



Air Quality Related Values (AQRVs) for Chihuahuan Desert Network (CHDN) Parks

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

Natural Resource Report NPS/CHDN/NRR—2016/1161



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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Contents

	Page
Figures.....	iv
Tables.....	iv
Maps.....	v
Summary	vii
Background.....	1
Atmospheric Emissions and Deposition	2
Acidification	7
Nutrient Nitrogen Enrichment	13
Ozone Injury to Vegetation	14
Visibility Degradation.....	18
Natural Background and Ambient Visibility Conditions	18
Composition of Haze	19
Trends in Visibility.....	26
Development of State Implementation Plans	26
Toxic Airborne Contaminants.....	29
References Cited	30

Figures

	Page
Figure 1a. Three representative photos of the same view in BIBE illustrating the 20% clearest visibility, the 20% haziest visibility, and the annual average visibility	20
Figure 1b. Three representative photos of the same view in GUMO illustrating the 20% clearest visibility, the 20% haziest visibility, and the annual average visibility	21
Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for BIBE	23
Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for CAVE, and GUMO	24
Figure 3. Trends in ambient haze levels at BIBE, CAVE, and GUMO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record.....	27
Figure 4. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in BIBE, CAVE, and GUMO.....	28

Tables

	Page
Table 1. Average changes in S and N deposition between 2001 and 2011 across park grid cells at CHDN parks	8
Table 2. Estimated I&M park rankings ¹ according to risk of acidification impacts on sensitive receptors	13
Table 3. Estimated park rankings ¹ according to risk of nutrient enrichment impacts on sensitive receptors	13
Table 4. Empirical critical loads for nitrogen in the CHDN, by ecoregion and receptor from Pardo et al. (2011b).....	15
Table 5. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the CHDN	16
Table 6. Ozone assessment results for I&M parks in the CHDN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007) ozone risk ranking for the period 1995-1999 ¹	17
Table 7. Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008.	22

Maps

	Page
Map 1. Network boundary and locations of parks and population centers with more than 10,000 people near the CHDN	3
Map 2. Total SO ₂ emissions, by county, near CHDN for the year 2011	4
. Data from EPA's National Emissions Inventory	4
Map 3. Total NO _x emissions, by county, near the CHDN for the year 2011.....	5
. Data from EPA's National Emissions Inventory.	5
Map 4. Total NH ₃ emissions, by county, near the CHDN for the year 2011.....	6
. Data from EPA's National Emissions Inventory.	6
Map 5. Total S deposition for the three-year period centered on 2011 in and around the CHDN	9
Map 6. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around the CHDN	10
Map 7. Reduced inorganic N deposition for the three-year period centered on 2011 in and around the CHDN	11
Map 8. Total N deposition for the three-year period centered on 2011 in and around the CHDN	12

Summary

This report describes the Air Quality Related Values (AQRVs) of the Chihuahuan Desert Network (CHDN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The CHDN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Amistad National Recreation Area (AMIS), Big Bend National Park (BIBE), Carlsbad Caverns National Park (CAVE), Fort Davis National Historic Site (FODA), Guadalupe Mountains National Park (GUMO), and White Sands National Monument (WNSA). BIBE, CAVE, and GUMO are designated as Class I, 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 (2007) conducted risk assessments for acidification, eutrophication and ozone (O_3) for all of the CHDN parks; their results are described in this report. This report also describes air pollutant emissions and air quality in the CHDN, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]), ground-level O_3 , haze-causing particles, and airborne toxics, including mercury (Hg) and pesticides. Background for this section can be found in Chapter 1 of “Air Quality Related Values (AQRVs) in the Inventory and Monitoring (I&M) National Parks: Status of Visibility Degradation, Ozone Effects on Vegetation, and the Effects on Natural Resources of Atmospheric Acid, Nutrient, and Toxics Deposition” (Sullivan 2016).

One of the most important AQRVs in the CHDN is visibility. Parks in the CHDN are affected by haze which is primarily due to SO_4^{2-} , and to a lesser extent coarse mass and organic particles. Relative contributions of those constituents to light extinction vary with season and reporting period. The highest haze values observed within the network occurred at BIBE. Prior to 1990, BIBE had the poorest visibility among the monitored Class I national parks in the western United States (Malm et al. 1990). At times, visibility is still significantly degraded in BIBE, but worse at some other western parks, notably in parts of California and Arizona (Hand et al. 2011).

The parks in the CHDN also appear to be highly sensitive to potential terrestrial eutrophication in response to nutrient N enrichment. Nevertheless, nutrient N pollutant exposure is relatively low at the parks in this network, and effects from N deposition will likely be confounded by future changes in precipitation timing and amount (Weltzin et al. 2003). Resource sensitivity to acidification in response to atmospheric contributions of S and N appears to be relatively high in three parks (CAVE, BIBE, and GUMO), although acid pollutant exposure in these parks is low and, as a consequence, acidification impacts are unlikely at this time.

Ozone exposure and risk rankings for the parks in the CHDN are low to moderate; generally dry soil conditions that predominate in this network are likely to limit O_3 uptake into foliage. Nevertheless, O_3 -sensitive species such as Goodings willow (*Salix gooddingii*) occupy riparian sites where soil moisture is higher and effects of O_3 exposure may be more pronounced. Concentrations of airborne toxic contaminants in vegetation measured in BIBE in the Western Airborne Contaminant Assessment Project (WACAP) effort were generally typical of other inventoried parks in the western

United States with respect to current use pesticides (CUPs), historic use pesticides (HUPs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

Data regarding emissions of semivolatile organic compounds (SOCs) near CHDN parks are not available. However, the WACAP studied airborne contaminants in a number of national parks of the western United States, including BIBE, from 2002 to 2007. Compared with other WACAP parks, BIBE had elevated concentrations of endosulfans and dichlorodiphenyldichloroethylene (DDE) in the air. Also detected were mid-range concentrations of dacthal, hexachlorocyclohexane- α , hexachlorocyclohexane- γ , and chlordanes, and low concentrations of trifluralin.

Background

Three parks in the Chihuahuan Desert Network (CHDN) are larger than 100 square miles: Big Bend National Park (BIBE), Guadalupe Mountains National Park (GUMO), and White Sands National Monument (WHSA). There are also three smaller parks: Amistad National Recreation Area (AMIS), Carlsbad Caverns National Park (CAVE), and Fort Davis National Historic Site (FODA). 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. Three of the parks (BIBE, CAVE, and GUMO) are Class I air quality areas, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA).

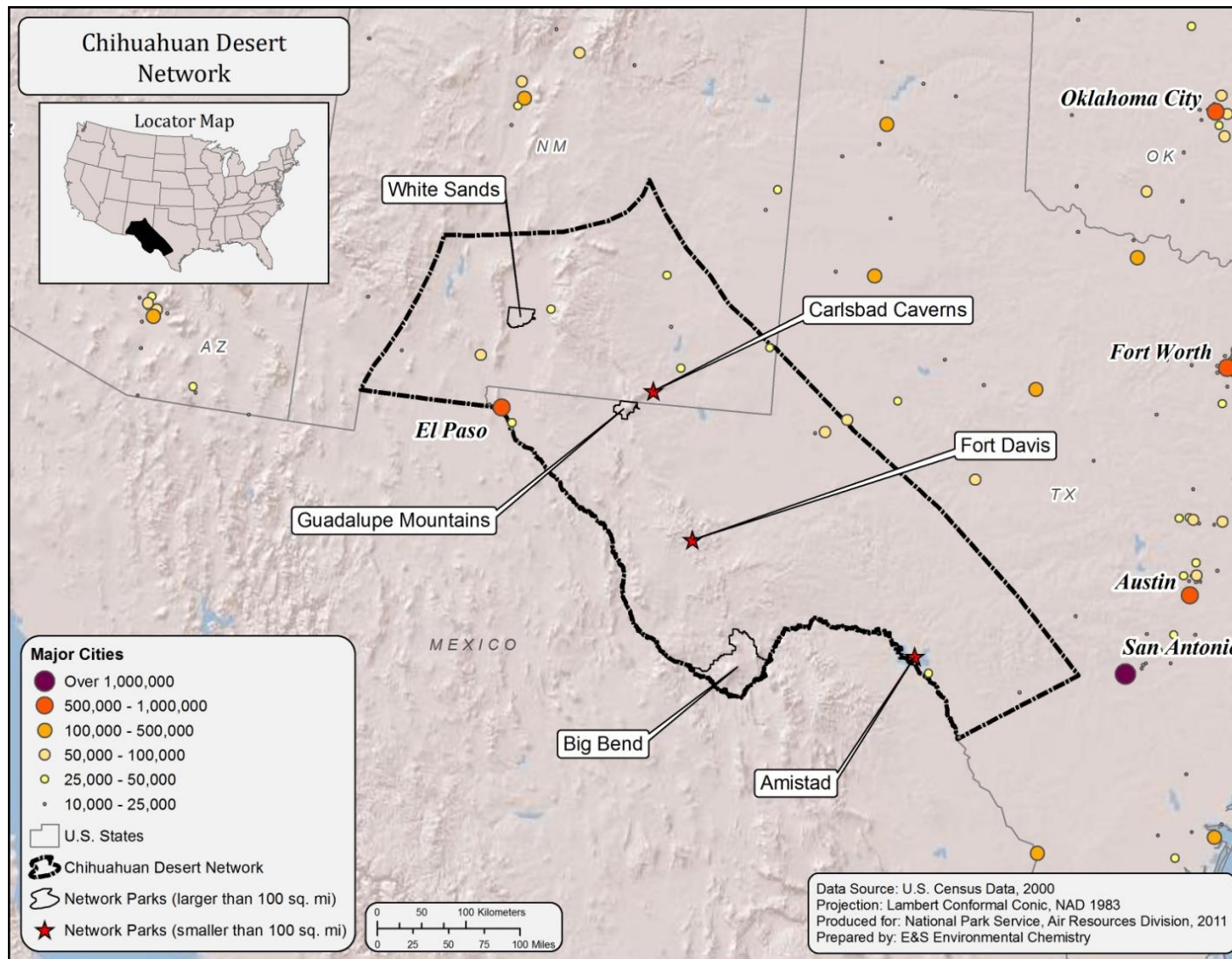
The only large population center within the CHDN is El Paso. There are, however, several large urban centers near the network boundary, including Dallas, Fort Worth, Austin, San Antonio, Houston, Phoenix, Tucson, and Albuquerque. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people.

