# AIR QUALITY MONITORING CONSIDERATIONS FOR THE NORTHERN GREAT PLAINS NETWORK PARKS

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by

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## Introduction

Data from state, national and other air monitoring programs described below were used in conjunction with park-specific resource information to evaluate the following needs relative to the Northern Great Plains Network: 1) the need for additional ambient air quality monitoring at any Network park, *i.e.*, wet deposition, dry deposition, visibility, particulate matter, ozone and/or air toxics monitoring (rough cost estimates for installation and annual operation of some typical air quality monitoring stations are attached), and 2) the need for air quality effects-related monitoring at any Network park. The results of this evaluation, as well as a brief summary of results of current air quality monitoring at sites in the Network, are discussed below.

## Air Inventory

With funds from the National Inventory & Monitoring (I&M) Program, the National Park Service's (NPS) Air Resources Division (ARD) contracted with the University of Denver to develop baseline values for ozone, deposition and visibility for all I&M parks. The analysis involved interpolating concentrations between monitors to estimate pollutant values at parks that do not have on-site monitoring. The products include web-based GIS maps and tables for the parks. These products constitute the I&M Air Inventory. These are included in Attachment 4. The Air Inventory is also available on the internet at: http://www2.nrintra.nps.gov/air/maps/airatlas/index.htm

## Deposition

### Wet Deposition

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide network of precipitation monitoring sites (http://nadp.sws.uiuc.edu). The network is a cooperative effort between many different groups, including the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), U.S. Department of Agriculture, and private entities. The NPS is a major participant in NADP/NTN, and the ARD recommends that any new wet deposition site installed in a park meet NADP/NTN siting criteria and follow NADP/NTN protocols. There are currently more than 200 NADP/NTN sites spanning the continental U.S., Alaska, Puerto Rico, and the Virgin Islands.

The purpose of the network is to collect data on the chemistry of precipitation to monitor geographical and temporal long-term trends. The precipitation at each station is collected weekly according to strict clean-handling procedures. It is then sent to the Central Analytical Laboratory in Illinois where it is analyzed for hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium). NADP/NTN's excellent quality assurance programs ensure that the data remain accurate and precise.

Deposition varies with the amount of annual on-site precipitation, and is useful because it gives an indication of the total annual pollutant loading at the site. Concentration is independent of precipitation amount, therefore, it provides a better indication of whether ambient pollutant levels are increasing or decreasing over the years. In general, annual average wet deposition and concentration of sulfate, nitrate, and ammonium are higher in

the eastern than in the western U.S. (see attached Air Inventory wet deposition maps; also see NADP/NTN maps on their website). At many NADP/NTN sites across the U.S., concentration and deposition of sulfate have declined in recent years as sulfur dioxide emissions have decreased. Trends have been variable for nitrate and ammonium, with concentration and deposition at sites increasing, decreasing, or showing no overall change.

These patterns are reflected in trend data from NADP/NTN sites in the Northern Great Plains region. A number of the regional sites show increases in nitrate and ammonium deposition and concentration starting in the mid-1990s. Sulfate concentrations and deposition are generally steady or decreasing. Trends in measurements from several NADP/NTN sites in the Northern Great Plains region are summarized below. The latest data can be obtained on the NADP web site: http://nadp.sws.uiuc.edu/

Wind Cave National Park, SD (Site SD04)
Wind Cave National Park, South Dakota has had a NADP/NTN site since 2002. Trend data are not yet available from the site. This is the nearest wet NADP site to AGFO, FOLA, JECA, MORU and WICA.

Jackson County, SD (Site SD08)
This NADP/NTN monitor is located about 30 miles ENE of BADL. It has operated since 1983. Site data show wet ammonium and nitrate concentrations have been increasing since the mid-1990s. Deposition of wet nitrate and ammonium appear to have also been increasing somewhat. There has been no overall trend in wet concentration and deposition of sulfate. Site SD08 is the nearest NADP site to BADL and NIOB.

Newcastle, WY (Site WY99)
This NADP/NTN monitor is located about 55 miles SE of DETO. It has operated since 1981. Trends are difficult to distinguish due to data not meeting criteria for 1999 and 2000, but wet ammonium and nitrate concentration and deposition appear to be increasing since the mid-1990s. Wet concentration and deposition of sulfate appear to be decreasing. Site WY99 is the nearest NADP site to DETO.

Weld County, Colorado (Site CO22)
This NADP/NTN monitor is located about 85 miles SW of SCBL. It has operated since 1979. Wet ammonium and nitrate concentration and deposition have been increasing since the mid-1990s. Wet concentration of sulfate is steady, while wet deposition of sulfate is decreasing. Site CO22 is the nearest NADP site to SCBL.

Roosevelt County, MT (Site MT96)
This NADP/NTN monitor is located about 50 miles NNW of FOUS. It has operated since 1999. This site has not been operating long enough to show any clear trends. Site MT96 is the nearest NADP site to FOUS.

THRO, South Unit (Site ND00)
This NADP/NTN monitor is located at the South Unit of THRO. It has operated since 2001, and is too new to show trends. From 1981-2000 a NADP site operated at the North Unit of THRO (Site ND07). Data from site ND07 does not show any clear trends in recent years. Site ND00 is the nearest NADP site to THRO.

Woodworth, ND (Site ND11)
This NADP/NTN monitor is located about 90 miles ESE of KNRI. It has operated since 1983. Wet ammonium and nitrate concentration and deposition have been increasing since the mid-1990s. Wet concentration and deposition of sulfate are steady. Site ND11 is the nearest NADP site to KNRI

Huron, SD (Site SD99)
This NADP/NTN monitor has operated since 1979. Wet ammonium concentrations and deposition have been increasing steadily since the mid-1980s. Wet nitrate concentration and deposition have also been increasing slightly. Wet concentration and deposition of sulfate have been decreasing. Site SD99 is the nearest NADP site to MNRR.

**Dry Deposition**
The Clean Air Status and Trends Network (CASTNet) is the nation's primary source for atmospheric data to estimate dry acidic deposition (http://www.epa.gov/castnet). Established in 1987, CASTNet now comprises over 80 monitoring stations across the U.S. The majority of the monitoring stations are operated by EPA; however, approximately 20 stations are operated by the NPS in cooperation with EPA. Each CASTNet dry deposition station measures weekly average atmospheric concentrations of sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid; hourly concentrations of ambient ozone; and meteorological conditions required for calculating dry deposition rates. Dry deposition rates are calculated using atmospheric concentrations, meteorological data, and information on land use, vegetation, and surface conditions. CASTNet complements the database compiled by NADP/NTN. Because of the interdependence of wet and dry deposition, NADP/NTN wet deposition data are collected at or near all CASTNet sites. Together, these two long-term databases provide the necessary data to estimate trends and spatial patterns in total atmospheric deposition. The ARD recommends that all new dry deposition sites installed in parks use CASTNet siting criteria and follow CASTNet protocols.

Because CASTNet uses different monitoring and reporting techniques than NADP/NTN, the dry deposition amounts are reported here as nitrogen and sulfur, rather than nitrate, ammonium, and sulfate. In addition, because CASTNet calculates dry deposition based on measured ambient concentrations and estimated deposition velocities, there is greater uncertainty in the reported values. Due to the small number of CASTNet sites nationwide,

use of dry deposition isopleth maps is not advised at this time. CASTNet data collected at sites in the Northern Great Plains region are summarized below.

THRO (Site THR422)
This site has been in operation since 1998. It is located at THRO. There has been no obvious trend in dry sulfur or dry nitrogen deposition. Total sulfur deposition at the site is composed of 38 percent dry deposition and 62 percent wet deposition, while total nitrogen deposition is 30 percent dry and 70 percent wet.

WICA (Site WNC429)
The CASTNet site at WICA is new, and data is not yet available.

Centennial, CO (Site CNT169)
This site has been operating since 1991. It is located about 210 miles SW of WICA. Data shows a slight upward trend in nitrogen deposition since the site began operating. Sulfur deposition has remained steady. Total nitrogen deposition is estimated to be 85% wet and 13% dry while total sulfur deposition is 87% wet and 13% dry.

**Surface Water Chemistry**
To determine sensitivity of Network park surface waters to atmospheric deposition, the Water Resources Division's (WRD) *Baseline Water Quality Data Inventory and Analysis* reports were reviewed for ten of the Northern Great Plains Network parks and water quality summaries contained in the Air Resources Division's (ARD) *Assessment of Air Quality and Air Pollutant Impacts in National Parks of the Rocky Mountains and Northern Great Plains* (1998) were reviewed for Badlands, Theodore Roosevelt, and Wind Cave NPs. In general, acid-sensitive surface waters have a pH below 6.0 and an acid neutralizing capacity (ANC) below 100 microequivalents per liter (μeq/l). None of the data contained in the reports met these criteria. In fact, the data showed surface waters in Northern Great Plains Network parks tend to be alkaline, with pH values approaching 8.0 and ANC values well above 100 μeq/l. Note that many of the Network WRD reports indicated a lack of recent, in-park, and/or small stream and spring data, so the data may not be entirely representative of water chemistry conditions in the parks.

