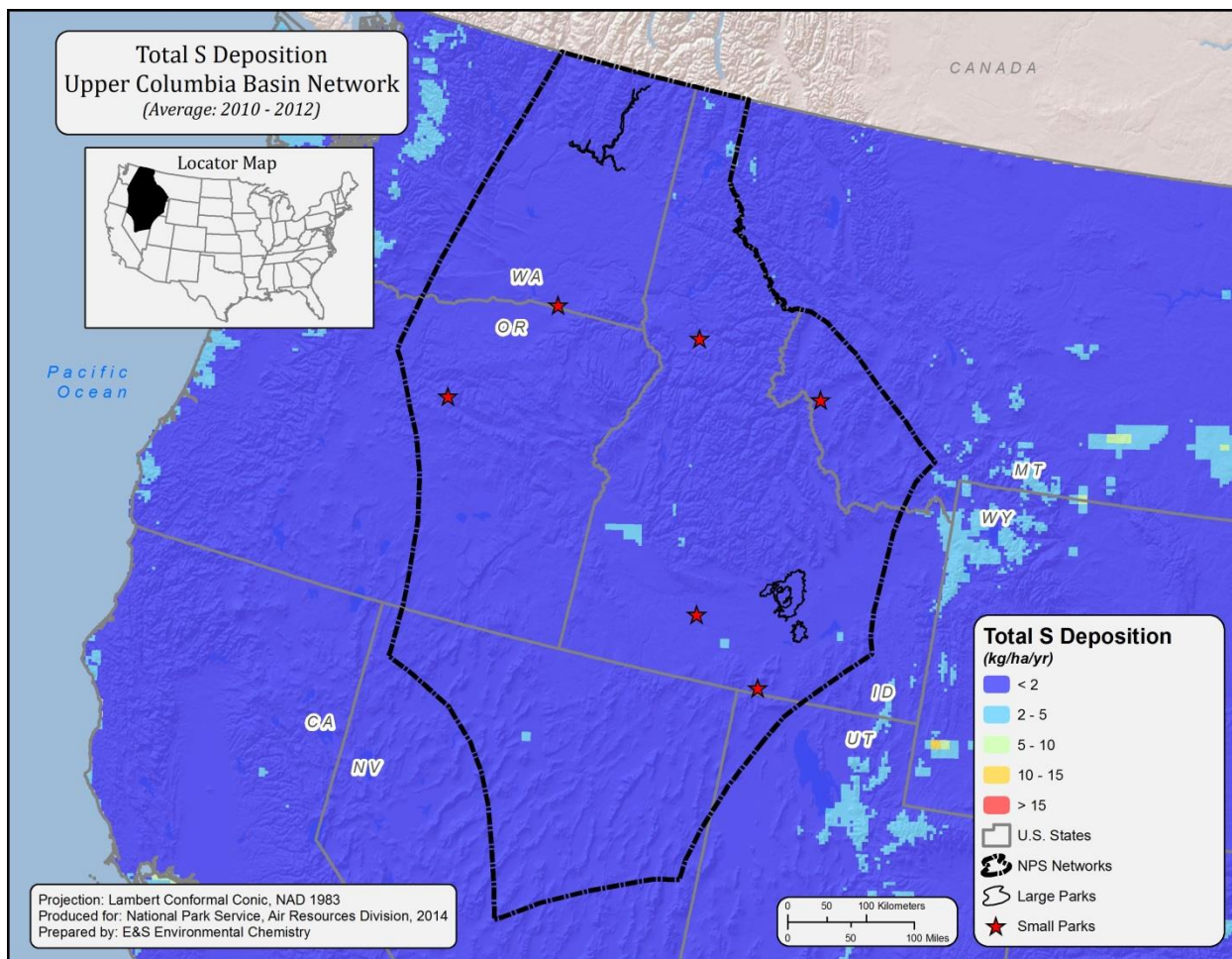
Similarly, little information is available regarding potential lake and stream acidification in the UCBN region. There are few lakes or streams in the Columbia Plateau. Precipitation in large portions of the region is only 25 to 50 cm/yr (10 to 20 in/yr; Daly 1993), resulting in desert vegetation. Water in the Columbia Basin is so limiting that its quality generally is secondary to its availability. Aquatic acidification is not an important concern for UCBN parks.