Atmospheric Emissions and Deposition

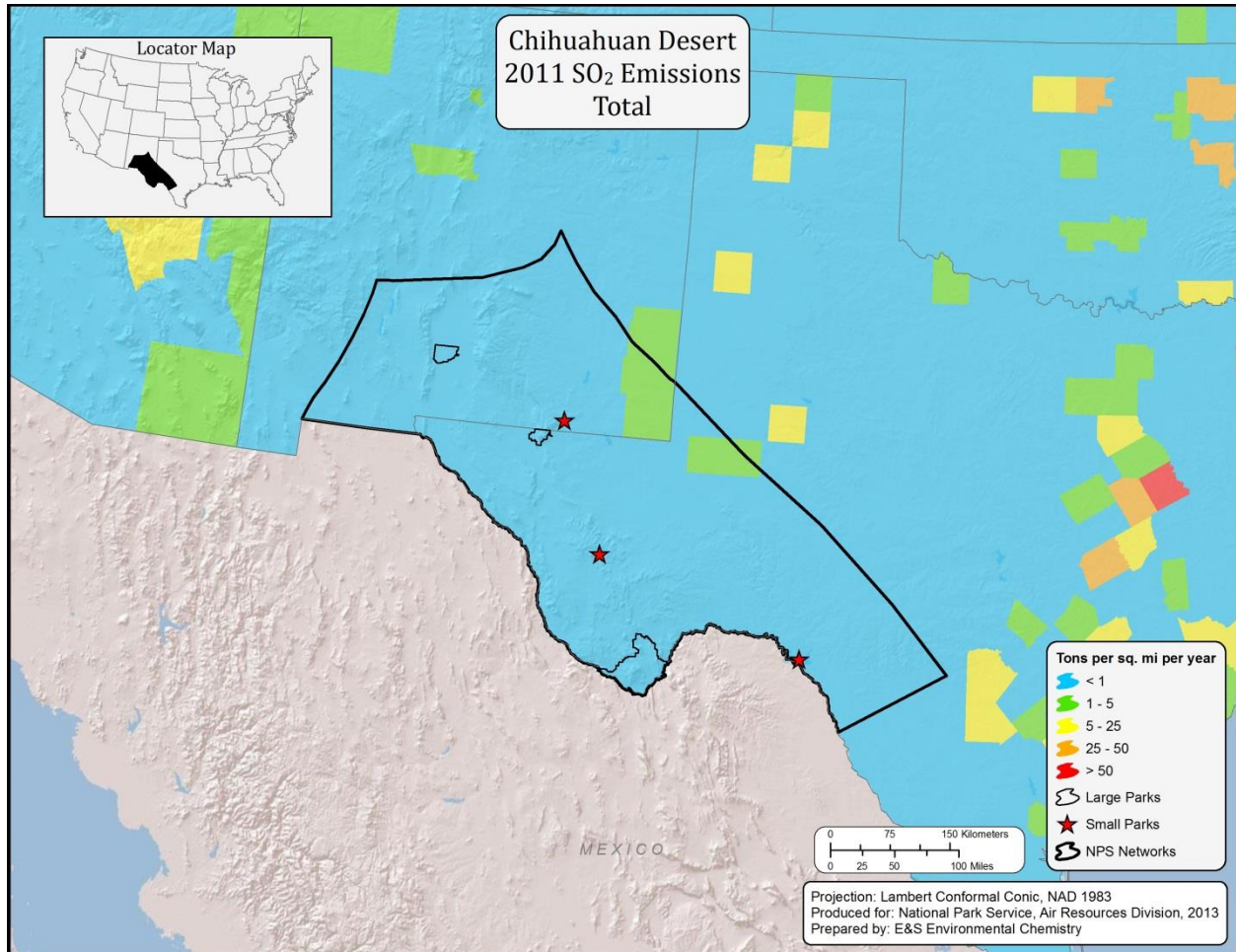
In general, county-level emissions of sulfur (S) and nitrogen (N) in the CHDN have been low. Most counties in the network region had estimated annual emissions of both sulfur dioxide (SO₂) and N that were less than 5 tons per square mile per year (tons/mi²/yr; Sullivan et al. 2011b). Point sources of both SO₂ and N were widely scattered throughout the network, but none were large compared with those in surrounding networks.

County-level emissions near the CHDN, 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 SO₂, oxidized N (NO_x), and reduced N (NH₃), respectively. Most counties near CHDN parks had low SO₂ emissions (< 1 ton/mi²/yr; Map 2). Emissions of NO_x were slightly higher, with most counties having < 5 tons/mi/yr (Map 3). Emissions of NH₃ near CHDN parks were somewhat lower, with all counties showing emissions levels below 2 tons/mi²/yr (Map 4).

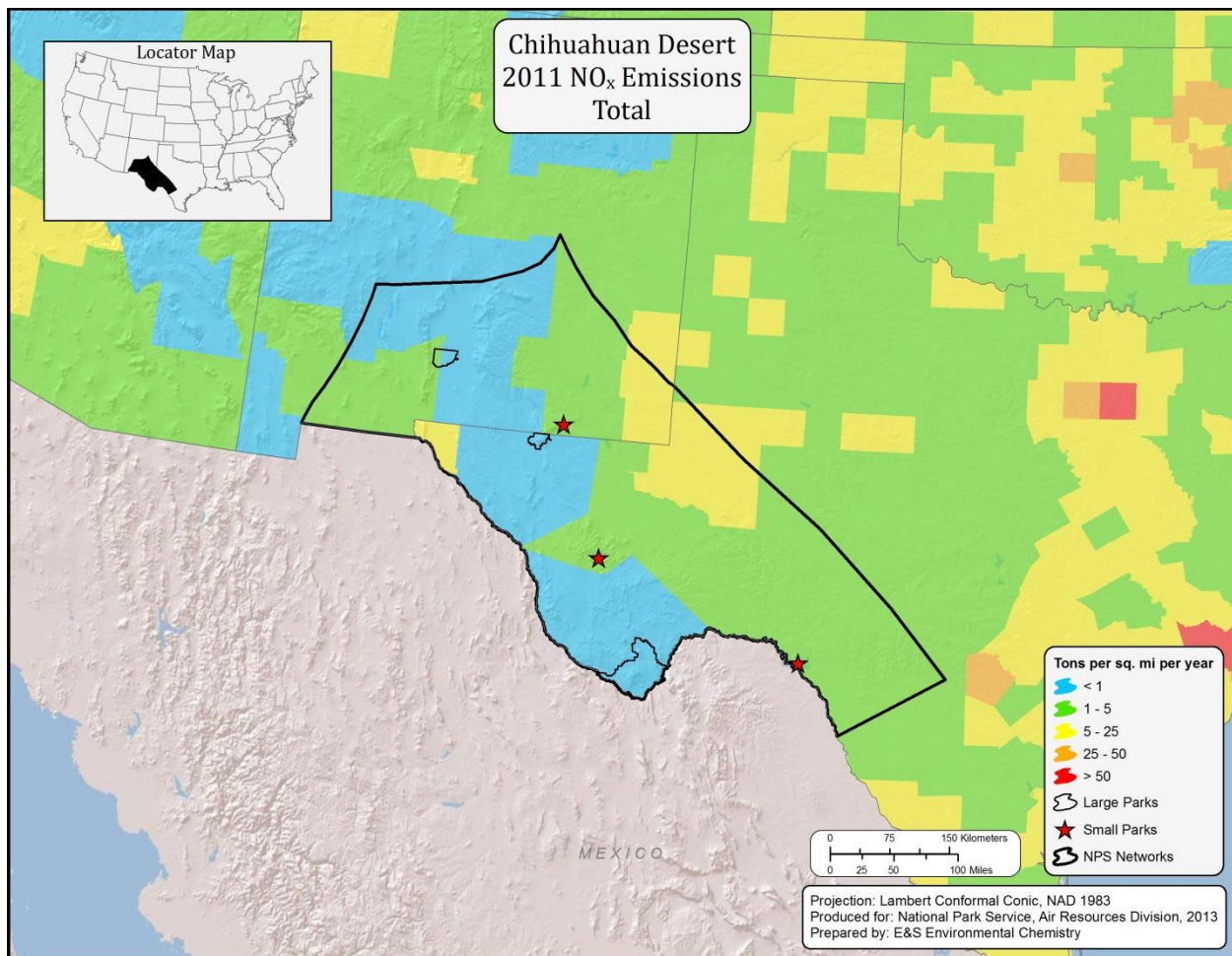
Estimated total S and N deposition levels in and around the network, including both wet and dry forms of deposition and both the NO_x and NH₃ species, have been generally low to moderate,