## Particulate Matter
Small or "fine" particles in the air, typically those less than 2.5 microns in diameter, $PM_{2.5}$, are a leading cause of human respiratory illness. Particles are present everywhere, but high concentrations and/or specific types have been found to present a serious danger to human health. Fine particles in the air are the main contributor to human-caused visibility impairment. The particles not only decrease the distance one can see; they also reduce the colors and clarity of scenic vistas. Moisture in the air enhances the impact, so areas in the Eastern U.S., with higher relative humidity, have worse visibility than areas in the arid West (see attached visibility maps).

The current human-health based National Ambient Air Quality Standards (NAAQS) for particulate matter (set by the EPA) are for particles 2.5 microns or less (PM2.5). Areas where air quality exceeds the NAAQS for PM2.5 are designated "nonattainment" for that pollutant. No areas in the Northern Great Plains region are currently designated nonattainment for PM2.5.

## Visibility

In 1985, in response to the mandates of the Clean Air Act, Federal and regional/state organizations established the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to protect visibility in Class I air quality areas (http://vista.cira.colostate.edu/improve). Class I areas are national parks greater than 5,000 acres and wilderness areas greater than 6,000 acres, that were established prior to August 7, 1977. All other NPS areas are designated Class II. In the Northern Great Plains area, BADL, THRO, and WICA are Class I areas. The objectives of the IMPROVE program are: to establish current visibility conditions in all Class I areas; to identify pollutants (particles and gases) and emission sources responsible for existing man-made visibility impairment; and to document long-term trends in visibility. In 1999, there were 30 official IMPROVE sites and 40 protocol sites. Because of recently enacted regulations that require improving visibility in Class I areas, the number of visibility monitors is increasing. Protocol sites are being upgraded to full IMPROVE sites and 80 new sites are being added to the IMPROVE network.

While the IMPROVE program has focused on Class I air quality areas, a great deal of visibility monitoring has been conducted in Class II areas. The ARD recommends that new visibility monitoring in NPS areas be conducted in coordination with the IMPROVE program (the IMPROVE program is managed out of the NPS ARD office in Fort Collins, Colorado). Some I&M Networks are considering monitoring visibility at scenic vistas with digital cameras. While this type of monitoring would not be adequate for regulatory purposes, it is useful for documenting visibility conditions and trends and provides an excellent means of sharing that information with the public. A camera is currently located at THRO:
http://www2.nature.nps.gov/air/WebCams/parks/throcam/throcam.htm

The following IMPROVE sites are located in the Northern Great Plains region:

Crescent Lakes NWR, NE (site #CRES1); Wind Cave, NP, SD (site #WICA1) established in 1999; Badlands NP, SD (site #BADL1) established in 1988; Thunder Basin NG, WY (site #THBA1); Medicine Lake NWR, MT (site #MELA1) established in 1999; Theodore Roosevelt NP, ND (site #THRO1), established in 1999; Lostwood NWR, ND (site #LOST1) established in 1999; and Nebraska NF, NE (site #NEBR1). See attached table for nearest monitors to Northern Great Plains parks.

Long-term visibility trends have not yet been determined for most of the IMPROVE sites in the Northern Great Plains region. An exception is the site at BADL, which has operated since 1988. The Badlands NP site shows visibility worsened between 1990 and 1999 on the clearest days as well as on the haziest days.

As for the sources of visibility impairment, 1996 to 1998 aerosol data from Badlands NP show that, in the summer, visibility impairment is primarily due to sulfates (sources include coal combustion and oil refineries), then organics (sources include automobiles and chemical manufacturing), then soil (from windblown dust), and then light absorbing carbon (sources include wood burning), then nitrates (sources include coal and natural gas combustion and automobiles). In winter, nitrates become much more significant and

organics become somewhat less significant. In winter, visibility impairment is primarily due to sulfates, followed by nitrates, organics, soil and carbon.

Visibility is generally worst in March and August. In March, the contribution of nitrates and sulfates both peak. Sulfates and organics are the most significant contributors to light extinction during the warmer months, when the contribution of nitrates is at its lowest.

This can be seen graphically on the IMPROVE web site:
http://vista.cira.colostate.edu/improve/Data/GraphicViewer/seasonal.htm

## Ozone

Ozone is created by a chemical reaction between oxides of nitrogen ($NO_x$) and volatile organic compounds (VOC) in the presence of heat and sunlight. Some major sources of ozone-forming chemicals are motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents.

High ozone concentrations cause respiratory problems in humans, and are a particular concern for those who are engaging in strenuous aerobic activity, such as hiking. Ozone also damages sensitive plant species. It injures plant leaves by causing a visible spotting or "stipple" on the upper surface of the leaves. Ozone can affect plant physiology by reducing growth, increasing susceptibility to disease, and increasing senescence.

**Ambient Monitoring**

The EPA sets NAAQS for ozone based on human health effects. The current ozone NAAQS is based on a 1-hr concentration of 0.12 parts per million (ppm). If this threshold is exceeded on more than one day per year (on a 3 year average) the area is considered "nonattainment" for the 1-hr ozone standard. There are no 1-hr ozone nonattainment areas in the Northern Great Plains region.

EPA recently established a new NAAQS for ozone, which is based on a 3-year average of the 4$^{th}$ highest daily maximum 8-hr ozone concentration. This value cannot exceed 0.08 ppm, or the area will be designated nonattainment. There are no 8-hr ozone nonattainment areas in the Northern Great Plains region.

The following is a summary of ozone monitor data at monitors in the Northern Great Plains region based on a review of monitored ozone values from 2002-2004, unless otherwise stated:

<u>BADL (site 46-071-1001)</u>

An ozone monitor has been operating at Badlands NP since 2003. In 1994, the maximum 8-hr ozone concentration at this monitor was 0.066 ppm, and the 4$^{th}$-high 8-hr concentration was 0.063 ppm. There is not enough data to show trends at this site.

<u>Rapid City, SD (site 46-103-0016)</u>

This monitor is in Rapid City and, due to the possiblity local impacts, might not be representative of air quality within a park. This monitor began operating in 2002. The average annual high measured 8-hr ozone concentration was 0.073 ppm. The average 4$^{th}$-

high measurement was 0.068ppm. There is not enough data at this monitor to show trends.

THRO S. Unit (site 38-007-002)
This monitor has been operating since 1985. The average maximum 8-hr ozone concentration at this monitor is 0.063 ppm. The average 4th high 8-hr concentration is 0.058 ppm. There is not a discernable trend in ozone concentrations at this site.

THRO N. Unit (site 38-053-0002)
This monitor has been operating since 1975. For 2002-2004, the average annual high 8-hr concentration was 0.069 ppm. The average 4th high was 0.063ppm. There is no obvious trend at this site.

Beulah, ND (site 38-057-0004)
This site began operating in 1998. For 2002-2004, the average annual maximum 8-hr concentrations was 0.064 ppm and 4th-high concentration was 0.061 ppm. There is no apparent trend.

Thunder Basin NG, WY (site 56-005-0123
This site was established in 2001. The average annual maximum 8-hr ozone concentration was 0.081 ppm. The average 4th high reading was 0.070 ppm. This site is too new to show trends.

Gillette, WY (site 56-005-0546)
This site began monitoring in 2003. For 2003-2004, the average maximum 8-hr ozone concentration at this monitor was 0.077 ppm. The average 4th high 8-hr concentration was 0.069 ppm. The site is too new to show trends.

**Vegetation**
For vegetation, the focus is on ozone sensitivity because ozone is a regional pollutant and is, therefore, more likely to affect park resources than other gaseous pollutants such as sulfur dioxide and nitrogen oxide which quickly convert to other compounds, and also the literature on ozone sensitivity is more recent and more reliable than that for other pollutants. In 2003, the ARD contracted with a plant physiologist to evaluate the risk of ozone injury of vegetation in each of the I&M parks. The risk assessment includes: 1) a list of the ozone sensitive species that occur in each park based on a comparison of the park's vascular plant list contained in NPSpecies with a master list of ozone sensitive species which was developed at a workshop in June 2003, 2) an evaluation of whether or not monitored or interpolated ozone values at each park exceed known thresholds for foliar injury, and 3) a consideration of the soil moisture status at each park to determine if ozone uptake is likely. The risk assessments for the Northern Great Plains Network parks can be found in Attachment 3.