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

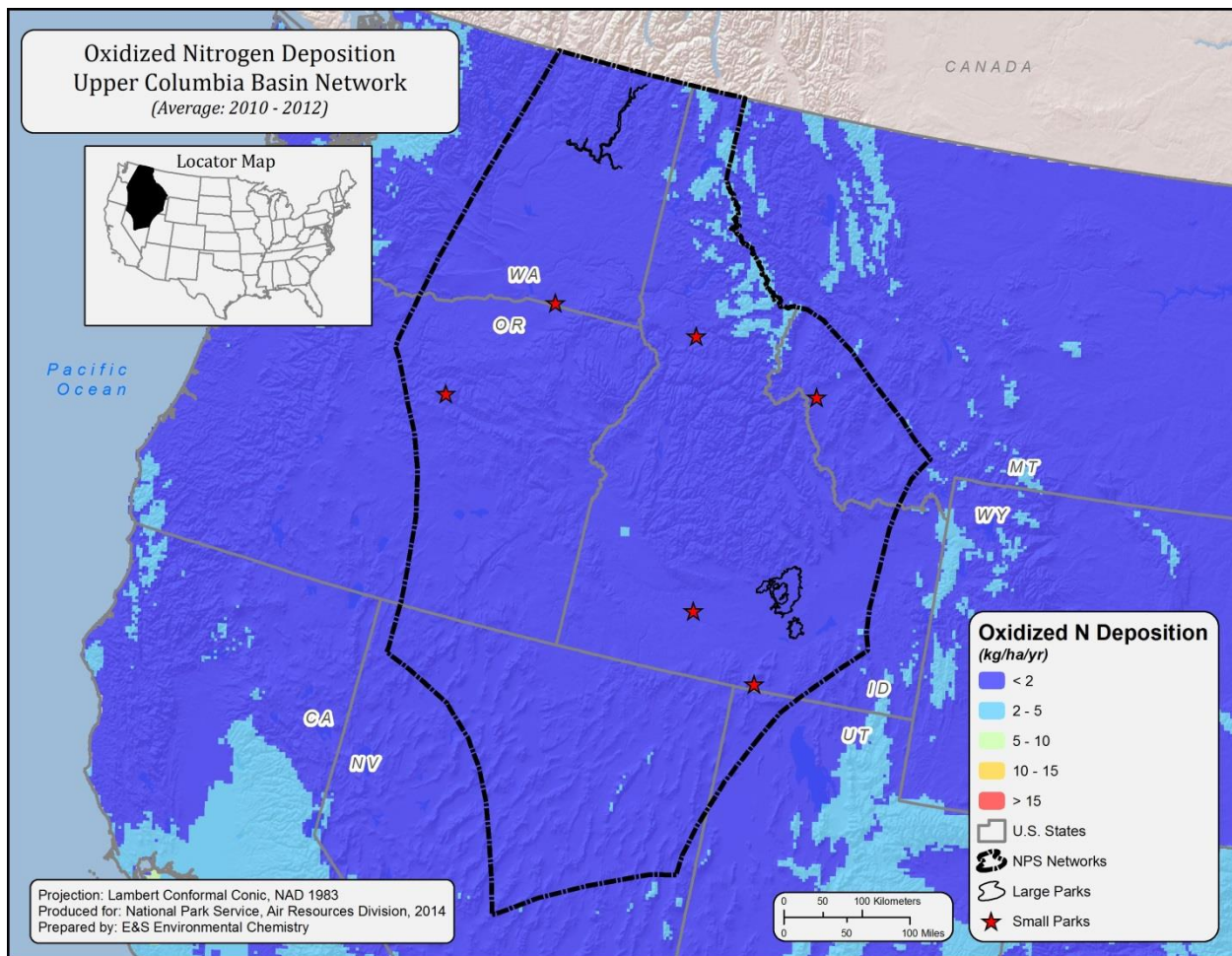
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
BIHO	Big Hole	Total S	0.54	0.67	0.14	27.3%	0.67	0.74	0.07
		Total N	1.88	2.28	0.41	22.3%	2.26	2.50	0.23
		Oxidized N	1.10	1.09	0.00	0.6%	1.09	1.20	0.11
		Reduced N	0.78	1.18	0.41	52.9%	1.18	1.30	0.12
CIRO	City of Rocks	Total S	0.76	0.87	0.11	16.0%	0.68	1.25	0.56
		Total N	3.66	4.56	0.90	27.6%	4.03	5.50	1.47
		Oxidized N	1.44	1.15	-0.28	-19.7%	0.98	1.52	0.54
		Reduced N	2.22	3.40	1.18	60.3%	3.05	3.98	0.93
CRMO	Craters of the Moon	Total S	0.40	0.48	0.09	21.7%	0.41	0.67	0.27
		Total N	2.60	2.73	0.13	5.7%	2.13	5.80	3.67
		Oxidized N	1.17	0.77	-0.40	-34.3%	0.65	0.98	0.32
		Reduced N	1.43	1.96	0.53	42.1%	1.46	4.87	3.41
HAFO	Hagerman Fossil Beds	Total S	0.40	0.70	0.30	75.8%	0.66	0.74	0.08
		Total N	9.26	14.71	5.45	58.8%	14.44	15.04	0.60
		Oxidized N	1.18	0.91	-0.27	-22.8%	0.90	0.94	0.04
		Reduced N	8.09	13.80	5.72	70.7%	13.55	14.10	0.55
JODA	John Day Fossil Beds	Total S	0.23	0.28	0.05	23.8%	0.27	0.34	0.08
		Total N	1.22	1.07	-0.15	-12.2%	1.01	1.21	0.21
		Oxidized N	0.80	0.53	-0.27	-33.8%	0.50	0.60	0.10
		Reduced N	0.42	0.54	0.12	28.6%	0.49	0.62	0.13
LARO	Lake Roosevelt	Total S	0.44	0.42	-0.02	-5.3%	0.28	0.81	0.53
		Total N	1.73	1.81	0.08	5.2%	1.41	2.35	0.94
		Oxidized N	1.05	0.81	-0.24	-22.1%	0.62	1.09	0.47
		Reduced N	0.68	1.00	0.31	48.1%	0.79	1.32	0.53

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

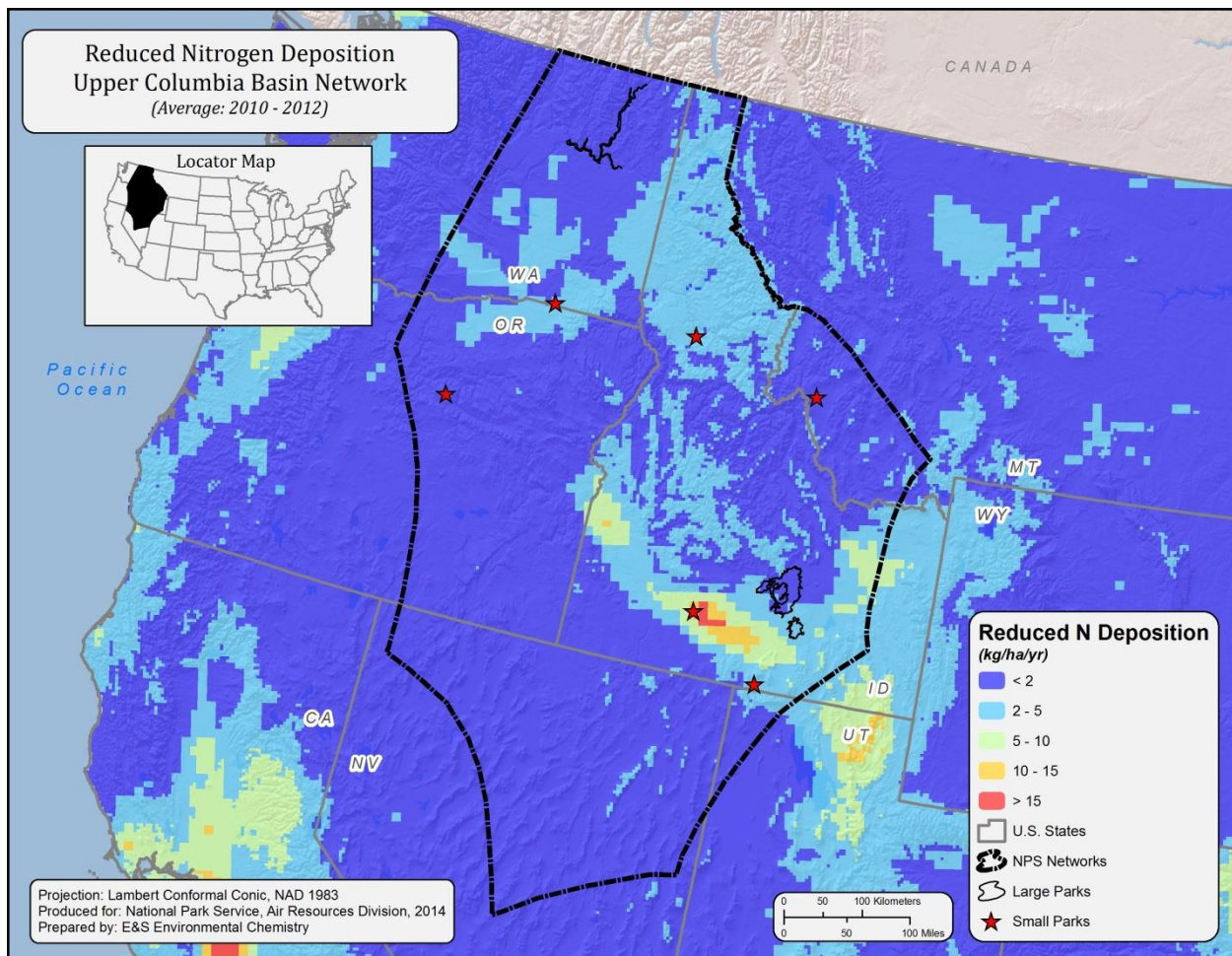
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
NEPE	Nez Perce	Total S	0.56	0.67	0.11	21.1%	0.39	1.23	0.84
		Total N	2.27	2.66	0.39	17.0%	1.72	3.22	1.50
		Oxidized N	1.21	1.05	-0.17	-13.7%	0.69	1.27	0.58
		Reduced N	1.05	1.61	0.56	53.5%	1.03	2.12	1.09
WHMI	Whitman Mission	Total S	0.45	0.46	0.01	1.6%	0.46	0.46	0.00
		Total N	2.69	3.05	0.36	13.5%	3.05	3.05	0.00
		Oxidized N	1.33	0.91	-0.42	-31.5%	0.91	0.91	0.00
		Reduced N	1.36	2.14	0.78	57.5%	2.14	2.14	0.00