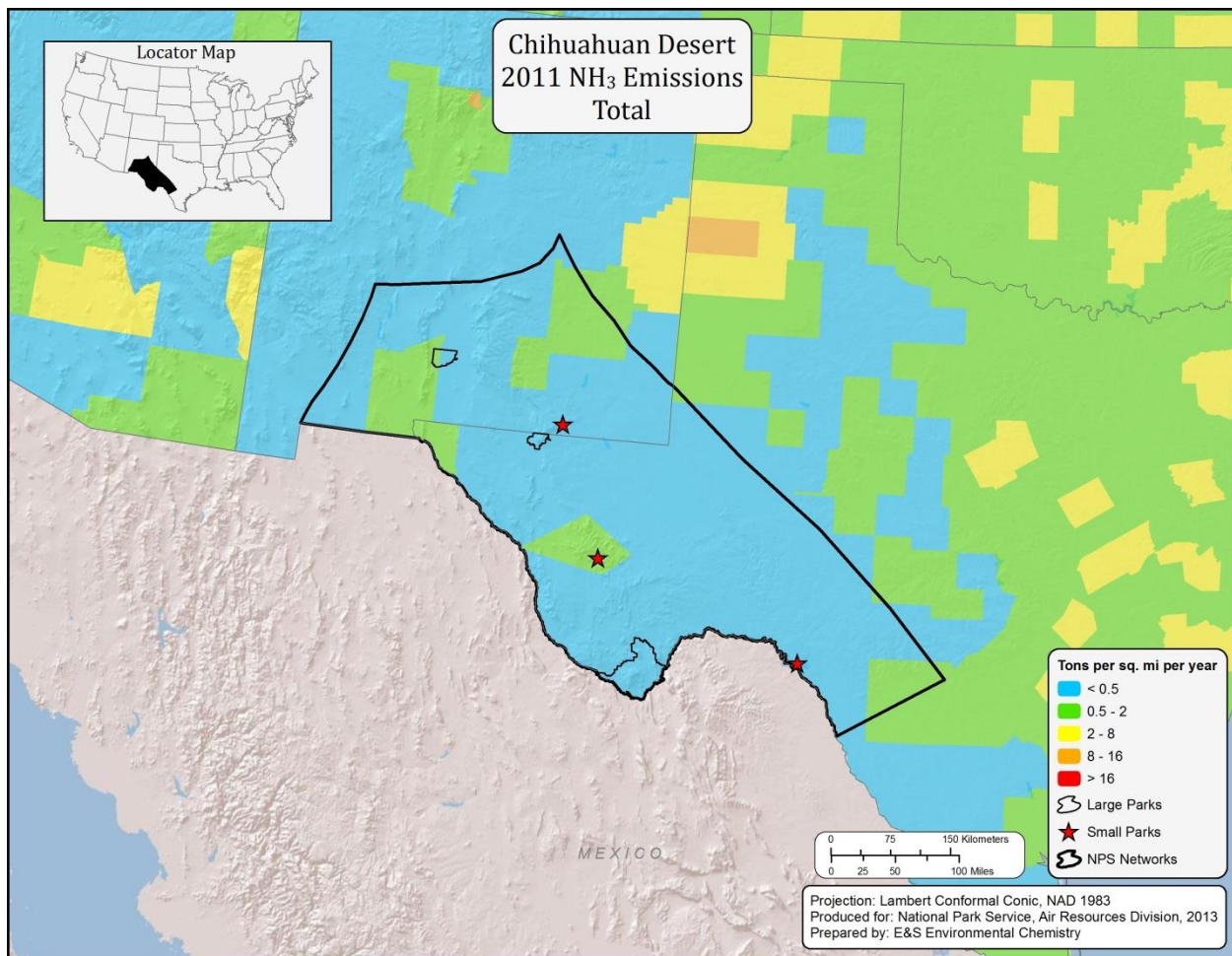
Map 1. Network boundary and locations of parks and population centers with more than 10,000 people near the CHDN



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



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



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

although recent oil and gas (O&G) development in proximity to CAVE contributes unknown, but potentially important, quantities of NO_x deposition.

In the southwestern United States, atmospheric N deposition increased during the last two decades of the 20th century (Fenn et al. 2003). This increase in N deposition was attributed to urban and agricultural development (Báez et al. 2007). When precipitation effects were removed statistically, N deposition in central New Mexico increased at an annual rate of 0.049 kg N/ha/yr between 1989 and 2004. From 2000-2009, N deposition was relatively unchanged at BIBE and GUMO, while S was unchanged at BIBE but decreased significantly at GUMO (NPS-ARD 2013). Emissions from recent O&G development likely affect visibility and N deposition in parks in the CHDN.

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 deposition levels have declined at CHDN parks since 2001, based on TDEP estimates (Table 1). Estimated total N deposition decreased over that same time period by -0.75 kg N/ha/yr (-19.8%) at CAVE and by lesser amounts at other parks, but increased slightly (0.03 kg N/ha/yr [0.9%]) at FODA. Oxidized N decreased more than reduced N at all of the parks in the network since the monitoring period 2000-2002. Reduced N deposition increased at FODA by 8.8%. Modeled deposition values for this recent period were less than 2.50 kg S/ha/yr and less than 3.50 kg N/ha/yr at all parks in the network except AMIS (3.60 kg S/ha/yr and 5.12 kg N/ha/yr).

Total S deposition in and around the CHDN for the period 2010-2012 was generally < 5 kg S/ha/yr at the location of park lands (Map 5). Oxidized inorganic N deposition (NO_x) for the period 2010-2012 was less than 5 kg N/ha/yr throughout the park land within the CHDN (Map 6). Most areas received less than 2 kg N/ha/yr of reduced inorganic N (NH_3 , NH_4^+) from atmospheric deposition during this same period (Map 7); a few areas received higher amounts. Total N deposition was less than 5 kg N/ha/yr at most park locations (Map 8); AMIS received higher amounts, up to 10 kg N/ha/yr.

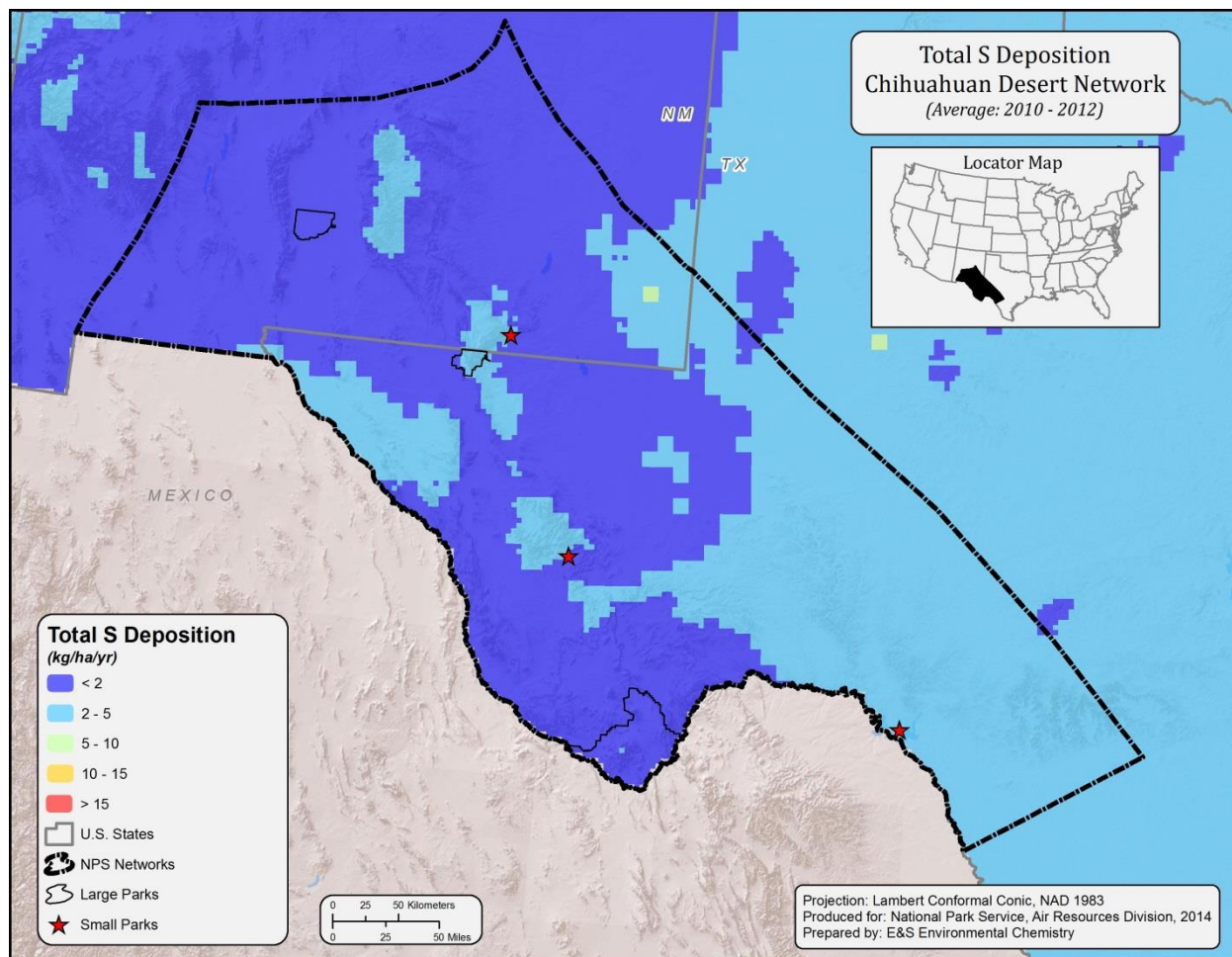
Acidification

The network rankings for acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection developed by Sullivan et al. (2011b) yielded an overall network Summary Risk ranking for acidification in the CHDN that was Low, at the lower end of the distribution among networks. The overall level of concern for acidification effects on Inventory and Monitoring (I&M) parks within this network was judged by Sullivan et al. (2011b) to be Low. The six parks in the CHDN were all ranked Low or Very Low in S and N acid Pollutant Exposure (Sullivan et al. 2011b; Table 2). Ecosystem Sensitivity to acidification rankings were generally higher and more variable. Parts of GUMO have average watershed slope in the range of 30% to 40%, and parts of BIBE have slope in the range of 20% to 30%. These relatively steep slopes would be expected to contribute to acidification sensitivity. Other park lands within the CHDN have average watershed slope less than 20%. Individual parks were ranked in the highest (CAVE), second highest (BIBE and GUMO), or second lowest (AMIS, FODA, and WHSA) quintiles in Ecosystem Sensitivity to acidification (Table 2). Thus, these data suggest that the inherent sensitivity to acidification of some park lands in this network might be relatively high, but the deposition load does not appear to be high enough to cause appreciable acidification effects at the present time. Among the parks within this network, GUMO, BIBE, and CAVE appear to be most likely to experience acidification impacts, albeit small in magnitude (Table 2).