## Lichens and Air Quality
The NPS Research Permit and Reporting System, Investigator's Annual Report website was searched for previous and current air pollution-effects related studies conducted in Northern Great Plains Network parks. The only relevant listed studies pertained to

lichens. In 1997 and 1998, Cliff Wetmore (University of Minnesota, 612-625-6292) conducted lichen inventories at Agate Fossil Beds NM, Fort Union Trading Post NHS, Knife River Indian Villages NHS, Scotts Bluff NM, and Theodore Roosevelt NP. Susan Will-Wolf (University of Wisconsin, 608-262-2179) conducted a lichen inventory at Badlands NP in 1995. A number of studies have been conducted at Theodore Roosevelt NP investigating potential effects of air pollution on lichens. These studies are discussed in detail in *Assessment of Air Quality and Air Pollutant Impacts in National Parks of the Rocky Mountains and Northern Great Plains* (http://www2.nature.nps.gov/air/Pubs/index.htm). The authors of the assessment report concluded none of the studies conducted at Theodore Roosevelt NP could conclusively demonstrate that park lichens were being significantly affected by air pollution.

Lichens have long been promoted as good indicators of air pollution because 1) lichens concentrate a variety of pollutants in their tissues, 2) pollutants can cause adverse physiological changes in some lichen species, and 3) biomonitoring is less expensive than traditional air quality monitoring with specialized equipment. However, because many past lichen studies were not designed to answer specific air pollution questions, the data were of limited use. Recognizing a need to clarify the advantages and limitations of lichen monitoring in an air pollution context, the NPS, U.S. Forest Service, and U.S. Fish and Wildlife Service published a report entitled *Air Pollution-Related Lichen Monitoring in National Parks, Forests, and Refuges: Guidelines Intended for Regulatory and Management Purposes* (http://www2.nature.nps.gov/air/Pubs/index.htm). A key conclusion of the report is that because lichens can be affected by many stressors besides air pollution (e.g., climate change, grazing, habitat alterations, and fire); it is very difficult to establish a cause-and-effect relationship between air quality and lichen health. Therefore, studies to document current or potential future impacts on lichens are most effective when used in conjunction with other data, e.g., deposition monitoring, visibility data, stream chemistry changes. If Northern Great Plains Network staff want to effectively incorporate lichen monitoring as an air quality indicator in their Vital Signs monitoring program, it is imperative that they determine exactly what questions they hope to answer, and that the monitoring strategy then be carefully designed to answer those questions.

## Conclusions

### Adequacy of Ambient Monitoring Network

The Class 1 air quality parks in the Northern Great Plains Network are very well monitored. BADL, THRO, and WICA each have several air monitors on site. Other parks in the Network, such as JECA, MORU, FOUS and DETO are also fairly well-monitored by nature of their proximity to a well-monitored park, wildlife refuge, or national grassland. However, there are some air monitoring gaps. The most poorly monitored parks are those located in Nebraska and SE Wyoming – FOLA, AGFO, KNRI, MNRR, NIOB and SCBL. These parks are often 100 miles or more from most types of ambient air monitoring. At the same time, Air Atlas predicts that these parks are likely to have the highest ambient ozone levels in the Network.

Monitored air concentration and deposition of air pollutants are currently low in the Northern Great Plains area, but trends indicate that nitrogen deposition is increasing and

visibility is decreasing. More information on trends will be available in the coming years as several recently-established monitoring sites continue to collect data.

**Options for Further Ambient Monitoring**

It is always desirable to collect ambient air quality data on-site, particularly if air pollution sensitive resources have been documented in a park. However, the high cost of monitoring precludes the NPS from monitoring ambient air quality in every park. Ideally, off-site data can be used to indicate pollutant concentrations at a park, but even this is not always possible when monitors are too far from a park or located in a substantially different environment that that represented in the park. Several new monitoring sites have been established in the Northern Great Plains area in the past few years, but it is not clear this trend of establishing new sites will continue in the future.

If the Network decides that further ambient air monitoring is needed, coordination with the NPS's Air Resources Division is highly recommended to avoid duplicate efforts and to ensure data compatibility with existing monitoring networks. It's also possible that costs can be reduced by working with ARD or an established ARD contractor.

Given that the most likely locations for high ozone levels are also the least well monitored, one monitoring option which might benefit the Network would be a portable ozone monitor. These monitors are relatively low-cost (see attached monitoring cost table), require limited operator time, and can be relocated from park to park. These monitors are generally sited at a park for about 3 years to establish a baseline, then are relocated to another park. ARD currently operates several of these monitors which are periodically relocated at various NPS units. However, it's unlikely that ARD would place one of their monitors in an unmonitored Northern Great Plains park since ozone levels are likely relatively low compared to other parks nationally.

For parks with scenic vistas, but no visibility monitoring (or to supplement a current IMPROVE monitor) an option is monitoring visibility at scenic vistas with digital cameras. While this type of monitoring is not adequate for regulatory purposes, it is useful for documenting visibility conditions and trends. It also provides an excellent means of sharing that information with the public via a web-cam.

**Vegetation Monitoring Opportunities**

<u>Plant Sensitivity to N and S</u>

For a number of reasons, the majority of the air pollution sensitivity work for plants has focused on ozone. First, while ozone is a regional pollutant, gaseous sulfur dioxide and nitrogen oxides quickly undergo chemical changes after they are emitted. Therefore, sulfur dioxide and nitrogen oxide-induced foliar injury typically only occurs immediately downwind of a source. Second, past studies of those pollutants were conducted with unrealistic pollutant exposures, so potential effects at lower concentrations are not well-documented. Third, natural resource managers have found that it is more effective to monitor the effects of nitrogen and sulfur on visibility or surface water chemistry than it is to monitor the effects on plants. It is highly unlikely that sulfur dioxide or nitrogen oxide concentrations in Northern Great Plains Network parks would reach concentrations that would injure vegetation. Nevertheless, *Assessment of Air Quality and Air Pollutant Impacts in National Parks of the Rocky Mountains and Northern Great Plains*

(http://www2.nature.nps.gov/air/pubs) provides lists of sulfur dioxide and nitrogen oxide-sensitive plant species for Badlands, Theodore Roosevelt and Wind Cave NPs. These lists can be compared to species lists for the rest of the Network parks to identify potential biomonitors.

Nitrogen Deposition

Ambient monitoring indicates nitrogen deposition is currently relatively low in the Northern Great Plains area. However, the proposed expansion of coal bed methane development in Wyoming and Montana would result in a significant increase in nitrogen oxide emissions, which would more than likely translate into an increase in nitrogen deposition in Network parks. Grasslands are a habitat type that is sensitive to nitrogen deposition. Some grassland species respond more quickly to fertilization than others, resulting in a change in community composition. There is also evidence that nitrogen deposition can enhance the establishment and expansion of invasive exotic plants. Given proposed emission increases near Northern Great Plains Network parks, it would be wise to incorporate nitrogen deposition effects into the design of a long-term vegetation monitoring program. Network parks may also want to take a pro-active approach and conduct controlled nitrogen fertilization studies using a series of nitrogen inputs (e.g., 1.5X current deposition, 2X current deposition, etc.). Controlled studies would enable Network staff to identify impacts that could occur in the future and would provide an argument for controlling emissions before expansion is completed.

Ozone

The ozone risk assessments (Attachment 3) indicate that ozone levels in Network parks are probably too low to cause foliar injury. For many parks, the risk assessments are based on interpolated data from the Air Inventory project. Lack of on-site data for these parks does introduce a level of uncertainty into the equation. Attachment 3 includes lists of ozone-sensitive plant species which could be used in monitoring ozone. For example, all the Network parks have ponderosa pine, which is commonly used in ozone monitoring.