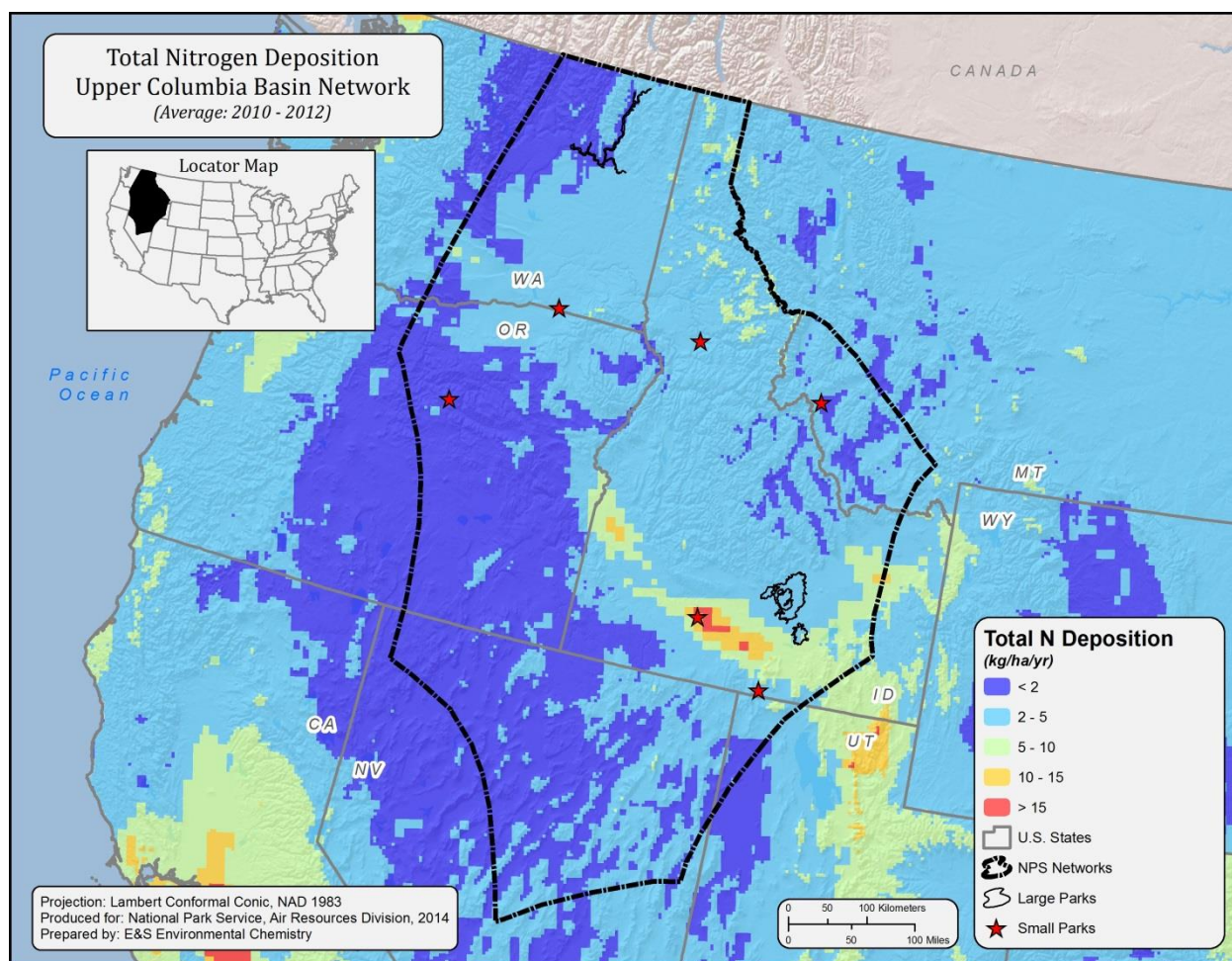
Map 5. Total S deposition for the three-year period centered on 2011 in and around the UCBN. (Source: Schwede and Lear 2014)



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



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



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

Table 2. Estimated I&M park rankings¹ according to risk of acidification of sensitive receptors (Source: Sullivan et al. 2011b). MIIN was not included in the assessment.

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Big Hole	BIHO	Very Low	Moderate
City of Rocks	CIRO	Very Low	High
<i>Craters of the Moon</i>	CRMO	Very Low	Very Low
Hagerman Fossil Beds	HAFO	Low	Moderate
John Day Fossil Beds	JODA	Very Low	Moderate
<i>Lake Roosevelt</i>	LARO	Very Low	Moderate
Nez Perce	NEPE	Very Low	Moderate
Whitman Mission	WHMI	Low	Very Low

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

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

Nutrient Nitrogen Enrichment

Crop fertilization and runoff from cattle and dairy operations contribute large amounts of nutrients to the Snake River in Idaho. As a consequence, several impounded reservoirs along the river corridor experience severe seasonal algal blooms. Chlorophyll *a* concentrations are above water quality standards. The pH of the lower Snake River tends to be high, ranging between about 6 and 9. The high pH in the Snake River promotes conversion of ammonium (NH_4^+) in the water column to gaseous NH_3 , which volatilizes and deposits to near-river vegetation (Geiser et al. 2008).

A gradient of N deposition that appears to be driven by atmospheric NH_3 concentrations has been identified across several UCBN parks, with the gradient increasing from CRMO to HAFO. As N deposition increases, the total cover of exotic invasive forbs and annual grasses (e.g., cheatgrass [*Bromus tectorum*]) increases, and the cover of native shrubs and bunch grasses decreases (Dr. Edith Allen, personal communication, August 2013). In a coarse screening assessment of relative eutrophication risk to park resources from N deposition, HAFO and WHMI were ranked in the middle quintile among all parks nationwide (Moderate) for nutrient N Pollutant Exposure (Table 3). Four parks in the network were ranked in the lowest quintile and two parks were ranked in the second lowest quintile for this theme. However, it is possible that N deposition at parks located near Snake River Valley agricultural emissions may have been underestimated. Ecosystem Sensitivity to nutrient N enrichment rankings were Moderate to Very High, in the highest quintile for HAFO and JODA, and in the second highest quintile for three other parks (Table 3). In general, the predominant vegetation type in the UCBN that is presumed to be especially sensitive to nutrient N enrichment is arid and semi-arid vegetation. 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.