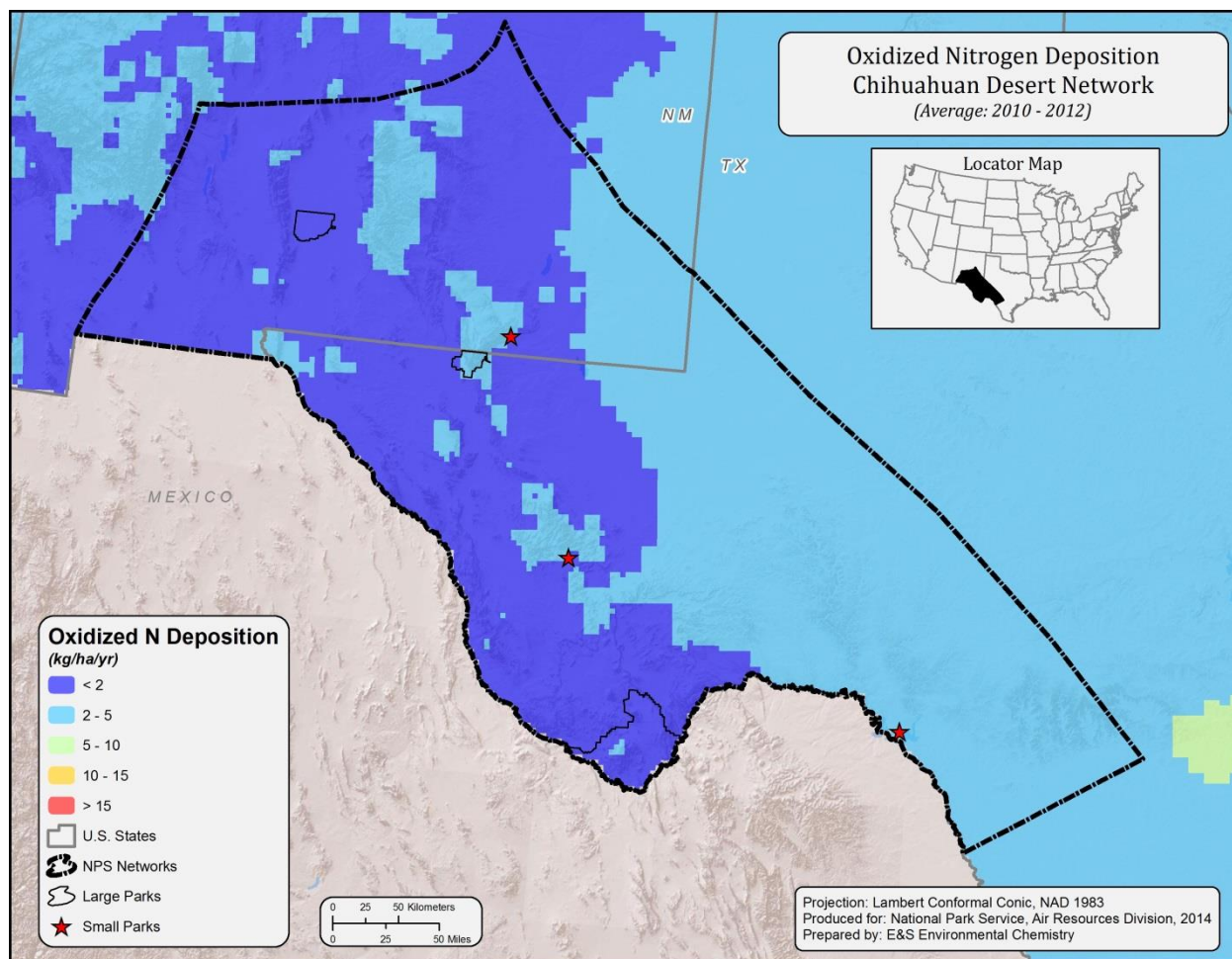
No information is available indicating the possible effects of acidic deposition on aquatic or terrestrial resources in the CHDN. In view of the low levels of S and N air pollutant exposure for the parks in this network, such effects are considered to be unlikely.

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

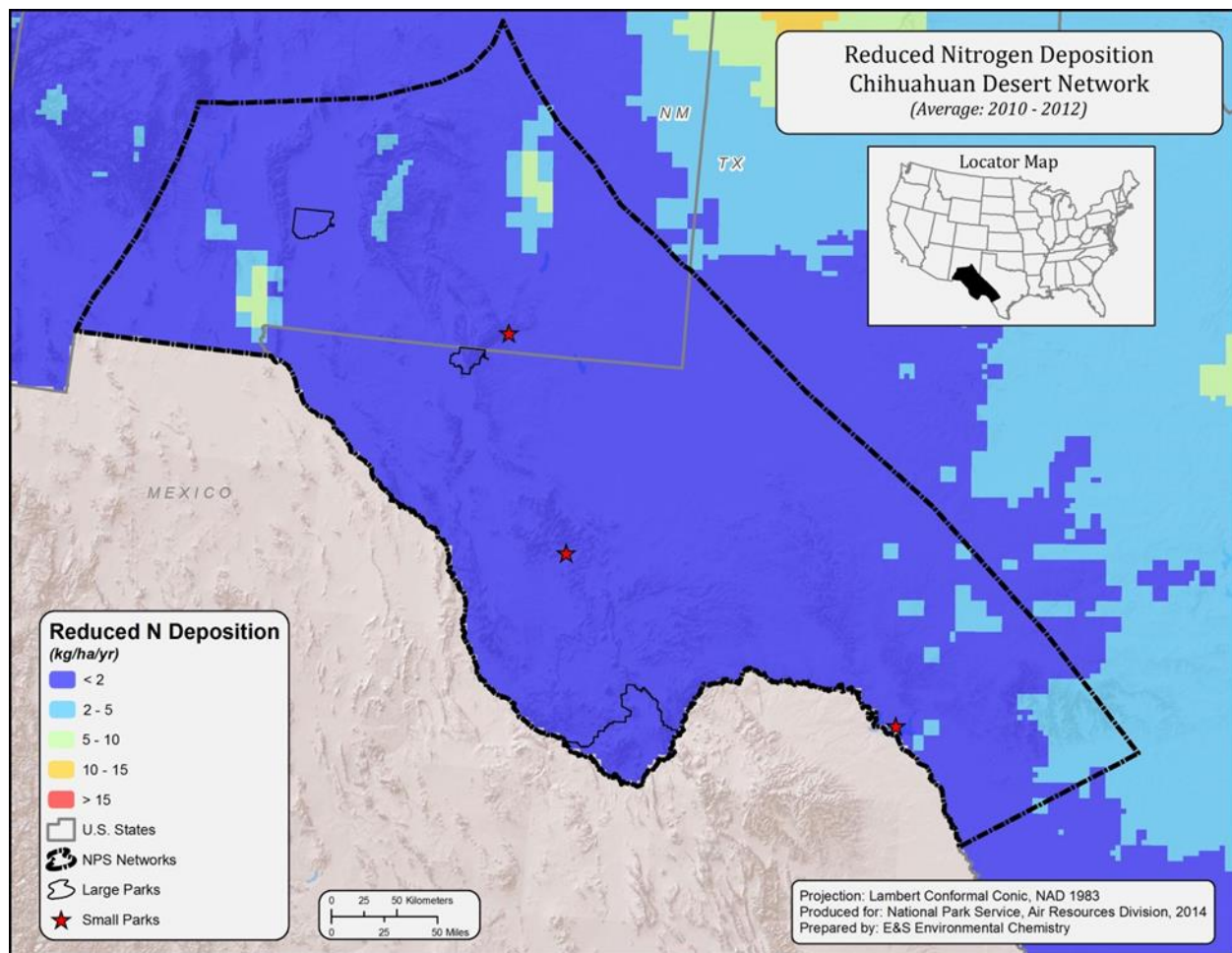
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
AMIS	Amistad	Total S	2.70	3.60	0.90	33.8%	3.00	4.11	1.11
		Total N	5.57	5.12	-0.45	-8.1%	4.03	5.41	1.38
		Oxidized N	3.98	3.59	-0.39	-9.8%	3.02	3.65	0.63
		Reduced N	1.59	1.53	-0.06	-3.6%	1.01	1.80	0.80
BIBE	Big Bend	Total S	1.44	1.30	-0.15	-10.4%	0.96	2.03	1.07
		Total N	2.79	2.39	-0.39	-14.2%	1.87	3.59	1.72
		Oxidized N	1.89	1.53	-0.36	-19.1%	1.19	2.22	1.03
		Reduced N	0.90	0.87	-0.03	-3.7%	0.68	1.37	0.70
CAVE	Carlsbad Caverns	Total S	1.71	2.00	0.29	16.8%	1.77	2.20	0.43
		Total N	3.82	3.06	-0.75	-19.8%	2.77	3.39	0.62
		Oxidized N	2.65	1.99	-0.66	-25.1%	1.80	2.21	0.41
		Reduced N	1.17	1.07	-0.09	-7.7%	0.97	1.18	0.21
FODA	Fort Davis	Total S	1.70	1.92	0.22	13.1%	1.89	2.00	0.11
		Total N	3.04	3.07	0.03	0.9%	3.03	3.17	0.14
		Oxidized N	2.06	2.00	-0.06	-2.9%	1.98	2.04	0.06
		Reduced N	0.99	1.07	0.09	8.8%	1.05	1.13	0.08
GUMO	Guadalupe Mountains	Total S	1.74	2.32	0.57	31.6%	1.38	2.93	1.56
		Total N	3.92	3.46	-0.46	-12.1%	2.34	4.42	2.08
		Oxidized N	2.73	2.34	-0.39	-14.6%	1.66	2.97	1.31
		Reduced N	1.19	1.12	-0.07	-6.5%	0.68	1.45	0.77
WHS	White Sands	Total S	0.92	0.84	-0.08	-8.3%	0.74	1.06	0.32
		Total N	2.73	2.05	-0.68	-24.9%	1.74	2.69	0.95
		Oxidized N	1.94	1.29	-0.65	-33.2%	1.09	1.68	0.58
		Reduced N	0.79	0.75	-0.03	-4.2%	0.62	1.01	0.39