# Attachment 1
# Monitoring Expenses

NPS FY 2005 Estimated Air Quality Monitoring Program Expenses – Dec. 28, 2004

| NPS Air Quality Monitoring Program | Capital Cost of Equipment | Installation/Preparation/ Operator Training Cost | Operation Cost/Year |
|---|---|---|---|
| Visibility-<br>35mm Film Camera | No longer available | $3,500 | $ 6,000 |
| Visibility-<br>Digital Memory-Card Camera | $ 5,300 | $4,000 | $ 6,000 |
| Visibility-<br>Digital Web Camera | $ 8,000 | $4,500 | $ 4,800 |
| Visibility-<br>Remote Digital Web Camera | $ 9,750 | $4,100 | $ 4,800 |
| Visibility –Nephelometer | $28,000 | $4,000 | $30,000 |
| Visibility-Transmissometer | $41,000 | $8,000 | $30,000 |
| Visibility-IMPROVE (Particulates) | $18,000 | $5,000 | $32,500 |
| Gaseous- Ozone | $18,850 | $4,000 | $28,000 |
| Gaseous Portable Ozone (operated indoors) | $ 4,500 | $2,000 | $8,000 (6 months) |
| Gaseous Movable Ozone (all outdoor equipment) | $28,000 | $5,000 | $8,000 (6 months) |
| CASTNet Filter Pack Flow System | $ 9,600 | $4,000 | $10,000 |
| Meteorology –<br>CASTNet style<br>Non-CASTNet style | <br>$ 11,650<br>$ 6,800 | <br>$ 4,500<br>$ 4,000 | <br>$10,000<br>$ 9,000 |
| NADP/NTN-<br>Wet Deposition | $ 8,700 | $4,000 | $ 7,000 |
| NADP/MDN-<br>Mercury Deposition | $ 5,100 | $4,000 | $9,000 |
| Other Site Costs* | | $5,000 - $30,000 | |
| Shelter System-<br>Climate Controlled | $15,200 | $6,000 | $ 500 |
| Datalogger-<br>Gaseous (ESC 8816)<br>Visibility (CR23X) | <br>$ 7,100<br>$ 4,350 | <br>N/A<br>N/A | <br>N/A<br>N/A |
| DataView and Computer | $ 3,250 | $ 2,500 | $1,500 |
| Utilities- Lower 48 States<br>Power/Phone/Access | $ 3,000 | $6,000 | $ 2,000 |

* All air quality monitoring has a contractor and site installation cost. Utility costs vary per site.

Program Name Key:

IMPROVE = Interagency Monitoring of Protected Visual Environments
CASTNet = Clean Air Status and Trends Network (Dry Deposition Sampling)
NADP = National Atmospheric Deposition Program
NTN = National Trends Network (Wet Deposition Sampling)
MDN = Mercury Deposition Network

**Using this Table:**

- The costs listed on this table are for planning purposes only. Each monitoring program has its own set of requirements and a unique set of options. No two installations are alike. This table presents average costs of recent installations.

- The capital cost of equipment column includes some items that are not capital in nature such as filters, plumbing parts, cabling, etc. These are typically supplies purchased at the same time as the instrument.

- The cost estimates are based on the purchase and installation of an individual instrument by a NPS contractor. Because of this, the costs are not additive. In most cases, adding instruments to an installation will decrease the cost because travel, labor, shipping and other instrument support items can be shared.

- It is assumed that the park unit will provide an operator for weekly duties associated with each instrument.

- It is assumed that the installations have reasonable access to utilities. Special situations such as solar-powered installations, satellite communications, etc. would change costs.

**Assumptions:**

- **Visibility Camera Options – 35mm camera** support includes supply and shipment costs for film-based data collection three (3) times/day. **Digital memory card camera** support includes supply and shipment costs for memory card (flash card) data collection three (3) times/day. **Digital web camera** support includes real-time posting of images for the IMPROVE/NPS web site (www.aqd.nps.gov/ard/cams/), but no long-term data collection or archive support. All system options include routine servicing and technical support, via the phone and/or e-mail.

- **Nephelometer - Capital costs** include NGN-2, 14' tower, lightning protection, solar radiation shield, nephelometer hood, serial data logging and control subsystem, modem, span and zero calibration system, AT/RH sensor and shield. **Annual costs** include maintenance and calibration visits once per year. It is assumed that the site is included in the IMPROVE network to take advantage of spare instruments.
- **Transmissometer - Capital costs** include LPV-2 transmitter and receiver with telescope, environmental enclosures, mounting piers, AT/RH sensor and shield, datalogging system, modem, and other support systems. **Annual costs** include maintenance and calibration visits once per year. It is assumed that the site is included in the IMPROVE network to take advantage of spare instruments.

- **IMPROVE Particulate Sampler** – Assumes **ion analysis, carbon analysis, and particle analysis** performed at 3 separate laboratories, program coordination, and report preparation.

- **Ozone Monitoring:**
  **Conventional Sampler** - Includes an analyzer, in-station reference, and zero air supply. The **capital cost** also includes signal/control cabling, station temperature monitor, plumbing, and sample inlet parts. Sheltering and a data- logger are required, but are not included in the cost. **Installation/ Preparation costs** assume installation in an EKTO-type shelter. **Annual costs** are based upon one sampler and association with the NPS gaseous pollutant monitoring program.

  **"Portable" Ozone Sampler** – Assmes the basic 2B Technology analyzer that is operated indoors with a sampling tube transmitted to the outside air.

  **"Movable" Ozone Sampler** – Assumes an entire station consisting of a shelter, tripod, solar panels, datalogger, meteorology equipment and tower operating outdoors. This does not include satellite connections (Orbcomm) which vary depending upon site location.

- **CASTNet Filter Pack** – **Capital costs** include the filter pack, tipping tower, plumbing, and flow box with mass flow controller. **Annual operation costs** include nitrate, sulfate, nitric acid, ammonium and sulfur dioxide analysis, semi-annual calibration and maintenance, data collection and validation, data reporting, and uploading to a program database.

- **Meteorology Monitoring:**
  **CASTNet style - Capital costs** include sensors for measuring wind direction, wind speed, air temperature, temperature gradient, relative humidity, solar radiation, precipitation, leaf wetness, and barometric pressure. Lightning protection and surge protection are provided on a 10-meter gin pole hinged tower. **Annual cost** includes semi-annual maintenance and calibration, data collection and validation, and data reporting.

  **Non-CASTNet style - Capital costs** include sensors for measuring wind direction, wind speed, air temperature, relative humidity, solar radiation, and precipitation. Lightning protection and surge protection are provided on a 10-meter fixed tower. **Annual cost** includes semi-annual maintenance and calibration, data collection and validation, and data reporting.

- **NADP/NTN** - **Capital costs** include a sampler and battery, rain gauge, single-pen recorder, pH meter, conductivity meter, scale, lab ware, power system, and cabling. **Operational costs** include weekly sample collection, laboratory analysis, quality assurance, program coordination, data reporting, and storage into a program database.

- **NADP/MDN** – **Capital costs** include the sampler (converted NADP sampler) and a duel-pen recorder. **Operational costs** include weekly sample collection, laboratory analysis, quality assurance, program coordination, data reporting, and storage into a program database.

- **Shelter System** – **Capital costs** include an 8' x 14' self-supporting shelter, 100 amp service panel, overhead lighting, wall outlets, climate control systems, and instrument racks as appropriate.

- **Datalogger:**
  **Gaseous (ESC 8816) - Capital costs** include a datalogger with meteorological input card, 16 analog voltage inputs, 8 status outputs, LCD screen, keyboard, 2 RS232 ports, 1 parallel printer port, and a US Robotics modem. This system is used to support a gaseous monitoring station with gas analyzers, meteorological sensors, CASTNet flow, and other sensors. The datalogger is installed with the other instrumentation and is not costed separately.

  **Visibility CR23X - Capital costs** include a datalogger, modem, 2 storage modules, and power supply. This system is used for more stand-alone applications such as a visibility sensor or isolated meteorological tower. The datalogger is installed with the other instrumentation and is not costed separately.

- **DataView** – The DataView computer-based management system is used to support gaseous monitoring stations.

- **Utilities** – Installation of power and telephone are often required. The cost to prepare a site varies with the location and availability of service. This price is an average cost and can vary widely.

Dave Maxwell – NPS Air Resources Division, Denver, CO
Air Resource Specialists, Fort Collins, CO
12/28/04 – Rev.