Table 3. Estimated park rankings¹ according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a). MIIN was not included in the assessment.

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
Big Hole	BIHO	Very Low	High
City of Rocks	CIRO	Low	High
<i>Craters of the Moon</i>	CRMO	Low	Moderate
Hagerman Fossil Beds	HAFO	Moderate	Very High
John Day Fossil Beds	JODA	Very Low	Very High
<i>Lake Roosevelt</i>	LARO	Very Low	Moderate
Nez Perce	NEPE	Very Low	High
Whitman Mission	WHMI	Moderate	Low

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

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

Portions of south-central Idaho and eastern Oregon and Washington lie within the Great Basin and Intermountain Desert and Semi-desert ecoregions. Limited research has been conducted on the potential impacts of air pollutants on natural resources in these ecoregions. Sagebrush vegetation types and salt desert shrub plant communities are common, and depend on the presence of cryptogamic ¹crusts for soil stabilization. The effects of air pollutants, including nitrogen (N) deposition and ozone (O₃) exposure, on cryptogams are not known.

In a southern Idaho semi-desert big sagebrush (*Artemisia tridentata*) plant community, N fertilization at 6 and 12 kg N/ha/yr for six years contributed to increased use of soil water by plants (Inouye 2006). Because there was no observable increase in above-ground productivity, Inouye (2006) speculated that there may have been an increase in root productivity. Similarly, Schwinning et al. (2005) reported increased water uptake and quicker onset of drought stress symptoms subsequent to N fertilization of desert vegetation.

Atmospheric N deposition can interact strongly with climate change in sagebrush steppe plant communities. Inouye (2006) monitored soil moisture profiles over a six-year period. Compared to control plots, N addition plots (6 and 12 kg N/ha/yr) had less soil moisture, especially at depths of 100-180 cm. Shrub removal plots had more soil moisture. Inouye (2006) interpreted these results as evidence that shrubs in the sagebrush steppe ecosystem extract more moisture from deeper in the soil profile as compared with perennial grasses and that increased N supply can significantly affect soil water balance.

National monuments in the UCBN have experienced increased cover of non-native plant species, most notably cheatgrass, in generally undisturbed areas. Although cheatgrass invades most readily at locations that have been burned or grazed (Chambers et al. 2007), this species also responds to increased N supply (Chambers et al. 2007, Lowe et al. 2003, Monaco et al. 2003). Apparent recent increases in N deposition in the vicinity of UCBN parks (Apel et al. 2014) may be increasing the amount of previously undisturbed land in UCBN that is sensitive to increased abundance of non-native plant species as a consequence of increased N deposition.

Pardo et al. (2011) compiled data on empirical critical loads (CL) for protecting sensitive resources in Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. The lower end of the reported range was 2.5-4 kg N/ha/yr for protecting lichens and herbaceous plants in the ecoregions that include the UCBN parks (Table 4). Estimated N deposition reported by Pardo et al. (2011) was higher than 2.5-4 kg N/ha/yr at many parks in the UCBN network. This suggests that current levels of N deposition may exceed nutrient CLs for some sensitive resources at these parks. Data compiled by Pardo et al. (2011) also suggested nutrient CL exceedance at CRMO for protecting forest vegetation and preventing NO₃⁻ leaching in drainage water. Among the parks in the UCBN, CRMO appears to be the park with the greatest number of potential CL exceedances.

¹ Communities of living organisms on the soil surface in arid and semi-arid ecosystems

Table 4. Empirical critical loads for nitrogen in UCBN, 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
Big Hole NB	Northwestern Forested Mountains	1.7	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
City of Rocks NR	North American Deserts	4.1	NA	3	3 - 8.4	NA	NA
Craters of the Moon NM	North American Deserts	4.1	NA	3	3 - 8.4	NA	NA
Craters of the Moon NM	Northwestern Forested Mountains	4.1	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Hagerman Fossil Beds NM	North American Deserts	5.2	NA	3	3 - 8.4	NA	NA
John Day Fossil Beds NM	Northwestern Forested Mountains	1.8	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Lake Roosevelt NRA	North American Deserts	2.5	NA	3	3 - 8.4	NA	NA
Lake Roosevelt NRA	Northwestern Forested Mountains	2.5	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Nez Perce NHP	Great Plains	3.6	12 - 12	NA	5 - 25	NA	10 - 25
Nez Perce NHP	North American Deserts	3.6	NA	3	3 - 8.4	NA	NA
Nez Perce NHP	Northwestern Forested Mountains	3.6	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Whitman Mission NHS	North American Deserts	3.4	NA	3	3 - 8.4	NA	NA

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or thought to occur within the I&M parks in the UCBN are listed in Table 5. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O₃ (e.g., dark stipple), are designated by an asterisk. Each park in this network contained at least two O₃-sensitive and/or bioindicator species. CRMO contained seven sensitive species, four of which are recognized as bioindicators. LARO contained 14 sensitive species, 7 of which are recognized as bioindicators.

The W126 is a measure of cumulative O₃ exposure that preferentially weights higher concentrations. The SUM06 is a measure of cumulative exposure that includes only hourly concentrations over 60

Table 5. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the UCBN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012); lists are periodically updated at <https://irma.nps.gov/NPSpecies/Report>). A vegetation list is not currently available for MIIN; it is not included in the table.

Species	Common Name	Park ¹							
		BIHO	CIRO	CRMO	HAFO	JODA	LARO	NEPE	WHMI
<i>Ailanthus altissima</i> *	Tree-of-heaven							x	
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry		x	x		x	x	x	
<i>Apocynum androsaemifolium</i> *	Spreading dogbane			x			x		
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp			x		x	x		
<i>Artemisia douglasiana</i> *	Mugwort							x	
<i>Artemisia ludoviciana</i> *	Silver wormwood					x		x	x
<i>Asclepias incarnata</i>	Swamp milkweed				x				
<i>Fraxinus americana</i> *	White ash						x		
<i>Fraxinus pennsylvanica</i>	Green ash				x		x		
<i>Oenothera elata</i> *	Evening primrose			x					
<i>Parthenocissus quinquefolia</i>	Virginia creeper						x	x	
<i>Physocarpus malvaceus</i> *	Pacific ninebark						x	x	
<i>Pinus banksiana</i>	Jack pine						x		
<i>Pinus ponderosa</i> *	Ponderosa pine	x				x	x	x	
<i>Platanus occidentalis</i> *	American sycamore								x
<i>Populus tremuloides</i> *	Quaking aspen	x	x	x			x		x
<i>Prunus virginiana</i>	Choke cherry					x	x	x	x
<i>Prunus virginiana</i> var. <i>melanocarpa</i>	Choke cherry			x					
<i>Robinia pseudoacacia</i>	Black locust							x	x
<i>Rubus parviflorus</i>	Thimbleberry						x	x	
<i>Salix scouleriana</i> *	Scouler's willow		x	x			x		
<i>Symphoricarpos albus</i> *	Common snowberry	x					x	x	x
<i>Vaccinium membranaceum</i> *	Huckleberry	x							

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

* Bioindicator species

parts per billion (ppb). The W126 and SUM06 O₃ exposure indices calculated by NPS staff are given in Table 6, along with Kohut's (2007) O₃ risk ranking. The two ranking systems differ. The NPS ranking system (NPS 2010) is a quick assessment of O₃ condition. It ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997). It uses a 5-year average of the W126 or SUM06 metric over a 3-month period. The W126 exposure was classified as Moderate at values between 7 and 13 parts per million-hours (ppm-hr), as defined by NPS (2010). Values higher than 13 ppm-hr were classified as High, and values lower than 7 ppm-hr were classified as Low. The SUM06 exposure was classified as Moderate at values between 8 and 15 ppm-hr. Higher and lower values were classified as High and Low, respectively, as defined by NPS (2010).