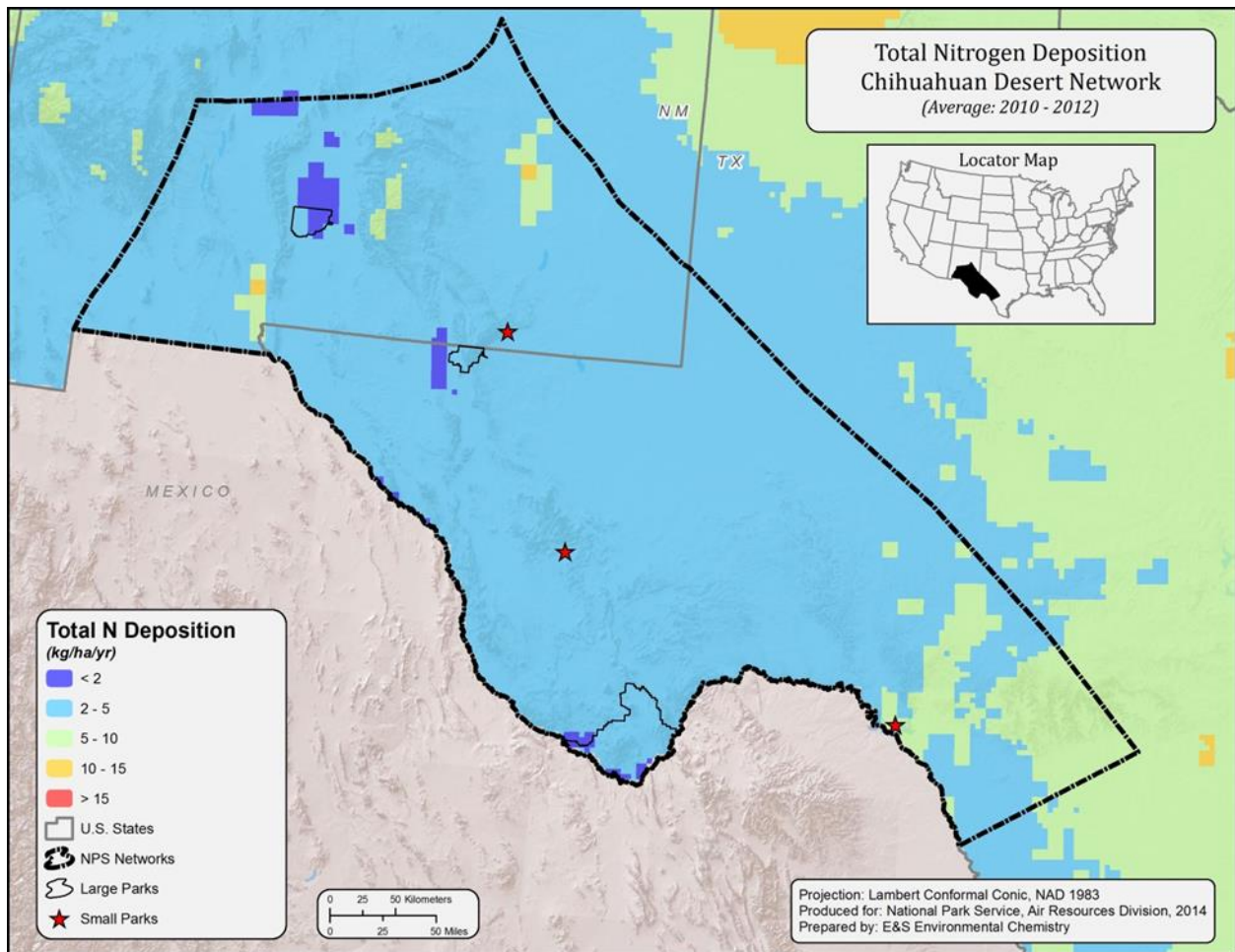
Map 5. Total S deposition for the three-year period centered on 2011 in and around the CHDN. (Source: Schwede and Lear 2014)



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



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



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

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

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Amistad	AMIS	Low	Low
<i>Big Bend</i>	BIBE	Very Low	High
Carlsbad Caverns	CAVE	Low	Very High
Fort Davis	FODA	Very Low	Low
<i>Guadalupe Mountains</i>	GUMO	Low	High
<i>White Sands</i>	WHSA	Very Low	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

The network rankings developed in a coarse screening assessment by Sullivan et al. (2011a) for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection in the CHDN yielded an overall network nutrient N enrichment Summary Risk ranking that was slightly below the median among all networks. The six individual parks in this network were all ranked Low to Very Low in nutrient N Pollutant Exposure (Sullivan et al. 2011a; Table 3). In contrast, park-specific Ecosystem Sensitivity to nutrient enrichment rankings were much higher. Individual parks were ranked in the highest (BIBE, CAVE, FODA, GUMO) or second highest (AMIS, WHSA) quintile among all I&M parks in Ecosystem Sensitivity to nutrient enrichment. These high sensitivity rankings were due to the widespread presence of arid and semi-arid vegetation types expected to be highly sensitive to N enrichment (Sullivan et al. 2011a). 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)

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
Amistad	AMIS	Low	High
<i>Big Bend</i>	BIBE	Very Low	Very High
Carlsbad Caverns	CAVE	Low	Very High
Fort Davis	FODA	Very Low	Very High
<i>Guadalupe Mountains</i>	GUMO	Low	Very High
<i>White Sands</i>	WHSA	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.

There are few published studies available documenting nutrient enrichment impacts on either aquatic or terrestrial resources in the CHDN. Given the low levels of N pollutant exposure of park lands in this network, such effects are not likely to be substantial at the present time. The ecosystems in these parks appear to be highly sensitive to nutrient N enrichment, however, and may be threatened by eutrophication if atmospheric N loads, such as those associated with local O&G development, increase substantially in the future.

Despite the fact that water is typically the key limiting driver of ecosystem processes in the Chihuahuan Desert and other arid regions, N can limit production where moisture is available, especially after rainstorms (Austin et al. 2004). Báez et al. (2007) quantified long-term trends in N deposition and its impacts on desert plant community structure. Based on two independent fertilization studies, Báez et al. (2007) concluded that continued inputs of N are likely to increase grass cover, decrease legume abundance, and may favor blue grama (*Bouteloua gracilis*) at the expense of the current dominant grass species, black grama (*B. eriopoda*). Even though N deposition levels are still relatively low, increased N deposition in the future might cause changes in plant community structure (Báez et al. 2007).

Nitrogen addition experiments at BIBE found that N affected functioning of soil fungi (Grizzle and Zak 2006). Additional studies in BIBE found that precipitation and N interact to affect plant productivity differently depending on dry versus wet years and vegetation type (shrub versus grass; Robertson et al. 2009).

Pardo et al. (2011b) compiled data on empirical critical load (CL) for protecting sensitive resources in Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. Available data on empirical CL of nutrient-N in the CHDN suggested that the CL for resource protection was consistently greater than or equal to 3 kg N/ha/yr for the protection of lichens and herbaceous plants (Table 4). In most parks within the CHDN, Pardo et al. (2011b) estimated that ambient atmospheric N deposition was less than 3 kg N/ha/yr, suggesting that the CL was likely not exceeded. The exception was AMIS, which was estimated to receive higher N deposition, possibly high enough to exceed the CL to protect lichens and herbaceous plants.

Ellis et al. (2013) estimated the CL for nutrient-N deposition to protect the most sensitive ecosystem receptors in 45 national parks. The lowest terrestrial CL of N is generally estimated for protection of lichens (Geiser et al. 2010). Changes to lichen communities may signal the beginning of other changes to the ecosystem that might affect structure and function (Pardo et al. 2011a). Ellis et al. (2013) estimated the N CL for BIBE, CAVE, and GUMO in the range of 3-8.4 kg N/ha/yr for protection of herbaceous plants.

Ozone Injury to Vegetation

The ozone (O₃)-sensitive plant species that are known or thought to occur within the I&M parks found in the CHDN are listed in Table 5. Some are not native to these parks and therefore are not desirable. Those considered to be bioindicators are designated by an asterisk. Each park within the network contains at least two O₃-sensitive and/or bioindicator species.

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

NPS Unit	Ecoregion	N Deposition (kg N/ha/yr)	Mycorrhizal Fungi	Critical Load (kg N/ha/yr)			
				Lichen	Herbaceous Plant	Forest	Nitrate Leaching
Amistad NRA	Great Plains	5.8	12	NA	5 - 25	NA	10 - 25
Amistad NRA	North American Deserts	5.8	NA	3	3 - 8.4	NA	NA
Big Bend NP	North American Deserts	2.8	NA	3	3 - 8.4	NA	NA
Carlsbad Caverns NP	North American Deserts	2.9	NA	3	3 - 8.4	NA	NA
Carlsbad Caverns NP	Temperate Sierras	2.9	NA	4 - 7	NA	NA	NA
Fort Davis NHS	North American Deserts	2.5	NA	3	3 - 8.4	NA	NA
Guadalupe Mountains NP	North American Deserts	2.8	NA	3	3 - 8.4	NA	NA
Guadalupe Mountains NP	Temperate Sierras	2.8	NA	4 - 7	NA	NA	NA
White Sands NM	North American Deserts	2.2	NA	3	3 - 8.4	NA	NA

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

Species	Common Name	Park ¹					
		AMIS	BIBE	CAVE	FODA	GUMO	WWSA
<i>Ailanthus altissima</i> *	Tree-of-heaven			x			
<i>Apocynum androsaemifolium</i> *	Spreading dogbane		x				
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp		x	x		x	
<i>Artemisia ludoviciana</i> *	Silver wormwood			x	x	x	
<i>Cercis canadensis</i> var. <i>texensis</i> *	Redbud	x					
<i>Fraxinus pennsylvanica</i>	Green ash			x			
<i>Parthenocissus quinquefolia</i>	Virginia creeper			x			
<i>Pinus ponderosa</i> *	Ponderosa pine			x		x	
<i>Platanus occidentalis</i> *	American sycamore	x					
<i>Populus tremuloides</i> *	Quaking aspen		x			x	
<i>Prunus serotina</i> var. <i>virens</i> *	Black cherry		x				
<i>Prunus virginiana</i>	Choke cherry			x		x	
<i>Rhus copallina</i>	Winged sumac			x			
<i>Rhus trilobata</i> var. <i>pilosissima</i> *	Skunkbush				x		
<i>Rhus trilobata</i> *	Skunkbush			x			x
<i>Salix gooddingii</i>	Gooding's willow	x	x	x		x	x
<i>Triadica sebifera</i> *	Chinese tallowtree	x					

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

* Bioindicator species

The W126 (a measure of cumulative O₃ exposure that preferentially weights higher concentrations) and SUM06 (a measure of cumulative exposure that includes only hourly concentrations over 60 ppb 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 (2010) system simply ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997). Kohut's (2007) rankings consider O₃ exposure, but also consider environmental conditions, especially soil moisture. The latter is important because dry conditions induce stomatal closure in plants, which has the effect of limiting O₃ uptake and injury. In areas where low soil moisture levels correspond with high O₃ exposure, uptake and injury are limited by stomatal closure even when exposures are relatively high. Although O₃ conditions are rated as Moderate by NPS in all network parks, Kohut (2007) concluded that,

Table 6. Ozone assessment results for I&M parks in the CHDN 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.