# Attachment 2
# Nearest Monitors to Parks

# Nearest Monitoring Sites to NPS Units in the Northern Great Plains Network

| PARK | NADP/NTN | | CASTNet | | IMPROVE | | OZONE | |
|---|---|---|---|---|---|---|---|---|
| | LOCATION | SITE # | LOCATION | SITE # | LOCATION | SITE # | LOCATION | SITE # |
| **AGFO** | WICA<br>80 miles N | SD04 | WICA<br>80 miles N | WNC429 | WICA<br>80 miles N | WICA1 | BADL<br>125 miles N | 46-071-1001 |
| | | | | | Crescent Lakes NWR<br>Garden Co., NE<br>115 miles E | CRES1 | Rapid City, SD<br>115 miles NE | 46-103-0016 |
| **BADL** | Jackson Co., SD<br>30 miles ENE | SD08 | WICA<br>30 miles W | WNC429 | At park. | BADL1 | At park | 46-071-1001 |
| | WICA<br>30 miles W | SD04 | Centennial, Albany Co, WY<br>220 miles SW | CNT169 | | | | |
| **DETO** | near Newcastle, Weston Co., WY<br>55 miles SE | WY99 | WICA<br>100 miles SE | WNC429 | Thunder Basin NG<br>40 miles W | THBA1 | Thunder Basin NG<br>40 miles W | 56-005-0123 |
| | | | | | | | Near Gillette, WY<br>60 miles WSW | 56-005-0456 |
| **FOLA** | WICA<br>110 miles NE | SD04 | WICA<br>110 miles NE | WNC429 | near Centennial, WY<br>105 miles W | BRLA1 | Fort Collins, CO<br>115 miles S | 08-069-1004 |
| | Weld Co., CO<br>100 miles S | CO22 | | | Crescent Lakes NWR<br>Garden Co., NE<br>115 miles E | CRES1 | Near Gillette, WY<br>145 miles N | 56-005-0456 |
| | | | | | | | BADL | 46-071-1001 |

| PARK | NADP/NTN | | CASTNet | | IMPROVE | | OZONE | |
|---|---|---|---|---|---|---|---|---|
| | LOCATION | SITE # | LOCATION | SITE # | LOCATION | SITE # | LOCATION | SITE # |
| | | | | | | | 100 miles E | |
| **FOUS** | Roosevelt, Co., MT<br>50 miles NNW | MT96 | THRO<br>75 miles S | THR422 | Medicine Lake NWR<br>35 miles NNW | MELA1 | THRO (N. Unit)<br>50 miles SE | 38-053-0002 |
| | THRO<br>75 miles S | ND00 | | | | | | |
| **JECA** | WICA<br>25 miles ESE | SD04 | WICA<br>25 miles ESE | WNC429 | WICA<br>25 miles ESE | WICA1 | Rapid City, SD<br>40 miles NE | 46-103-0016 |
| | near Newcastle, Weston Co., WY<br>50 miles WNW | WY99 | | | | | Thunder Basin NG<br>90 miles NW | 56-005-0123 |
| | | | | | | | Gillette, WY<br>95 miles WNW | 56-005-0456 |
| | | | | | | | BADL<br>100 miles E | 46-071-1001 |
| **KNRI** | THRO S. Unit<br>100 miles WSW | ND00 | THRO<br>100 miles WSW | THR422 | THRO<br>100 miles WSW | THRO1 | Beulah, ND<br>20 miles WNW | 38-057-0004 |
| | Woodworth ND<br>90 miles ESE | ND11 | | | Lostwood NWR<br>105 miles NNE | LOST1 | | |
| **MNRR** | Huron SD<br>110 miles N | SD99 | Stockton, IL<br>350 miles E | STK138 | | | Sioux Falls, SD<br>60 miles N | 46-099-0007 |
| | Meade, NE<br>120 miles S | NE15 | | | | | Pisgah, IA<br>70 miles SE | 19-085-1101 |
| **MORU** | WICA<br>20 miles S | SD04 | WICA<br>20 miles S | WNC429 | WICA<br>20 miles S | WICA1 | Rapid City, SD<br>20 miles NNE | 46-103-0016 |
| | Newcastle WY<br>35 miles W | WY99 | | | | | BADL<br>75 miles E | 46-071-1001 |
| **NIOB** | Jackson Co., SD | SD08 | WICA | WNC429 | Fort Niobrara NWR | NIOB1 | BADL | 46-071-1001 |

| PARK | NADP/NTN | | CASTNet | | IMPROVE | | OZONE | |
|---|---|---|---|---|---|---|---|---|
| | **LOCATION** | **SITE #** | **LOCATION** | **SITE #** | **LOCATION** | **SITE #** | **LOCATION** | **SITE #** |
| | 110 miles NW | | 200 miles WNW | | | | 110 miles NW | |
| | N. Platte, NE<br>120 miles S | NE99 | | | | | | |
| **SCBL** | Pawnee NG, CO<br>85 miles SW | CO22 | Centennial, WY<br>130 miles WSW | CNT169 | Crescent Lks. NWR<br>Garden Co., NE<br>65 miles E | CRES1 | Fort Collins, CO<br>110 miles SW | 08-069-1004 |
| **THRO** | At park (S. Unit)<br>(ND07 at N. Unit<br>1981-2000) | ND00 | At park (S. Unit) | THR422 | At park (S. Unit) | THRO1 | At park N. Unit | 38-053-0002 |
| | | | | | | | At park S. Unit | 38-007-0002 |
| **WICA** | At park | SD04 | At park | WNC429 | At park | WICA1 | Rapid City, SD<br>35 miles NNE | 46-103-0016 |
| | | | | | | | BADL<br>75 miles ENE | 46-071-1001 |

NADP/NTN = National Atmospheric Deposition Program/National Trends Network (wet deposition)
CASTNet = Clean Air Status and Trends Network (dry deposition)
IMPROVE = Interagency Monitoring of Protected Visual Environments (visibility)
NG = National Grassland
NWR= National Wildlife Refuge

# Attachment 3
# Ozone Assessments
(Prepared through Air Resources Division Contract)

# AGATE FOSSIL BEDS NATIONAL MONUMENT (AGFO)

## Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

## Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for AGFO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 13 | 19 | 14 | 21 | 14 |
| W126 | 18.9 | 25.8 | 20.9 | 34.2 | 24.4 |
| N60 | 266 | 454 | 309 | 605 | 391 |
| N80 | 19 | 21 | 13 | 53 | 20 |
| N100 | 1 | 1 | 0 | 7 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at AGFO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 4.89 | 1.94 | -1.08 | 5.59 | -1.85 |
| Month 2 | 5.49 | 1.58 | 2.62 | 5.27 | -1.01 |
| Month 3 | 1.74 | 0.04 | 0.59 | 4.13 | -1.68 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at AGFO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.59 | 0.38 | -0.30 | 1.45 | 0.21 |
| May | 6.18 | 2.34 | -1.08 | 5.59 | -1.85 |
| June | 4.89 | 1.94 | 2.62 | 5.27 | -1.01 |
| July | 5.49 | 1.58 | 0.59 | 4.13 | -1.68 |
| August | 1.74 | 0.04 | -0.60 | 0.14 | 0.24 |
| September | -0.72 | -0.64 | -0.07 | 6.51 | -1.44 |
| October | -1.74 | -0.29 | -1.10 | 0.66 | -1.32 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The similar levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between the levels of ozone and soil moisture. Three months of mild drought occurred in one year, and three years had favorable soil moisture. With this incidence and pattern of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and the Sum06 index of exposure. There appears to be no relationship between the seasonal W126 index of exposure and soil moisture conditions. The highest ozone year, 1998, had favorable soil moisture, while the lowest exposure year, 1995, had one month of

mild drought. A middle ozone year had five months of mild drought. There is no relationship between ozone and soil moisture in this pattern of drought.

The risk of foliar ozone injury at Agate Fossil Beds National Monument is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are unrelated to the level of exposure and conditions in most years favor the uptake of ozone.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

# BADLANDS NATIONAL PARK
# (BADL)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for BADL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 2 | 6 | 6 | 8 | 6 |
| W126 | 18.4 | 24.8 | 15.2 | 30.3 | 28.2 |
| N60 | 170 | 340 | 185 | 512 | 420 |
| N80 | 3 | 5 | 1 | 4 | 5 |
| N100 | 0 | 0 | 0 | 0 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at BADL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 3.16 | -0.59 | -2.19 | -1.32 | 0.95 |
| Month 2 | -1.68 | 3.49 | -1.92 | -0.85 | 6.46 |
| Month 3 | 7.19 | -1.42 | 2.27 | -1.33 | 0.67 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at BADL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.87 | -0.09 | 2.62 | -1.48 | 0.95 |
| May | 3.16 | 0.09 | -2.19 | -1.32 | 6.46 |
| June | -1.68 | -0.59 | -1.92 | -0.85 | 0.67 |
| July | 7.19 | 3.49 | 2.27 | -1.33 | 1.54 |
| August | 0.31 | -1.42 | -0.69 | 1.38 | 6.87 |
| September | -0.85 | 0.67 | 0.61 | -2.52 | 2.21 |
| October | 2.04 | 0.22 | 1.10 | 4.86 | -0.86 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between 90-day Sum06 accumulation period indices of ozone and soil moisture. This is largely a consequence of the low and consistent levels of exposure of the five-year period. Three years, 1996, 1997 and 1999, had the same index of exposure and experienced one, two and no months of drought, respectively. Similarly, there does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. In 1998 when ozone exposure was highest, there were four months of mild and moderate drought, while in 1999 when the index was slightly lower there were

favorable soil moisture conditions throughout. There were two months of mild and severe drought in the year with the lowest exposure, 1997. Collectively, there is no relationship between the W126 index of exposure and soil moisture.