Table 6. Ozone assessment results for I&M parks in UCBN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007) ozone risk ranking for the period 1995-1999¹. MIIN was not included in the assessment.

Park Name ²	Park Code	W126		Sum06		Kohut O ₃ Risk Ranking
		Value (ppm-hr)	Ranking	Value (ppm-hr)	Ranking	
Big Hole	BIHO	7.37	Moderate	8.32	Moderate	Low
City of Rocks	CIRO	16.40	High	22.47	High	Moderate
<i>Craters of the Moon</i>	CRMO	10.74	Moderate	12.43	Moderate	Low
Hagerman Fossil Beds	HAFO	11.61	Moderate	14.97	Moderate	Low
John Day Fossil Beds	JODA	3.89	Low	4.49	Low	Low
<i>Lake Roosevelt</i>	LARO	3.74	Low	3.75	Low	Low
Nez Perce	NEPE	5.66	Low	6.25	Low	Low
Whitman Mission	WHMI	4.33	Low	4.45	Low	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.

Kohut's approach constitutes a rigorous 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. Ozone condition, as rated by NPS, ranged from Low to High in the UCBN parks. Kohut's evaluation of risk to plants ranged from Low to Moderate. 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 exposures (2005-2009), but not environmental conditions. Within the UCBN, O₃ exposures were estimated to be highest at CIRO. However, results of portable O₃ monitoring in 2010 and 2011 suggested that concentrations at CIRO were actually lower than at CRMO (data compiled and reported by John Ray, NPS-ARD, Denver).

Ozone forms when nitrogen oxides (NO_x) from combustion react with volatile organic compounds (VOCs - either natural or human-caused) in the presence of sunlight. NO_x sources include power plants and vehicles. In addition, forest fires emit considerable quantities of NO_x and hydrocarbons. The concentration of O₃ in the atmosphere in the nonurban western United States has increased since the late 1980s by about 5 ppb (Jaffe and Ray 2007). Jaffe et al. (2008) investigated the role of forest fire in this trend. The summer burned area (BA) was significantly correlated with O₃ concentration at atmospheric chemistry monitoring sites, including sites within CRMO. 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 ppb, respectively. The estimated amount of biomass consumed (BC) was a slightly better predictor of O₃ concentration than BA. This relationship between atmospheric O₃ concentration and BA or BC 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 forest 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.

NPS (2010) reported long-term trends in annual fourth highest 8-hour daily maximum O₃ concentration (i.e., the human health-based O₃ standard) for 31 monitoring sites in 27 national parks having more than 10 years of data through 2008. Statistically significant increases were reported for only four parks, including CRMO.

Visibility Degradation

Natural Background and Ambient Visibility Conditions

The Clean Air Act set a specific goal for visibility protection in Class I areas: “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution” (42 U.S.C. 7491). In 1999, EPA passed the Regional Haze Rule (RHR), which requires each state to develop a plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions by 2064. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network and typically reported using the haze index called the deciview² (dv). Lower dv values correspond with better visibility 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

Natural background visibility, the goal of the RHR, assumes no human-caused visibility impairment³, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic emissions from vegetation. Using on-site data, IMPROVE estimated natural background visibility at CRMO. IMPROVE used representative data to estimate visibility conditions in two additional UCBN parks, BIHO and NEPE. A visibility monitoring site is considered representative if it is within 60 miles (100 km) and 425 ft (130 m) in elevation of a park.

The three parks in the UCBN had relatively good natural background visibility compared to other monitored I&M parks for the 20% clearest days, 20% haziest days, and for days with average visibility (Table 7).

deciview change in haziness is a small but noticeable change in haziness under most circumstances when viewing scenes in Class I areas.

³ *Visibility impairment* means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

Table 7. Estimated natural background and measured visibility in UCBN parks averaged over the period 2004 through 2008¹.

Park Name ²	Park Code	Site ID	Estimated Natural Background (dv)					
			20% Clearest Days	20% Haziest Days	Average Days			
Big Hole	BIHO	SULA1	1.12	7.43	3.74			
City of Rocks	CIRO	No Site						
<i>Craters of the Moon</i>	CRMO	CRMO1	1.72	7.53	4.21			
Hagerman Fossil Beds	HAFO	No Site						
John Day Fossil Beds	JODA	No Site						
<i>Lake Roosevelt</i>	LARO	No Site						
Nez Perce	NEPE	SULA1	1.12	7.43	3.74			
Whitman Mission	WHMI	No Site						
Park Name ²	Park Code	Site ID	Measured Visibility (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking	dv	Ranking	dv	Ranking
Big Hole	BIHO	SULA1	2.60	Very Low	17.17	Moderate	7.81	Very Low
City of Rocks	CIRO	No Site						
<i>Craters of the Moon</i>	CRMO	CRMO1	3.69	Low	13.99	Low	8.34	Low
Hagerman Fossil Beds	HAFO	No Site						
John Day Fossil Beds	JODA	No Site						
<i>Lake Roosevelt</i>	LARO	No Site						
Nez Perce	NEPE	SULA1	2.60	Very Low	17.17	Moderate	7.81	Very Low
Whitman Mission	WHMI	No Site						

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.

Monitored visibility reflects current pollution levels and was used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and air pollution across the United States. Given the substantially greater amount of human-caused emissions in the eastern United States, visibility is generally much better at western parks than at eastern parks. Relative rankings range from very low haze (very good visibility) to very high haze (very poor visibility). Only parks with on-site or representative IMPROVE monitors were used to generate the visibility ranking. Table 7 gives the relative park visibility rankings on the 20% clearest, 20% haziest, and average days. Measured visibility was only slightly worse (2 to 6 dv) than natural background conditions in CRMO (site CRMO1), and levels were ranked Low relative to other I&M parks for all groups (20% clearest days, 20% haziest days, and average days). In BIHO and NEPE, monitored visibility was only slightly worse (1.5 to 4 dv) than estimated natural background conditions on the 20% clearest and average days; haze levels were ranked Very Low. However, on the 20% haziest days, the difference was nearly 10 dv and monitored haze was ranked Moderate.