Park Name ²	Park Code	W126		SUM06		Kohut O ₃ Risk Ranking
		Value (ppm-hr)	Ranking	Value (ppm-hr)	Ranking	
Amistad	AMIS	8.63	Moderate	10.64	Moderate	Moderate
<i>Big Bend</i>	BIBE	9.64	Moderate	10.05	Moderate	Low
Carlsbad Caverns	CAVE	11.95	Moderate	14.23	Moderate	Low
Fort Davis	FODA	11.13	Moderate	13.21	Moderate	Low
<i>Guadalupe Mountains</i>	GUMO	11.64	Moderate	13.87	Moderate	Low
<i>White Sands</i>	WHSA	10.44	Moderate	12.42	Moderate	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.

because of generally dry soil conditions during the summer, the risk to vegetation is Low in most of the parks, except AMIS which he rated as 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 to plants in the field 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.

Visibility Degradation

Visibility is an important AQRV in BIBE, with views of the canyons cut by the Rio Grande River, and the Chisos and Sierra Del Carmen Mountains arising from the Chihuahuan Desert. It has been estimated that visibility at BIBE decreased about 20% during the 1990s in response to increased SO₂ emissions in Texas and neighboring states and construction of the Carbón coal-fired electric generating stations to the south near Piedras Negras, Coahuila in Mexico. During this time period, particulate SO₄²⁻ concentrations on the 20% of days having highest SO₄²⁻ concentrations increased about 30% (Schichtel et al. 2005).

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 in 2064. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic emissions. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments Network (IMPROVE) and typically reported using the haze index deciview¹ (dv).

Natural haze is the haze that would occur due to natural conditions in the absence of anthropogenic pollution. It has been estimated by IMPROVE for BIBE and GUMO within the CHDN. Data from GUMO are considered by EPA to also be representative of CAVE, although O&G emissions of NO_x adjacent to CAVE may alter this relationship. Data from a nearby site are considered to be representative if the site is located within 60 mi (100 km) and 425 ft (130 m) elevation of the area.

All three of these parks experience natural haze levels that are relatively low compared with other monitored I&M parks for the 20% clearest days, the 20% haziest days, and the average of the results for all days (Table 7). Natural haze does not appear to be a large component of visibility for the monitored parks in this network. Current visibility estimates reflect current pollution levels. They provide park managers with information on spatial differences in visibility and air pollution. Haze levels were similar across the monitored parks in the network (Table 7).

The highest 90th percentile summer concentrations of atmospheric SO₄²⁻ in the West during the period 1995 to 1999 were at BIBE (Malm et al. 2002). Measured ambient haze values in BIBE and GUMO for the period 2004 through 2008 were considerably higher than the estimated natural haze conditions (Table 7).

¹ The *deciview* visibility metric expresses uniform changes in haziness in terms of common increments across the entire range of visibility conditions, from pristine to extremely hazy conditions. Because each unit change in deciview represents a common change in perception, the deciview scale is like the decibel scale for sound. A one deciview change in haziness is a small but noticeable change in haziness under most circumstances when viewing scenes in Class I areas.

Representative photos of selected vistas in BIBE and GUMO under three differing visibility conditions are shown in Figure 1a and Figure 1b. 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 illustrates the consequences of haze to the visibility at a representative vista in each park.

Composition of Haze

Various pollutants make up the haze that causes visibility degradation. IMPROVE measures these pollutants and reports them as ammonium sulfate, ammonium nitrate, elemental carbon, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO_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, and fires. Organic compounds are emitted from a variety of both natural (biogenic) and anthropogenic sources, including agriculture, industry, and fires. Atmospheric sea salt concentrations are higher in coastal areas. Soil and coarse mass can enter the atmosphere through both natural processes and human disturbance.

Extinction charts are shown for BIBE in Figure 2a and CAVE and GUMO in Figure 2b. Under the estimated natural conditions at all three parks, SO_4^{2-} contributed less than 14% of the haze on clear, average, and hazy days. On average, SO_4^{2-} , derived primarily from coal-burning power plants, contributed 53.9% of current annual total particulate light extinction (b_{ext}) in BIBE. Other substantial contributors in this park were coarse mass (15.7%) and organics (15.0%). On the current 20% haziest days, the contribution of SO_4^{2-} to b_{ext} increased to 61.7%, coarse mass contributed 11.7%, and organics contributed 14.1%. On the clearest 20% visibility days, SO_4^{2-} contributed 40.1%, organics 17.8%, and coarse mass 23.5% of b_{ext} in BIBE.

Much of the annual average b_{ext} in CAVE and GUMO was also contributed by SO_4^{2-} . On average, 40.5% of annual b_{ext} in these parks was due to SO_4^{2-} , 23.8% to coarse mass, and 15.9% to organics (Figure 3). On the 20% haziest days, SO_4^{2-} contributed 41.6% of the b_{ext} , coarse mass 26.0%, and organics 14.2%. On the clearest 20% visibility days, the contribution of SO_4^{2-} decreased to 37.2% of b_{ext} , organics increased to 17.4%, and coarse mass decreased to 20.3%. 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 impairment² throughout the western United States, including within the CHDN. In addition, air pollution sources outside the WRAP domain, 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).

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

Big Bend

20% Clearest Days

Taken: 9:00 AM

Haze = 5 dv

$B_{\text{ext}} = 16 \text{ Mm}^{-1}$

VR = 240 km



20% Haziest Days

Taken = 9:00 AM

Haze = 17 dv

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

VR = 70 km



Average Days

Taken = 9:00 AM

Haze = 10 dv

$B_{\text{ext}} = 28 \text{ Mm}^{-1}$

VR = 140 km



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

Guadalupe Mountains

20% Clearest Days

Taken: 3:00 PM

Haze = 5 dv

$B_{\text{ext}} = 17 \text{ Mm}^{-1}$

VR = 230 km



20% Haziest Days

Taken = 3:00 PM

Haze = 16 dv

$B_{\text{ext}} = 49 \text{ Mm}^{-1}$

VR = 80 km



Average Days

Taken = 3:00 PM

Haze = 10 dv

$B_{\text{ext}} = 27 \text{ Mm}^{-1}$

VR = 145 km



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

Table 7. Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008.

Park Name²	Park Code	Site ID	Estimated Natural Haze		
			20% Clearest Days	20% Haziest Days	Average Days
			dv	dv	dv
Amistad	AMIS	No Site			
<i>Big Bend</i>	BIBE	BIBE1	1.62	7.16	4.01
Carlsbad Caverns ³	CAVE	GUMO1	0.99	6.65	3.41
Fort Davis	FODA	No Site			
<i>Guadalupe Mountains</i>	GUMO	GUMO1	0.99	6.65	3.41
<i>White Sands</i>	WHSA	No Site			
Park Name	Park Code	Site ID	Measured Ambient Haze (For Years 2004 through 2008)		
			20% Clearest Days	20% Haziest Days	Average Days
			dv	dv	dv
Amistad	AMIS	No Site			
<i>Big Bend</i>	BIBE	BIBE1	5.69	17.00	11.19
Carlsbad Caverns ³	CAVE	GUMO1	5.50	16.16	10.46
Fort Davis	FODA	No Site			
<i>Guadalupe Mountains</i>	GUMO	GUMO1	5.50	16.16	10.46
<i>White Sands</i>	WHSA	No Site			

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

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

BIBE

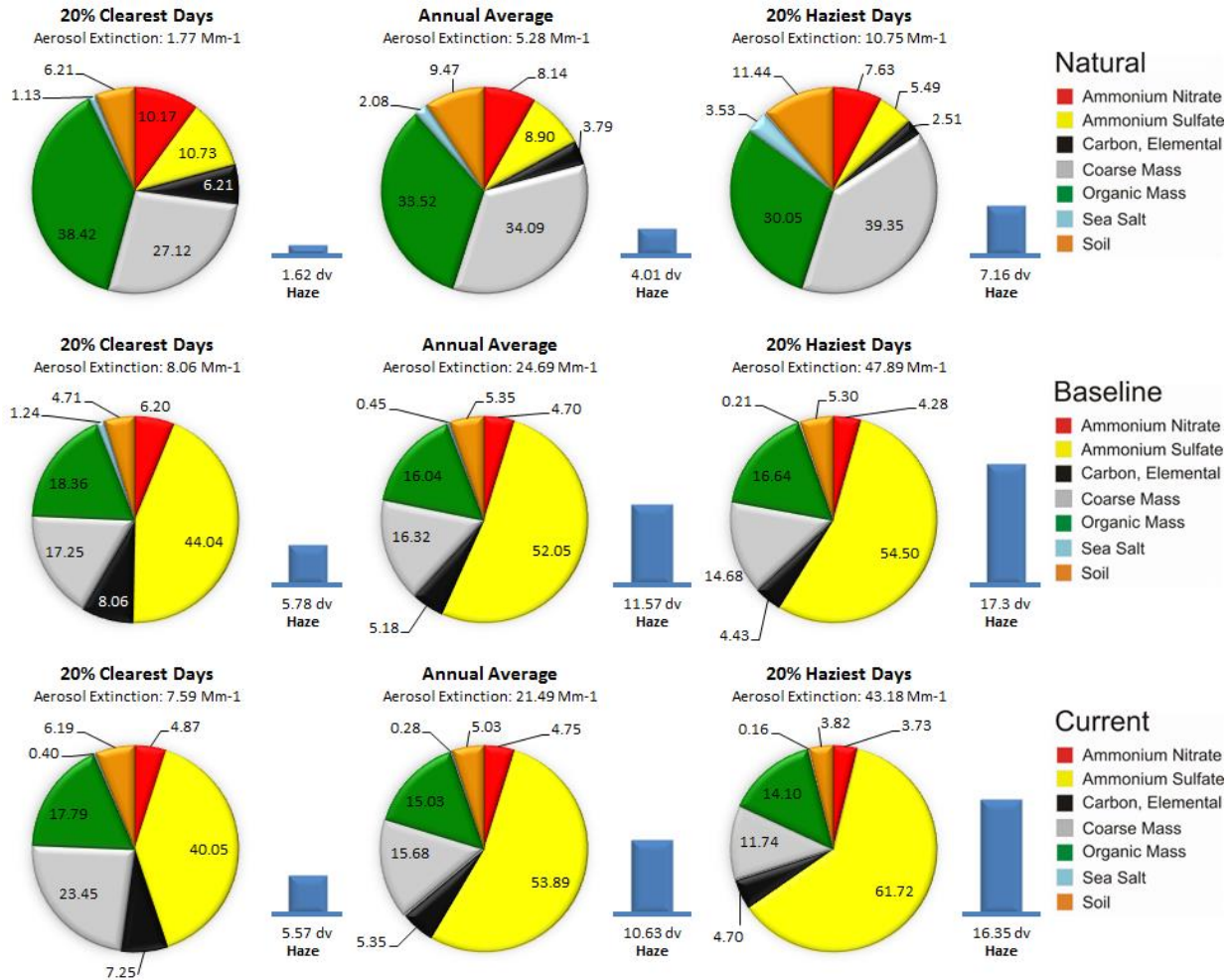


Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for BIBE. Data Source: NPS-ARD.