The risk of foliar ozone injury at Badlands National Park is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are rare exposures to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or common snowberry.

# DEVILS TOWER NATIONAL MONUMENT
# (DETO)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for DETO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 3 | 6 | 6 | 6 | 7 |
| W126 | 15.5 | 20.1 | 19.5 | 29.9 | 19.4 |
| N60 | 167 | 295 | 248 | 485 | 256 |
| N80 | 10 | 7 | 6 | 25 | 4 |
| N100 | 0 | 0 | 0 | 2 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at DETO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 1.50 | -2.47 | 3.57 | -1.49 | 0.88 |
| Month 2 | 6.04 | -0.37 | 0.09 | -2.74 | 4.13 |
| Month 3 | 1.59 | 1.48 | -1.40 | 2.33 | -0.21 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at DETO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.50 | 1.06 | 3.57 | -1.49 | 4.13 |
| May | 6.04 | 3.38 | 0.09 | -2.74 | -0.21 |
| June | 1.59 | -2.47 | -1.40 | 2.33 | 3.31 |
| July | 3.60 | -0.37 | 4.26 | 1.15 | 2.60 |
| August | 2.36 | 1.48 | 0.17 | 2.14 | 2.74 |
| September | 0.07 | -0.46 | -0.60 | 0.85 | 0.69 |
| October | 5.40 | 2.52 | 0.05 | 9.06 | -1.72 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between 90-day Sum06 accumulation period indices of ozone and soil moisture. This is largely a consequence of the low and consistent levels of exposure of the five-year period. Both the highest and lowest ozone years, 1999 and 1995, had consistently normal soil moisture conditions. The three mid-ozone years, 1996, 1997 and 1998, had the same index of exposure and experienced one, one, and two months of drought, respectively. Similarly, there does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. Only five months of drought

occurred over the five –year period. Two months of drought were in the highest ozone year 1998, and there were favorable conditions in the lowest year 1995. However, one month of drought occurred in each of the intermediate ozone years. While suggestive of an inverse relationship between exposure and drought, the few months of drought and rather uniform distribution preclude such a conclusion at this time.

The risk of foliar ozone injury at Devils Tower National Monument is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are few exposures to concentrations of ozone greater than 80 ppb, and exposure to 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and skunkbush.

# FORT LARAMIE NATIONAL HISTORIC SITE (FOLA)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for FOLA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 12 | 19 | 14 | 21 | 15 |
| W126 | 20.0 | 27.8 | 22.2 | 35.4 | 25.8 |
| N60 | 276 | 496 | 323 | 632 | 414 |
| N80 | 18 | 19 | 12 | 49 | 18 |
| N100 | 1 | 1 | 0 | 6 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at FOLA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.21 | -1.35 | 0.96 | -0.94 | -1.95 |
| Month 2 | 7.25 | 0.03 | 1.17 | 0.46 | 4.11 |
| Month 3 | 6.41 | 0.68 | 0.48 | 1.51 | 0.31 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at FOLA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.21 | -0.21 | 0.96 | -0.70 | 4.11 |
| May | 7.25 | 2.05 | 1.17 | -0.94 | 0.31 |
| June | 6.41 | -1.35 | 0.48 | 0.46 | 1.58 |
| July | 2.39 | 0.03 | 2.42 | 1.51 | 0.81 |
| August | 0.86 | 0.68 | 5.46 | 1.41 | 0.63 |
| September | 4.16 | 0.44 | 1.20 | -1.30 | 3.32 |
| October | 1.65 | 0.72 | 2.30 | 6.70 | -1.53 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than six hours in which the concentration exceeded 100 ppb, and most had only one hour. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The risk of foliar ozone injury at Fort Laramie National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are occasional exposures to concentrations

of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are generally favorable for the uptake of ozone, although isolated months of mild drought can occur.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.

# FORT UNION TRADING POST NATIONAL HISTORIC SITE (FOUS)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Robinia pseudoacacia | Black locust | Fabaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for FOUS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 1 | 1 | 5 | 1 | 1 |
| W126 | 9.2 | 12.3 | 13.3 | 8.8 | 9.2 |
| N60 | 32 | 61 | 139 | 147 | 54 |
| N80 | 1 | 0 | 4 | 1 | 0 |
| N100 | 0 | 0 | 0 | 0 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at FOUS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.92 | -0.19 | 1.98 | -2.54 | -0.08 |
| Month 2 | 3.21 | 0.98 | -1.78 | -1.85 | 6.77 |
| Month 3 | -2.09 | -0.73 | -2.39 | 1.16 | 0.47 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at FOUS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.92 | 0.04 | 1.98 | -2.54 | -0.08 |
| May | 3.21 | 1.12 | -1.78 | -1.85 | 6.77 |
| June | -2.09 | -0.19 | -2.39 | 1.16 | 0.47 |
| July | 5.28 | 0.98 | 3.99 | -1.20 | 0.62 |
| August | 2.25 | -0.73 | -1.37 | -0.15 | 4.58 |
| September | -0.52 | 1.46 | -2.35 | -2.18 | 1.87 |
| October | 0.06 | 0.04 | -0.35 | 5.76 | -0.90 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, however none of them are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations rarely exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years, and no relationships are apparent. There also does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. In both 1998, when ozone exposure was highest, and 1997, when it was lowest, there were four months of mild and moderate drought. Relationships are also difficult to assess because the W126 indices of exposure over the five years were low and relatively similar.

The risk of foliar ozone injury at Fort Union Trading Post National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are rare exposures to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

There are no bioindicators for ozone at the site.

# JEWEL CAVE NATIONAL MONUMENT
# (JECA)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Asclepias exaltata | Tall milkweed | Asclepiadaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for JECA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 8 | 13 | 10 | 14 | 10 |
| W126 | 17.8 | 24.2 | 20.8 | 32.2 | 21.5 |
| N60 | 226 | 404 | 295 | 560 | 318 |
| N80 | 15 | 17 | 11 | 43 | 13 |
| N100 | 0 | 1 | 0 | 5 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at JECA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 6.17 | -1.99 | 1.66 | -0.81 | 2.81 |
| Month 2 | 2.72 | 0.07 | -0.92 | 4.14 | -0.54 |
| Month 3 | 2.63 | 3.99 | 5.81 | 2.45 | 3.50 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at JECA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.63 | 0.76 | 2.70 | -1.45 | 2.81 |
| May | 6.17 | 3.79 | 1.66 | -0.81 | -0.54 |
| June | 2.72 | -1.99 | -0.92 | 4.14 | 3.50 |
| July | 2.63 | 0.07 | 5.81 | 2.45 | 0.32 |
| August | 0.03 | 3.99 | 2.58 | 4.47 | 3.67 |
| September | 0.67 | 1.88 | 1.03 | 2.09 | 0.46 |
| October | 4.16 | 6.49 | 0.69 | 8.42 | -1.44 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Jewel Cave National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposures above 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

# KNIFE RIVER INDIAN VILLAGE NATIONAL HISTORIC SITE (KNRI)

## Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |

## Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for KNRI | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 1 | 1 | 3 | 2 | 2 |
| W126 | 6.3 | 7.1 | 9.0 | 10.4 | 6.5 |
| N60 | 15 | 22 | 86 | 82 | 41 |
| N80 | 0 | 0 | 0 | 0 | 1 |
| N100 | 0 | 0 | 0 | 0 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at KNRI | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.92 | -0.19 | 1.98 | -0.95 | -0.16 |
| Month 2 | 3.21 | 0.98 | -1.78 | -2.54 | -0.08 |
| Month 3 | -2.09 | -0.73 | -2.39 | -1.85 | 6.77 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at KNRI | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.92 | 0.04 | 1.98 | -2.54 | -0.08 |
| May | 3.21 | 1.12 | -1.78 | -1.85 | 6.77 |
| June | -2.09 | -0.19 | -2.39 | 1.16 | 0.47 |
| July | 5.28 | 0.98 | 3.99 | -1.20 | 0.62 |
| August | 2.25 | -0.73 | -1.37 | -0.15 | 4.58 |
| September | -0.52 | 1.46 | -2.35 | -2.18 | 1.87 |
| October | 0.06 | 0.04 | -0.35 | 5.76 | -0.90 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only one hour in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods preclude assessing relationships between the levels of ozone and soil moisture. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The highest ozone years, 1998 and 1997, each experienced four

months of mild and moderate drought. The three years with lower levels of ozone exposure experienced favorable soil moisture conditions with only one month of drought among them.

The risk of foliar ozone injury at Knife River Indian Village National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there was only one hour of exposure to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, and quaking aspen.