Reconstructed visibility conditions from IMPROVE data indicate that air pollution at CRMO has reduced average natural visual range (VR) from 160 miles to 95 miles (257 km to 153 km). On the haziest days, VR at CRMO has been reduced from 110 to 60 miles (177 to 97 km). Severe haze episodes occasionally reduce visibility to 11 miles (18 km). At the Sula Peak, Montana, (SULA1) IMPROVE site, which is representative of BIHO and NEPE, air pollution has reduced average VR from 160 to 100 miles (257 to 161 km). On the haziest days, VR has been reduced from 110 to 55 miles (177 km to 89 km). Severe haze episodes occasionally reduce visibility to 3 miles (5 km).

Composition of Haze

Various pollutants make up the haze that causes visibility degradation. IMPROVE measures these pollutants and reports them as ammonium sulfate (NH_4SO_4), ammonium nitrate, elemental carbon, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO_2 emissions generated by coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, power plants, industry, and fires. Organic compounds are emitted from a variety of both natural and anthropogenic sources, including agriculture, industry, and fires. Soil can enter the atmosphere through both natural processes and human disturbance.

At IMPROVE sites throughout and near the greater Columbia River basin, from North Cascades and Glacier NPs in the north to Lassen Volcanic and Yellowstone NPs in the south, carbon in various forms, including fine particulate organics and soot, typically dominates the light extinction (b_{ext}) budget (Schoettle et al. 1999). The second most important contributor is SO_4^{2-} . Light scattering by NH_4SO_4 in the northwestern United States is unique in that it does not peak during summer as it does in other places in the United States (Grenon and Story 2009). At Boise, Idaho, and Missoula Montana, NH_4SO_4 light scattering typically peaks during winter (Debell et al. 2006).

Figure 1 shows estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze and its composition for the parks in the UCBN. In BIHO and NEPE, organics was by far the largest contributor on the 20% haziest (74.5%) and average days (62.5%). On the 20% clearest days, SO_4^{2-} dominated, contributing 44.5% to b_{ext} . Organics contributed 23.5% on the 20% clearest days in these two parks. In CRMO, organics was the largest contributor to b_{ext} on the 20% haziest days (38.4%) and annual average days (30.2%); SO_4^{2-} and NO_3^- also contributed appreciably. On the 20% clearest days, SO_4^{2-} was the largest contributor to haze in this park (35.6%), followed by NO_3^- (20.4%) and organics (18.3%).

SULA (representative of BIHO and NEPE)

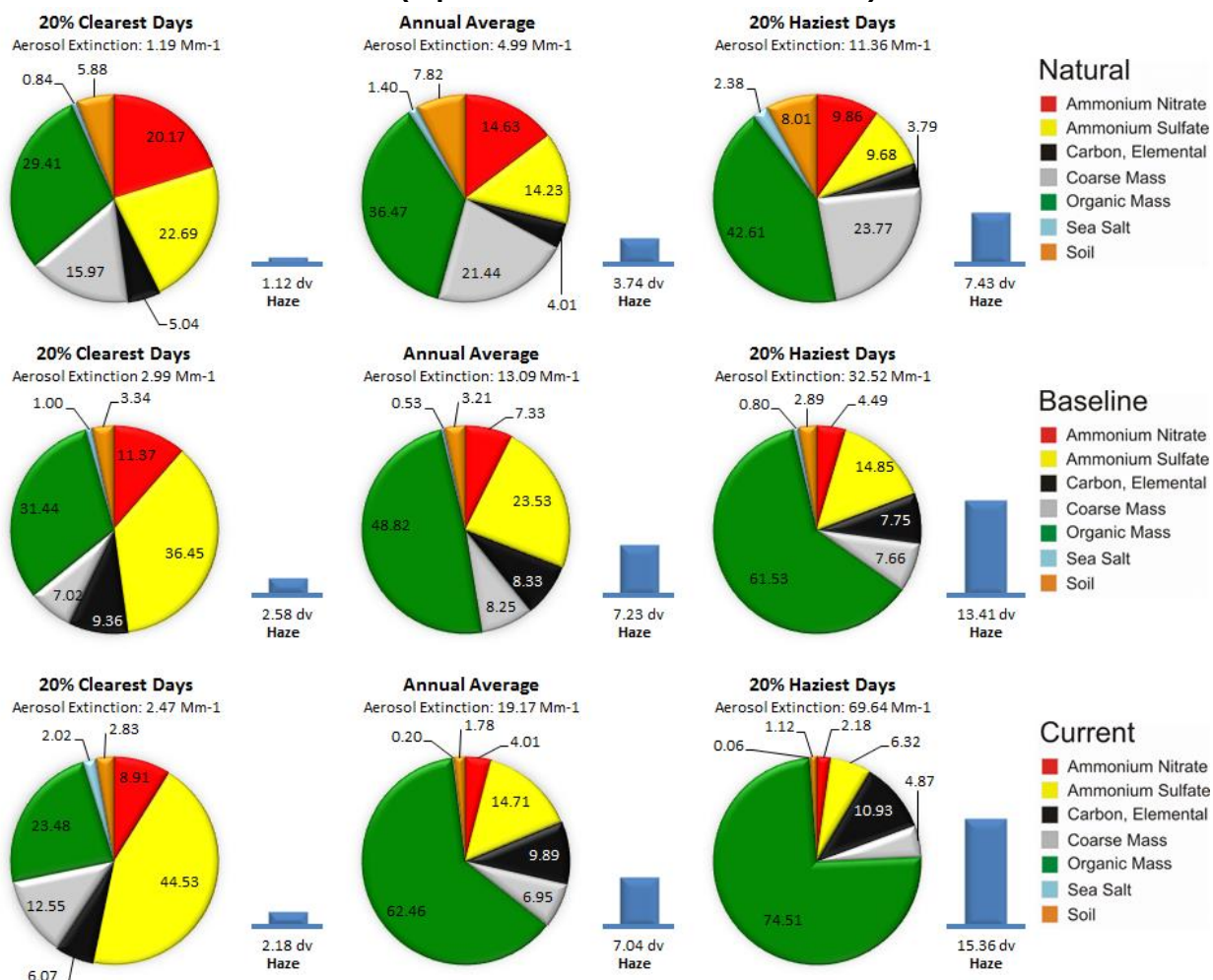


Figure 1a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest days for BIHO and NEPE. Data for BIHO and NEPE are based on a nearby representative site, Sula Peak, Montana (SULA). SULA has no data for the years 2000, 2006, and 2008. Data Source: NPS-ARD