CAVE and GUMO

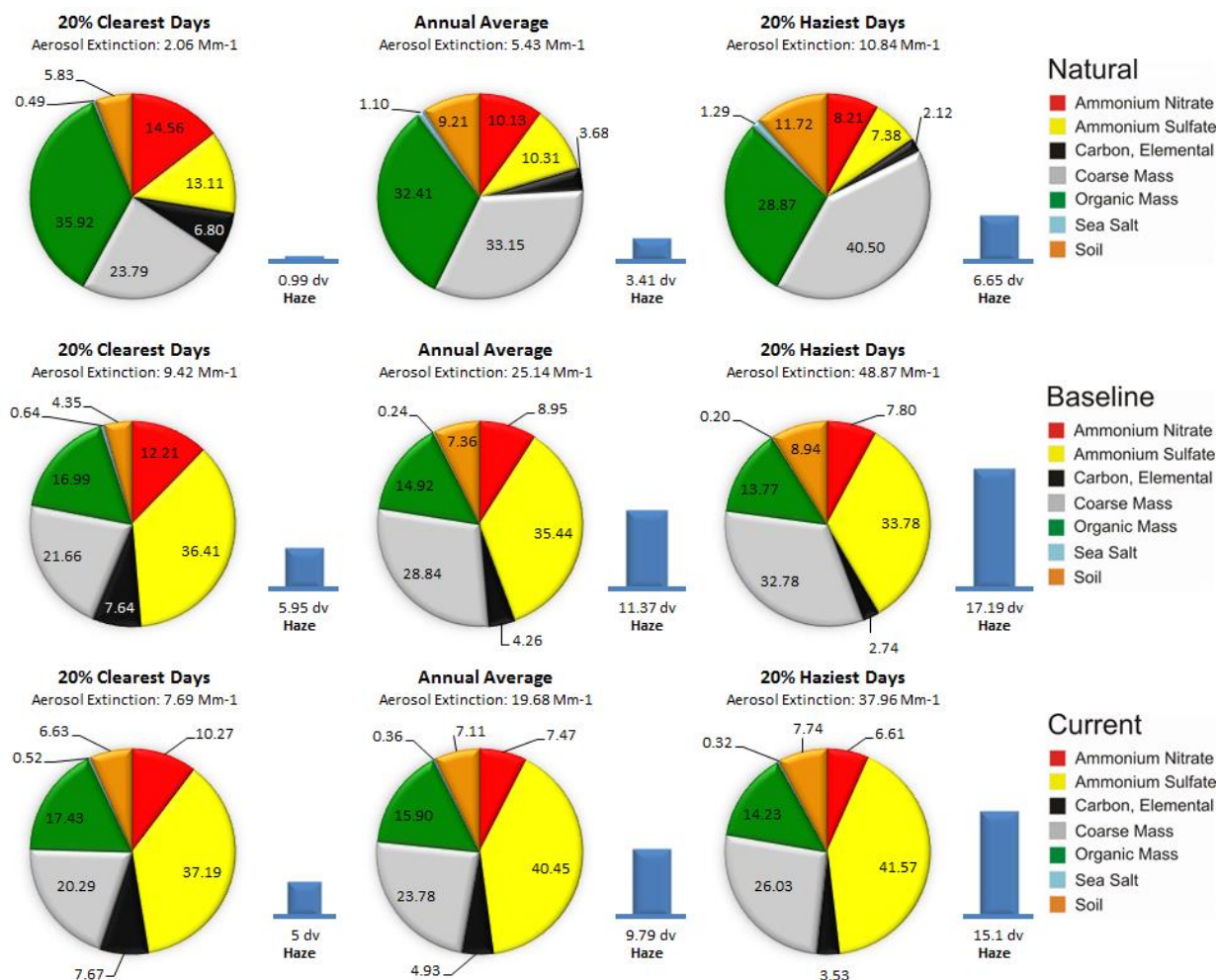


Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for CAVE, and GUMO. Data for CAVE were taken from a nearby site (GUMO1). Data Source: NPS-ARD.

The U.S. EPA and NPS initiated the Big Bend Regional Aerosol and Visibility Observational (BRAVO; Pitchford et al. 2004) study to monitor possible changes in aerosol concentrations and visibility at BIBE over time and to determine the identity and origins of particulates that were causing the observed haze. Atmospheric haze at BIBE had been increasing since the late 1980s (http://www.nps.gov/bibe/naturescience/upload/Bravo_Fact_Sheet.pdf). The BRAVO study was intended to determine the major sources and source regions contributing to haze at BIBE (Schichtel et al. 2005). The major focus was on fine particulate SO_4^{2-} for a four-month period (July-October, 1999). Several approaches were developed using air quality models, receptor models, and various sources of meteorological data (Barna et al. 2006, Gebhart et al. 2006, Schichtel et al. 2005).

In agreement with the data for baseline and current conditions shown in Figure 2, results of the BRAVO study suggested that haze in BIBE was caused mainly by SO_4^{2-} , organic C, and coarse mass,

followed by low concentrations of fine particles of light-absorbing C, fine soils, and nitrates. The composition and air concentrations of these pollutants were found to vary seasonally; high haze levels were most common in the spring, when carbonaceous particles are most prevalent, and in the late summer to mid-fall, when SO_4^{2-} compounds dominate (Gebhart et al. 2001). This seasonal cycle was attributed to different wind patterns throughout the year, leading to variations in atmospheric transport of particulate matter from emissions sources to BIBE. Spring haze was predominantly caused by smoke from fires in Mexico and Central America. Summer haze was influenced by easterly winds carrying dust from Africa across the Atlantic Ocean and Gulf of Mexico into the CHDN. Nevertheless, the dominant source of haze-forming particulate air pollution in BIBE during the late summer and early fall is SO_2 emissions from sources within the United States (Pitchford et al. 2005). During intense episodes of relatively high particulate SO_4^{2-} concentrations in the late summer and fall, SO_2 emissions are derived mainly from sources in Texas and states to the east of Texas. In the spring and early summer, however, sources in northeastern Mexico are responsible for the majority of particulate SO_4^{2-} in BIBE (Pitchford et al. 2005).

Chemical transport and receptor models were used in BRAVO to apportion observed SO_4^{2-} concentrations at BIBE to various source regions and to the Carbón power plants (Schichtel et al. 2005). Opposing biases in the various modeling approaches were identified and a hybrid receptor model was developed. The best estimates from the model/data reconciliation process suggested that 55% of the SO_2 emissions impacting visibility at BIBE originated in the United States, and 38% originated in Mexico. Among U.S. source regions, the distribution was 16% Texas, 30% eastern United States, and 9% western United States. Contributions from Texas and the eastern United States were generally episodic, with their greatest contribution during high SO_4^{2-} episodes. Sources in Mexico were more chronic in nature.

On the 20% of the days having highest fine particulate SO_4^{2-} concentrations in the atmosphere at BIBE, sources in the United States contributed an estimated 71% of the SO_4^{2-} . In contrast, on the 20% of the days having lowest SO_4^{2-} concentrations, sources in the United States accounted for only 40% of the ambient SO_4^{2-} .

Schichtel et al. (2005) concluded that Mexican sources of SO_2 contributed more frequently than sources in the United States. Nevertheless, the highest SO_4^{2-} concentrations and highest haze events at BIBE result from emissions derived from Texas and the eastern United States. To substantially reduce haze during the intensive haze episodes that occur at BIBE during late summer and fall would require SO_4^{2-} emissions reductions in Texas and the eastern United States.

The work of Pitchford et al. (2005) illustrated the considerable variability in the nature of haze levels and atmospheric transport pathways from diverse source regions to BIBE on daily to weekly, seasonal, and inter-annual time scales. The relative importance of the various pollutant source areas changed dramatically depending on the time scale and period considered. Therefore, short-term results of source attribution studies might provide unrepresentative results. Fine particulate SO_4^{2-} concentrations at BIBE are seasonal; concentrations are highest during summer and fall when air masses commonly travel to the park from the southeast after passing over Mexico.

The Trajectory Mass Balance (TrMB) model was applied by Gebhart et al. (2006) to estimate source apportionment of particulate SO_4^{2-} in BIBE during the period July-October, 1999. Mean SO_4^{2-} source apportionment results suggested a 39-50% contribution from Mexico, 12-45% from Texas, 7-26% from the eastern United States, and 3-25% from the western United States.

Episodically high concentrations of fine mass and high light extinction also occur periodically at BIBE due to fine particles of organic C attributed to seasonal agricultural burning in Mexico, or blowing soil dust, likely from the Sahara Desert in Africa (Gebhart et al. 2001). Nevertheless, light scattering by SO_4^{2-} accounts for about half of the non-Raleigh light extinction at BIBE.

Trends in Visibility

In much of the western United States, atmospheric SO_4^{2-} concentrations decreased during the 1990s. In west Texas, however, concentrations increased. There were only two national park areas in the United States that showed a statistically significant increase in atmospheric SO_4^{2-} concentrations during the period 1988 to 1999. One was BIBE (Malm et al. 2002).

NPS (2010) reported long-term trends in annual dv on the clearest and haziest 20% of days at monitoring sites in 29 national parks. All 27 parks that showed statistically significant ($p \leq 0.05$) dv trends on the clearest days for the 11-20 year monitoring periods through 2008 exhibited decreases in dv over time. None of the sites showed increasing trends on the clearest days. One of the parks (GUMO) showed a statistically significant increase in dv on the haziest days. From 2000-2009, visibility improved on the clearest days at GUMO and CAVE, but was unchanged on the haziest days (NPS-ARD 2013).