# MISSOURI NATIONAL RECREATION RIVER (MNRR)

## Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Sambucus canadensis | American elder | Caprifoliaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

## Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for MNRR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 2 | 1 | 4 | 3 | 5 |
| W126 | 10.4 | 6.5 | 9.7 | 9.7 | 10.3 |
| N60 | 149 | 69 | 136 | 133 | 137 |
| N80 | 19 | 6 | 6 | 10 | 8 |
| N100 | 2 | 0 | 0 | 1 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at MNRR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 4.84 | -0.28 | 1.22 | 3.14 | 4.46 |
| Month 2 | -1.96 | -1.13 | -0.94 | -1.50 | 0.29 |
| Month 3 | -1.14 | 3.33 | -0.69 | 3.45 | 4.93 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at MNRR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 3.32 | -1.13 | 1.75 | 3.14 | 4.46 |
| May | 4.84 | 3.33 | 1.22 | -1.50 | 0.29 |
| June | -1.96 | -0.75 | -0.94 | 3.45 | 4.93 |
| July | -1.14 | 1.47 | -0.69 | 1.81 | 2.36 |
| August | 2.70 | 2.57 | -0.85 | 3.32 | 0.15 |
| September | 2.45 | 2.17 | 0.87 | -2.45 | -1.87 |
| October | 2.92 | -0.47 | 1.41 | 3.82 | -1.78 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Exposure indices were similar over the five-year period. The two highest exposure years, 1999 and 1997, had favorable soil moisture throughout, while the remaining three years each experienced one or two months of drought. Collectively, there is no relationship between the levels of ozone and soil moisture conditions. The seasonal W126 exposure indices were similar over the five-year period making it difficult to assess relationships between ozone exposure and soil moisture. However, soil moisture levels appear to be inversely related to ozone concentrations: when

ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. Years with the highest and second highest exposure indices, 1995 and 1999, each experienced two months of mild drought. Years with two slightly lower levels of exposure had either favorable conditions or two months of drought, while the lowest exposure year, 1996, had one month of mild drought.

The low levels of ozone exposure at Missouri National Recreation River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare. The apparent inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone and further reduces the likelihood that the exposures will produce foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

# MOUNT RUSHMORE NATIONAL MEMORIAL (MORU)

## Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

## Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for MORU | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 7 | 11 | 8 | 11 | 8 |
| W126 | 17.0 | 22.9 | 20.1 | 30.6 | 19.8 |
| N60 | 210 | 374 | 282 | 526 | 285 |
| N80 | 14 | 16 | 11 | 40 | 11 |
| N100 | 0 | 1 | 0 | 4 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at MORU | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 6.17 | -1.99 | 1.66 | -0.81 | 2.81 |
| Month 2 | 2.72 | 0.07 | -0.92 | 4.14 | -0.54 |
| Month 3 | 2.63 | 3.99 | 5.81 | 2.45 | 3.50 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at MORU | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.63 | 0.76 | 2.70 | -1.45 | 2.81 |
| May | 6.17 | 3.79 | 1.66 | -0.81 | -0.54 |
| June | 2.72 | -1.99 | -0.92 | 4.14 | 3.50 |
| July | 2.63 | 0.07 | 5.81 | 2.45 | 0.32 |
| August | 0.03 | 3.99 | 2.58 | 4.47 | 3.67 |
| September | 0.67 | 1.88 | 1.03 | 2.09 | 0.46 |
| October | 4.16 | 6.49 | 0.69 | 8.42 | -1.44 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation, but some levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb while the others had one or none. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Mount Rushmore National Memorial make the risk of foliar ozone injury to plants low. While the Sum06 exposures marginally exceed the threshold levels for injury, the W126 do not

since the N100 criterion is not satisfied.  There are only a few hours with concentrations of ozone above 80 ppb, and no year has more than four hours greater than 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

# NIOBRARA NATIONAL SCENIC RIVER
# (NIOB)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Sambucus canadensis | American elder | Caprifoliaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for NIOB | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 2 | 1 | 4 | 3 | 5 |
| W126 | 10.4 | 6.5 | 9.7 | 9.7 | 10.3 |
| N60 | 149 | 69 | 136 | 133 | 137 |
| N80 | 19 | 6 | 6 | 10 | 8 |
| N100 | 2 | 0 | 0 | 1 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at NIOB | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 7.22 | -0.37 | 0.22 | 0.65 | 4.09 |
| Month 2 | 0.20 | -0.45 | -0.77 | 0.26 | 0.51 |
| Month 3 | 0.31 | 4.42 | 2.54 | 4.63 | 3.22 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at NIOB | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 5.00 | -0.45 | 2.53 | 0.65 | 4.09 |
| May | 7.22 | 4.42 | 0.22 | 0.26 | 0.51 |
| June | 0.20 | -1.28 | -0.77 | 4.63 | 3.22 |
| July | 0.31 | 0.17 | 2.54 | 2.50 | 1.45 |
| August | -0.23 | 1.58 | 1.13 | 1.75 | -0.86 |
| September | 3.17 | 5.40 | 1.46 | -1.16 | 1.50 |
| October | 4.41 | 0.72 | 3.84 | 5.12 | -1.79 |

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. There were no months of drought stress in the five-year assessment period. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years and there were only three months of drought stress. There does not appear to be any association between the W126 levels of ozone and drought.

The low levels of ozone exposure at Niobrara National Scenic River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

# SCOTTS BLUFF NATIONAL MONUMENT
# (SCBL)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |
| Robinia pseudoacacia | Black locust | Fabaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for SCBL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 13 | 18 | 13 | 20 | 14 |
| W126 | 18.2 | 24.7 | 20.1 | 33.2 | 23.7 |
| N60 | 259 | 431 | 300 | 585 | 380 |
| N80 | 19 | 21 | 13 | 54 | 20 |
| N100 | 1 | 1 | 0 | 7 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at SCBL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.56 | -1.69 | 0.85 | -1.67 | -1.79 |
| Month 2 | 5.38 | 0.56 | 1.61 | 0.47 | 4.74 |
| Month 3 | 4.76 | 4.46 | 0.78 | 2.20 | -0.17 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at SCBL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.56 | -0.83 | 0.85 | -1.62 | 4.74 |
| May | 5.38 | 2.94 | 1.61 | -1.67 | -0.17 |
| June | 4.76 | -1.69 | 0.78 | 0.47 | 2.73 |
| July | 2.56 | 0.56 | 1.75 | 2.20 | 2.03 |
| August | 1.61 | 4.46 | 1.67 | 0.58 | 2.16 |
| September | 1.03 | 3.76 | -0.40 | -1.58 | 4.01 |
| October | 2.89 | 0.81 | 2.96 | 6.50 | -1.56 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had seven hours in which the concentration exceeded 100 ppb, but in most years there was one hour. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar and there were only three months of mild drought over the five-year period. Although there were only five months of mild drought during the seasonal W126 assessment period, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone year, 1998, there were three months of drought,

and one month in each of the two next highest ozone years, 1996 and 1999. Soil moisture was favorable throughout the two lowest ozone years.

The low levels of ozone exposure at Scotts Bluff National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare. In addition, mild drought in the higher exposure years constrains the uptake of ozone and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, ponderosa pine, skunkbush, and common snowberry.

# THEODORE ROOSEVELT NATIONAL PARK (THRO)

## Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

## Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

## Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for THRO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 1 | 2 | 10 | 1 | - |
| W126 | 7.7 | 8.5 | 14.6 | - | 9.7 |
| N60 | 19 | 30 | 178 | - | 25 |
| N80 | 0 | 0 | 8 | - | 0 |
| N100 | 0 | 0 | 0 | - | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at THRO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.77 | -1.69 | 4.10 | -2.19 | -0.98 |
| Month 2 | 5.04 | 0.37 | -1.36 | -2.11 | 0.08 |
| Month 3 | -1.74 | -0.99 | -1.85 | 2.59 | 3.36 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at THRO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.77 | -0.57 | 4.10 | -2.19 | 0.45 |
| May | 5.04 | 2.69 | -1.36 | -2.11 | 3.27 |
| June | -1.74 | -1.69 | -1.85 | 2.59 | -0.98 |
| July | 4.47 | 0.37 | 4.94 | -1.29 | 0.08 |
| August | 4.32 | -0.99 | 0.17 | 2.01 | 3.36 |
| September | -1.19 | 2.89 | -2.10 | -0.86 | 1.97 |
| October | 0.40 | -0.28 | -0.36 | 7.46 | -0.88 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone and one year of missing data make it difficult to assess relationships between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Each year had one or two months of mild to moderate drought, and no relationships between ozone and soil moisture are evident. Although the seasonal W126 index of exposure shows greater range of values, one year of missing data makes it difficult to accurately assess relationships. Although the exposure index in 1997 was considerably greater than the other indices, the year experienced three months of mild and moderate drought, while the year with the lowest index, 1995, had two months of mild drought. The two intermediate years had favorable conditions and one month of mild drought. Overall, there did not appear to be any clear relationship between ozone and soil moisture conditions.