CRMO

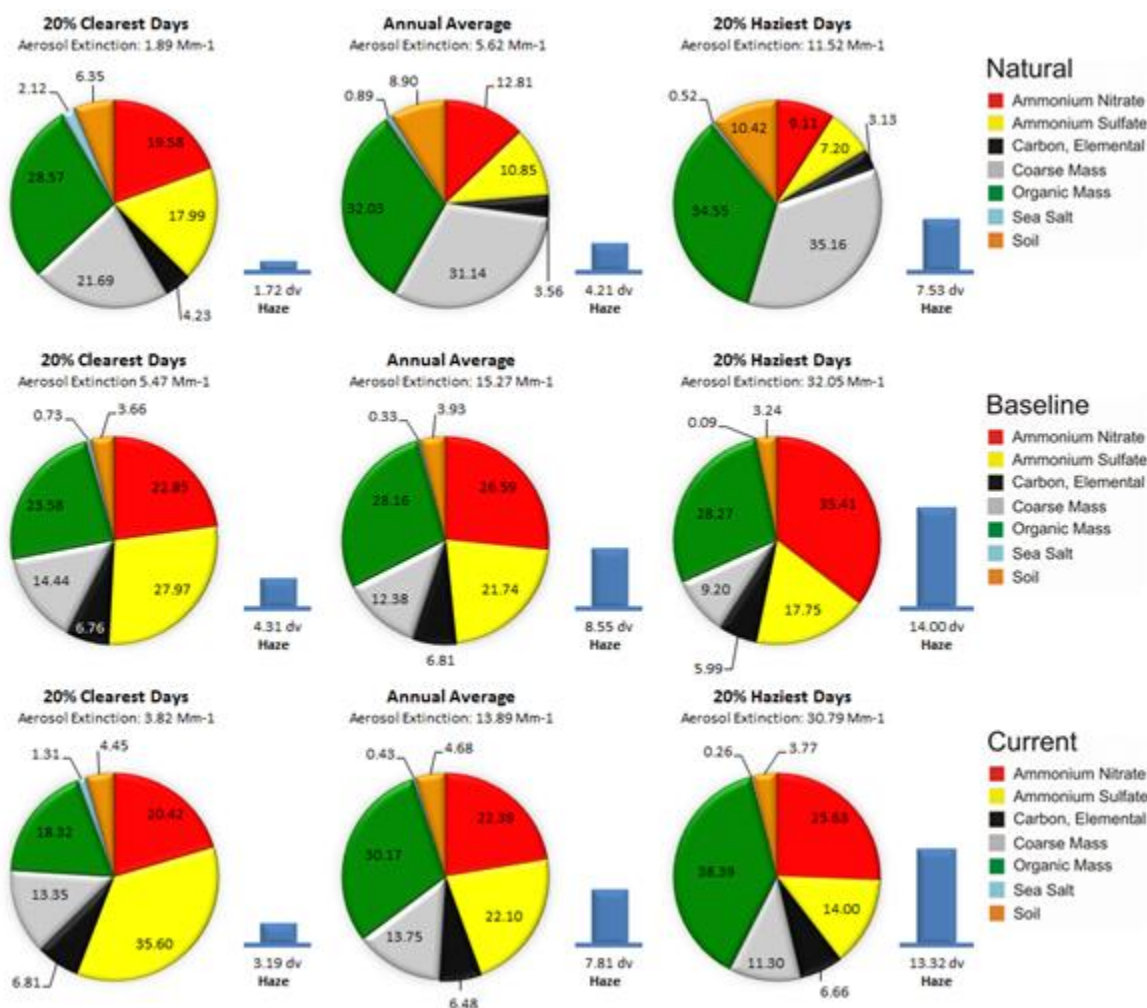


Figure 1b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest days for CRMO. CRMO has no data for the year 2000. Data Source: NPS-ARD

Analyses conducted by the Western Regional Air Partnership (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 the UCBN. In addition, 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 in this region (Suarez-Murias et al. 2009).

Trends in Visibility

IMPROVE data do not suggest any pronounced trends in visibility over time at monitored UCBN parks. Highest levels of haze on the 20% worst and average days were recorded in 2006 and 2007 (Figure 2). Since then, haze values appear to have decreased through the period of available monitoring data (2010).

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 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).

Progress to date in meeting the national visibility goal in UCBN parks is illustrated in Figure 3 using a uniform rate of progress glideslope. Although the RHR does not require Class II areas to meet the natural background goal, it is anticipated that Class II areas will benefit from emissions reductions. It is unclear, based on the available data, to what extent visibility on the 20% haziest days is decreasing sufficiently to comply with the glideslope required by the RHR. Additional years of data are needed.

Toxic Airborne Contaminants

Information is generally not available regarding possible effects of air toxics deposition on park resources in the UCBN.

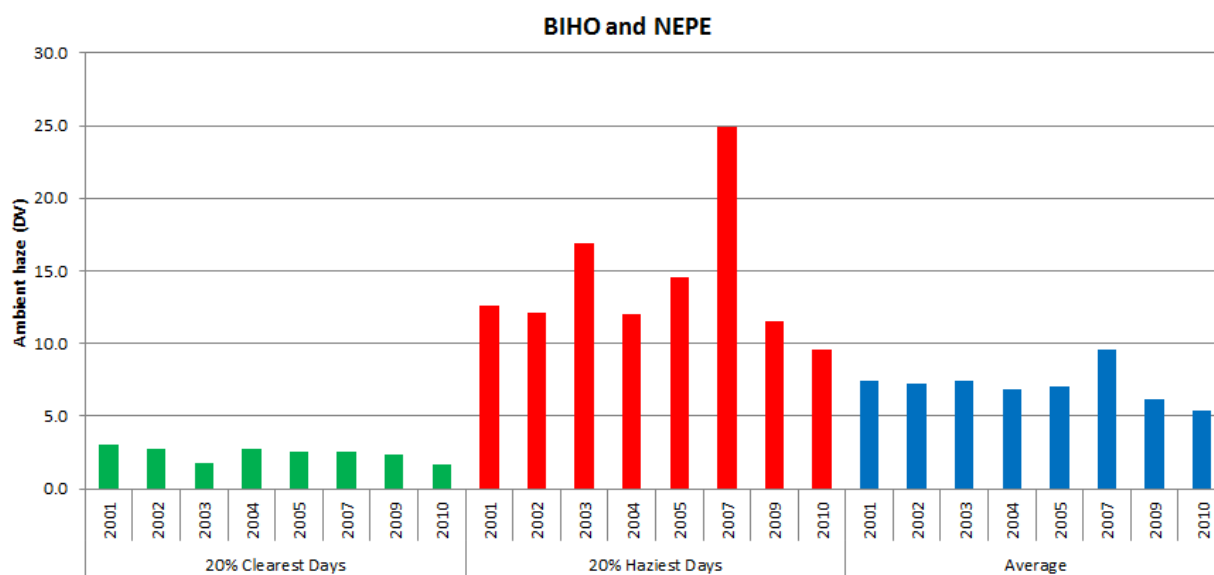


Figure 2a. Trends in monitored visibility at UCBN parks, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for BIHO and NEPE were taken from a representative site, Sula Peak, Montana (SULA). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