Available haze monitoring data suggest that highest values were reached at BIBE, CAVE, and GUMO around the late 1990s. There is evidence that haze levels have decreased since then (Figure 3).

Development of State Implementation Plans

According to the RHR, states and tribes must establish and meet reasonable progress goals for each federal Class I area to improve visibility on the 20% haziest days and to prevent visibility degradation on the 20% clearest days. The national goal is to return visibility in Class I areas to natural background levels in 2064. States must evaluate progress by 2018 (and every 10 years thereafter) based on a baseline period of 2000 to 2004 (Air Resource Specialists 2007).

Monitoring data suggest that recent measured haze values at BIBE, CAVE, and GUMO are in compliance with the RHR, and roughly follow the glideslopes needed to reach natural haze levels of about 7.7 dv on the 20% haziest days by 2064 (Figure 4). Substantial additional reductions in haze will be required to meet the aforementioned goal.

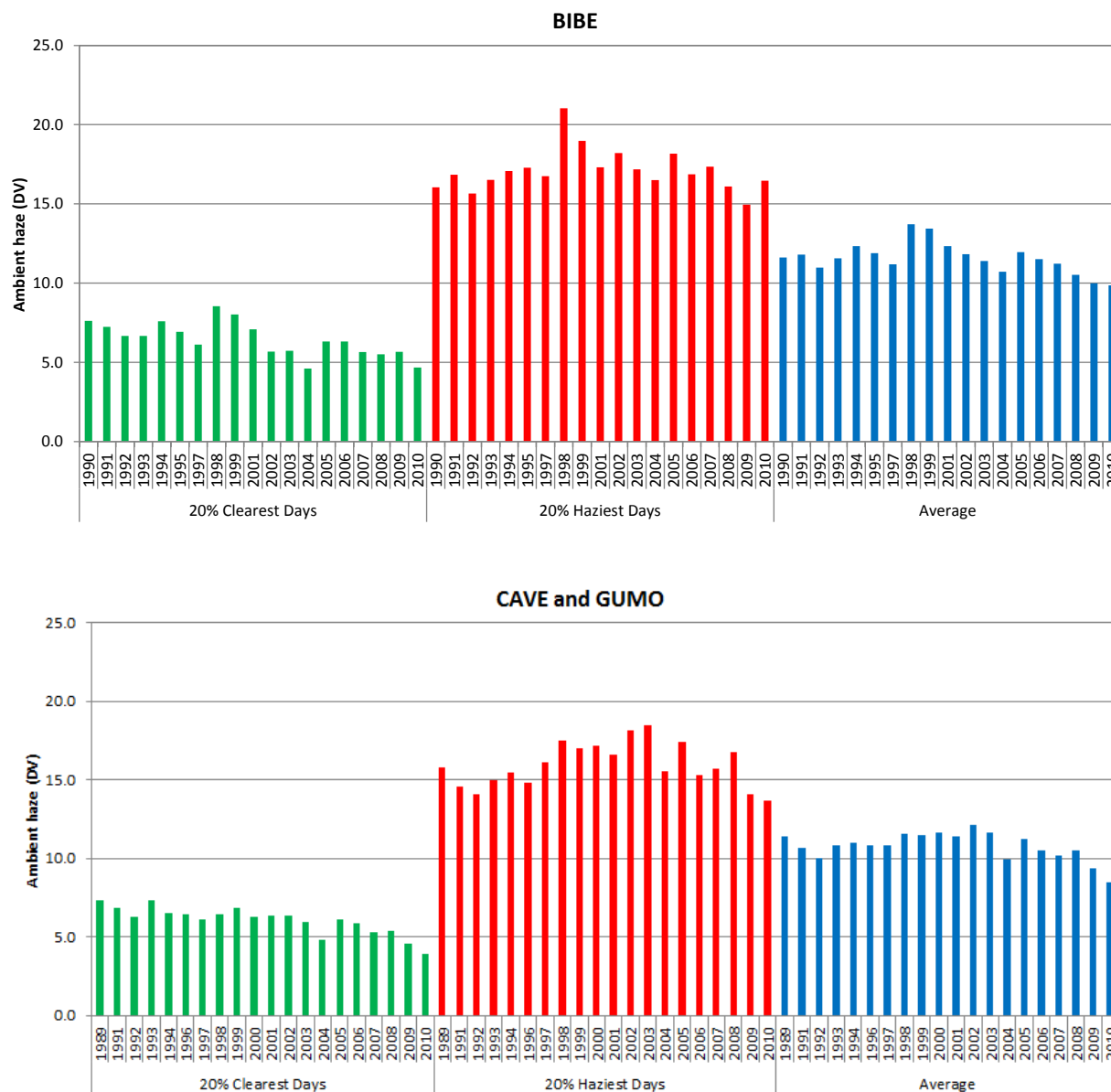


Figure 3. Trends in ambient haze levels at BIBE, CAVE, and GUMO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for CAVE were taken from a nearby site (GUMO1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

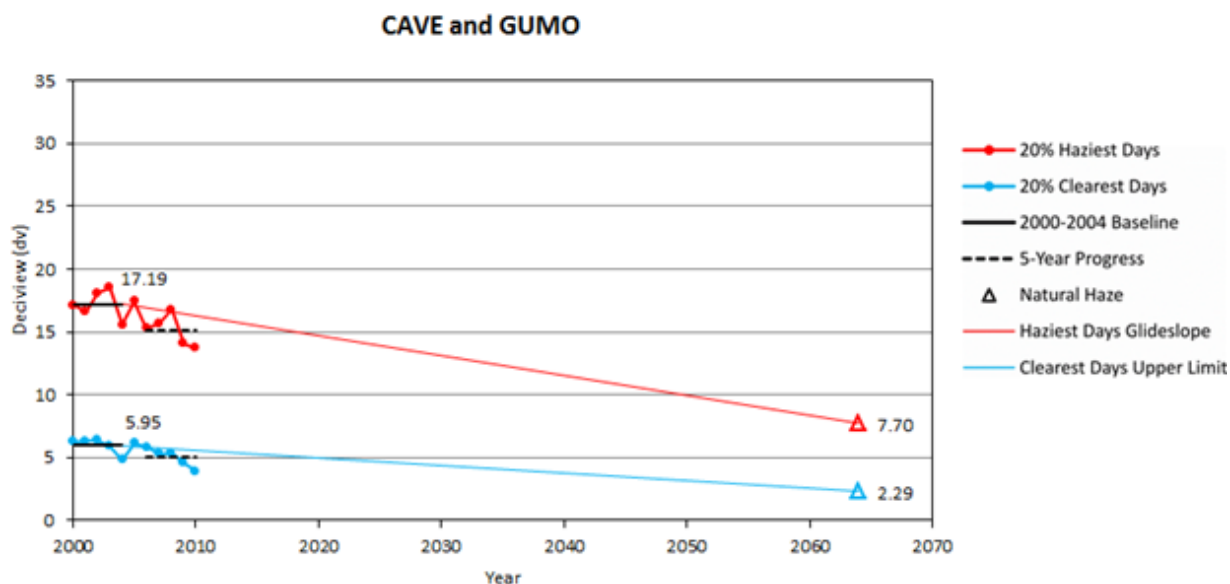
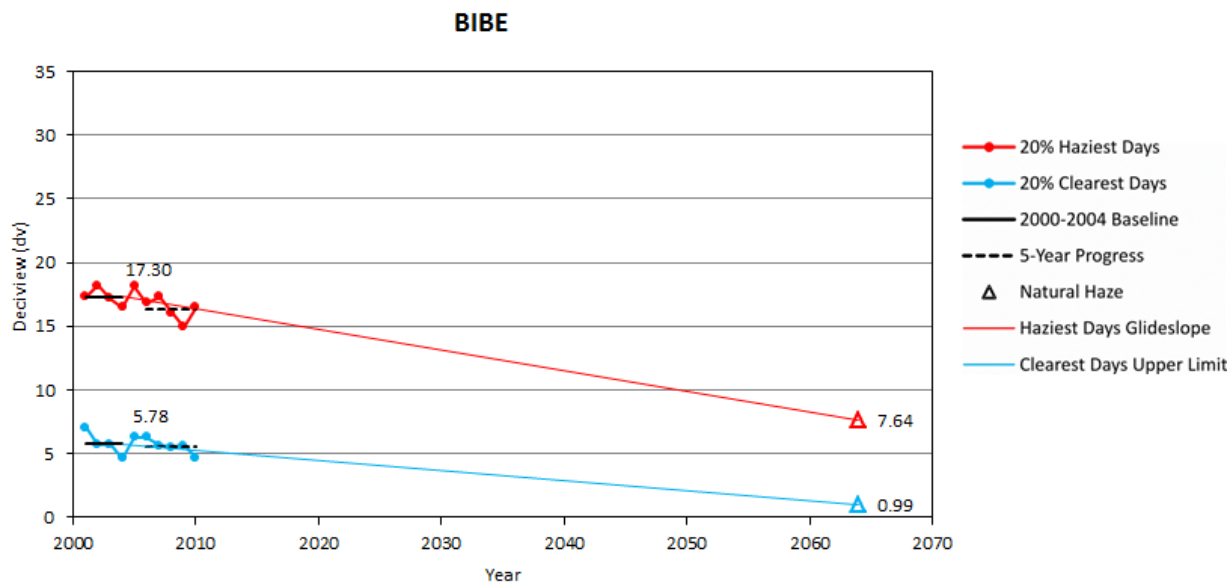


Figure 4. Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in BIBE, CAVE, and GUMO. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for CAVE were taken from a nearby site (GUMO1).
http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Toxic Airborne Contaminants

Limited data are available regarding the potential influence of airborne toxic substances on natural resources in the CHDN. Concentrations of current use pesticides (CUPs) in vegetation in BIBE were at or slightly above the median for WACAP parks; these CUPs included chlorpyrifos, dacthal, endosulfans, and hexachlorocyclohexane- γ . Concentrations of historic use pesticides (HUPs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) were at or slightly below the median among WACAP study sites. Data are not available for other parks in the CHDN or with which to evaluate the effects of atmospherically deposited toxic substances on sensitive receptors in the CHDN.

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