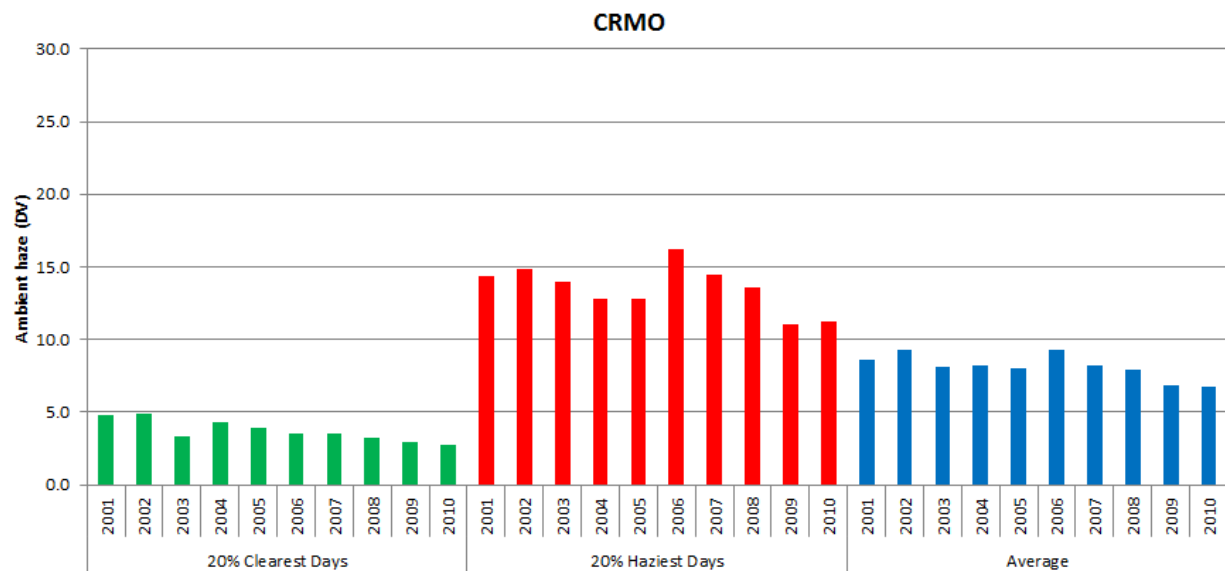


Figure 2b. Trends in monitored visibility at UCBN parks, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for BIHO and NEPE were taken from a representative site, Sula Peak, Montana (SULA). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

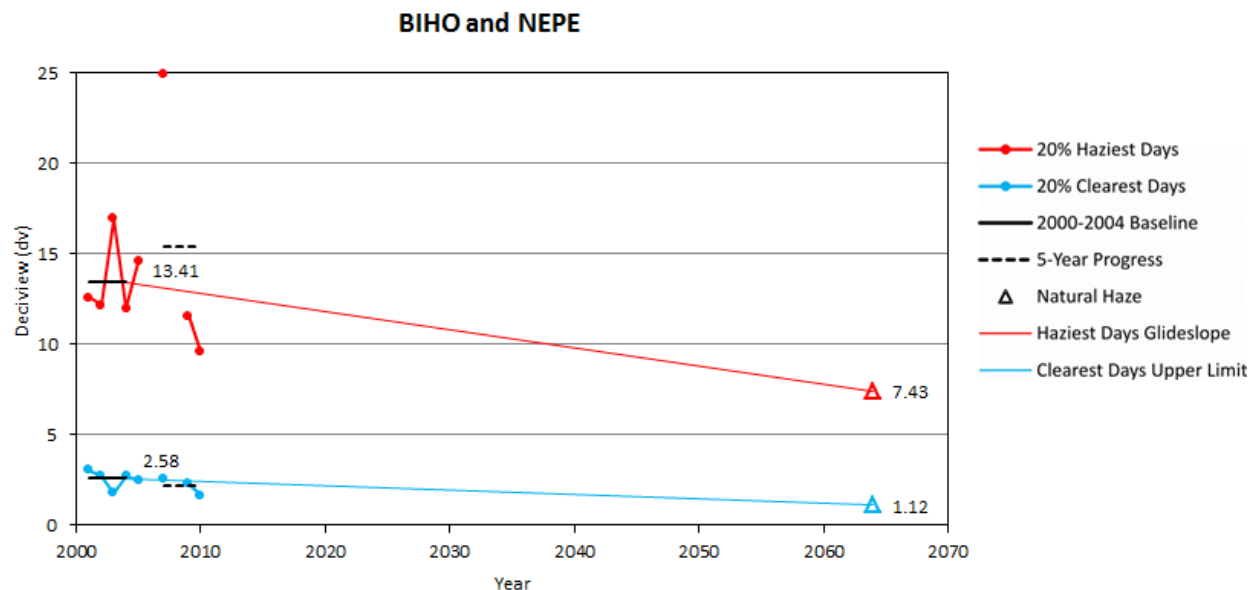


Figure 3a. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in UCBN parks. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for BIHO and NEPE were taken from a representative site at Sula Peak, Montana (SULA1)). SULA1 has no data for the years 2000, 2006, and 2008. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

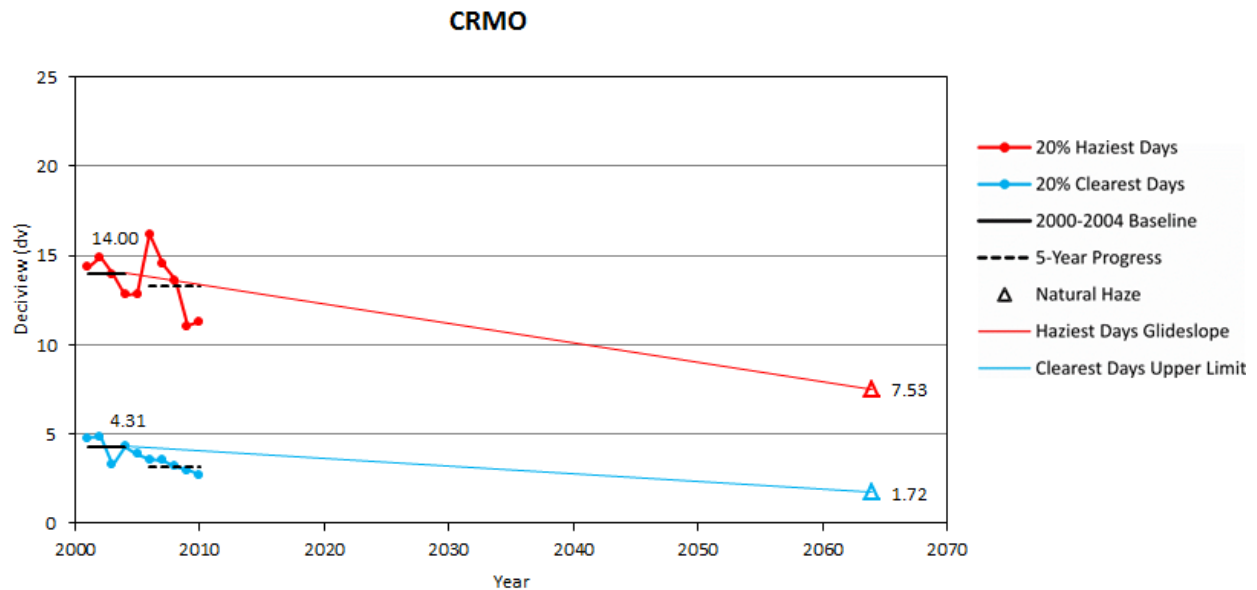


Figure 3b. Glideslopes to achieving natural visibility conditions by 2064 for the 20% hazeiest (red line) and the 20% clearest (blue line) days in UCBN parks. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. CRMO has no data for the year 2000. Data Source:

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

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