The low levels of ozone exposure at Theodore Roosevelt National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, and in only one year did concentrations of ozone exceed 80 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar

ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

# WIND CAVE NATIONAL PARK
# (WICA)

**Plant Species Sensitive to Ozone**

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Apocynum androsaemifolium | Spreading dogbane | Apocynaceae |
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Parthenocissus quinquefolia | Virginia creeper | Vitaceae |
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Populus tremuloides | Quaking aspen | Salicaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |
| Symphoricarpos albus | Common snowberry | Caprifoliaceae |

**Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

**Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure

values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for WICA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 9 | 14 | 10 | 15 | 10 |
| W126 | 17.8 | 24.2 | 20.6 | 32.1 | 21.6 |
| N60 | 231 | 408 | 295 | 560 | 324 |
| N80 | 16 | 17 | 11 | 45 | 14 |
| N100 | 0 | 1 | 0 | 5 | 1 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at WICA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 6.17 | -1.99 | 1.66 | -0.81 | 2.81 |
| Month 2 | 2.72 | 0.07 | -0.92 | 4.14 | -0.54 |
| Month 3 | 2.63 | 3.99 | 5.81 | 2.45 | 3.50 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at WICA | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.63 | 0.76 | 2.70 | -1.45 | 2.81 |
| May | 6.17 | 3.79 | 1.66 | -0.81 | -0.54 |
| June | 2.72 | -1.99 | -0.92 | 4.14 | 3.50 |
| July | 2.63 | 0.07 | 5.81 | 2.45 | 0.32 |
| August | 0.03 | 3.99 | 2.58 | 4.47 | 3.67 |
| September | 0.67 | 1.88 | 1.03 | 2.09 | 0.46 |
| October | 4.16 | 6.49 | 0.69 | 8.42 | -1.44 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb, and two years had no hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Wind Cave National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

# Attachment 3
# Air Inventory/Air Atlas
(Prepared through Air Resources Division Contract)

# AirAtlas Summary Tables for I&M Parks

The Air Atlas is a mini-GIS tool available on the Internet that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. Air Atlas was produced by the National Park Service Air Resources Division (ARD) in association with the University of Denver. Air Atlas will serve as the Air Inventory for the parks and is available on the Internet at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm

The estimated air quality values provided in the look-up table are based on the center of the polygon defining the park or multiple units of the park. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations throughout the park. Greater variability may exist for other parameters, such as deposition and visibility. In the future, the full Air Atlas dataset will be available on the internet, and users of ArcView and ArcGIS will be able to obtain air quality values for multiple points in a park by entering the latitude and longitude coordinates.

Air Atlas contains a comprehensive set of air quality parameters for all I&M parks. In addition, ARD has prepared a summary table that includes a select group of air quality parameters for each I&M network. The summary version is intended to provide parks with a synopsis useful for characterizing air quality conditions. Air quality parameters selected for the summary version are described below.

**Ozone Parameters**

Ozone can be expressed as concentration or cumulative dose. Relevant concentration and dose parameters include:

2nd Hi 1-hr: expressed in parts per billion (ppb), this value is the 2nd highest hourly value in a year and can be compared to the former Environmental Protection Agency (EPA) human health-based standard for ozone of 125 ppb (0.12 ppm).

4th Hi 8-hr: expressed in parts per billion (ppb), this value is the average hourly value in the 4th highest 8 hour period and can be compared to the present EPA human health-based standard for ozone of 85 ppb (0.08 ppm).

# 8 hrs > 85 ppb: indicates how often the site would exceed the present ozone standard.

# 1 hr > 100 ppb: indicates how often the site experiences high ozone concentrations; high concentrations contribute to vegetation (foliar) injury in sensitive plant species.

SUM06_3Mo: The running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 ppm; represents cumulative exposure dose of ozone to plants.

Ozone is one of the most widespread air pollutants. Ozone is not emitted directly from smokestacks or vehicles, but is formed when other pollutants, primarily nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight, usually during the warm summer months. In addition to harming human health, ozone is phytotoxic, and causes considerable damage to vegetation throughout the world, including agricultural crops and native plants in natural ecosystems. The Environmental Protection Agency has established an ozone standard to protect human health; however, EPA has not set a standard to protect vegetation and there is much evidence to suggest that the human health-based standard is not protective of sensitive vegetation.

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone injury can be induced by a sufficiently high seasonal dose of ozone (expressed as SUM06, in ppm-hrs), high peak concentrations of ozone (expressed in ppb), or a combination of both. Ozone effects to natural vegetation have been documented throughout the country, particularly in many areas of the East and in California. For sensitive natural vegetation in the East, researchers have recommended SUM06 effects endpoints of 8-12 ppm-hrs for foliar injury and 10-15 ppm-hrs for growth effects on tree seedlings in natural forest stands. In the West (Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs), researchers have found that foliar injury on ponderosa and Jeffrey pines ranges from about 15-50 percent at ozone values between 25-30 ppm-hrs. Sites with values above these endpoints may be at risk for vegetation injury if sensitive species are present. However, to adequately assess risk, other factors, including temperature and soil moisture, must be considered. In conditions of low moisture, for example, stomates may close, preventing ozone uptake. Ozone peak concentrations exceeding 100 ppb are also considered to be important in inducing injury and the number of hours in a year above 100 ppb may be significant for evaluating risk.

**Atmospheric Deposition Parameters**

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. (at over 200 sites), as part of the National Atmospheric Deposition Program (NADP). Dry deposition is monitored at about 70 sites as part of the Clean Air Status and Trends Network (CASTNet). Clouds and fog may contribute significantly to total deposition at certain locations (e.g., high

elevation areas and areas that experience a high frequency of clouds and fog), but monitoring cloud and fog deposition is difficult and is done at only a couple of locations in the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Deposition can be expressed as concentration (e.g., micrograms per cubic meter or milligrams per liter) or deposition rates (e.g., kilograms per hectare per year – kg/ha/yr). Deposition rates are included in Air Atlas summaries, as these rates best characterize the amount of deposition an ecosystem experiences.

NADP dep (kg/ha/yr): pollutant ions in wet deposition from rain or snow are measured by the National Atmospheric Deposition Program (NADP) and expressed as kg/ha/yr. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

NADP Total S (kg/ha/yr): total sulfur from sulfate ions in wet deposition.

NADP Total N (kg/ha/yr): total inorganic nitrogen from ammonium and nitrate ions in wet deposition.

Atmospheric deposition affects ecosystems in a variety of ways, including acidification, fertilization or eutrophication, and accumulation of toxics. Acid deposition from sulfur and nitrogen compounds affects freshwater lakes, streams, and watersheds. Acid deposition effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. Deposition can also cause changes in soil that affect soil microorganisms, understory plants, and trees. Excess nitrogen deposition can cause unwanted fertilization effects, leading to changes in plant community structure and diversity. In estuaries and coastal waters, nitrogen can cause algae blooms, decreases in dissolved oxygen, and loss of seagrasses (i.e., eutrophication).

All areas of the country are experiencing levels of atmospheric deposition above natural levels. The ability of ecosystems to deal with increased levels of deposition varies widely. High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition. Other sensitive areas include the upper Midwest, New England, and Florida, including the shallow bays and estuaries along the Atlantic and Gulf Coasts. Streams in both Shenandoah and Great Smoky Mountains NPs are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain NP is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition. In some areas, excess nitrogen deposition has caused shifts in plant species composition, with native species being replaced by invasive and exotic species that are better able to utilize nitrogen.

**Visibility Parameters**

A number of visibility indices, or measurements, can be used to express visibility conditions. The measurement used in Air Atlas summaries is light extinction.

bextClear: annual average light extinction, expressed in inverse megameters, on the 20 percent clearest days

bextHazy: annual average light extinction, expressed in inverse megameters, on the 20 percent haziest days

Light extinction, expressed in the form of inverse megameters ($Mm^{-1}$), is proportional to the amount of light lost because of scattering or absorption by particles in the air as the light travels over a million meters (one million meters = one megameter). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase.

Extinction can be measured directly, with a transmissometer and nephelometer, or it can be calculated from representative aerosol measurements. Air Atlas extinction estimates, so-called "reconstructed" estimates, are calculated from aerosol measurements. Total extinction is the sum of the individual extinctions caused by gases, particles, and air molecules in the atmosphere. Relative humidity, as well as particle concentrations, is considered in the equation, as relative humidity increases the extinction efficiency of certain particles.

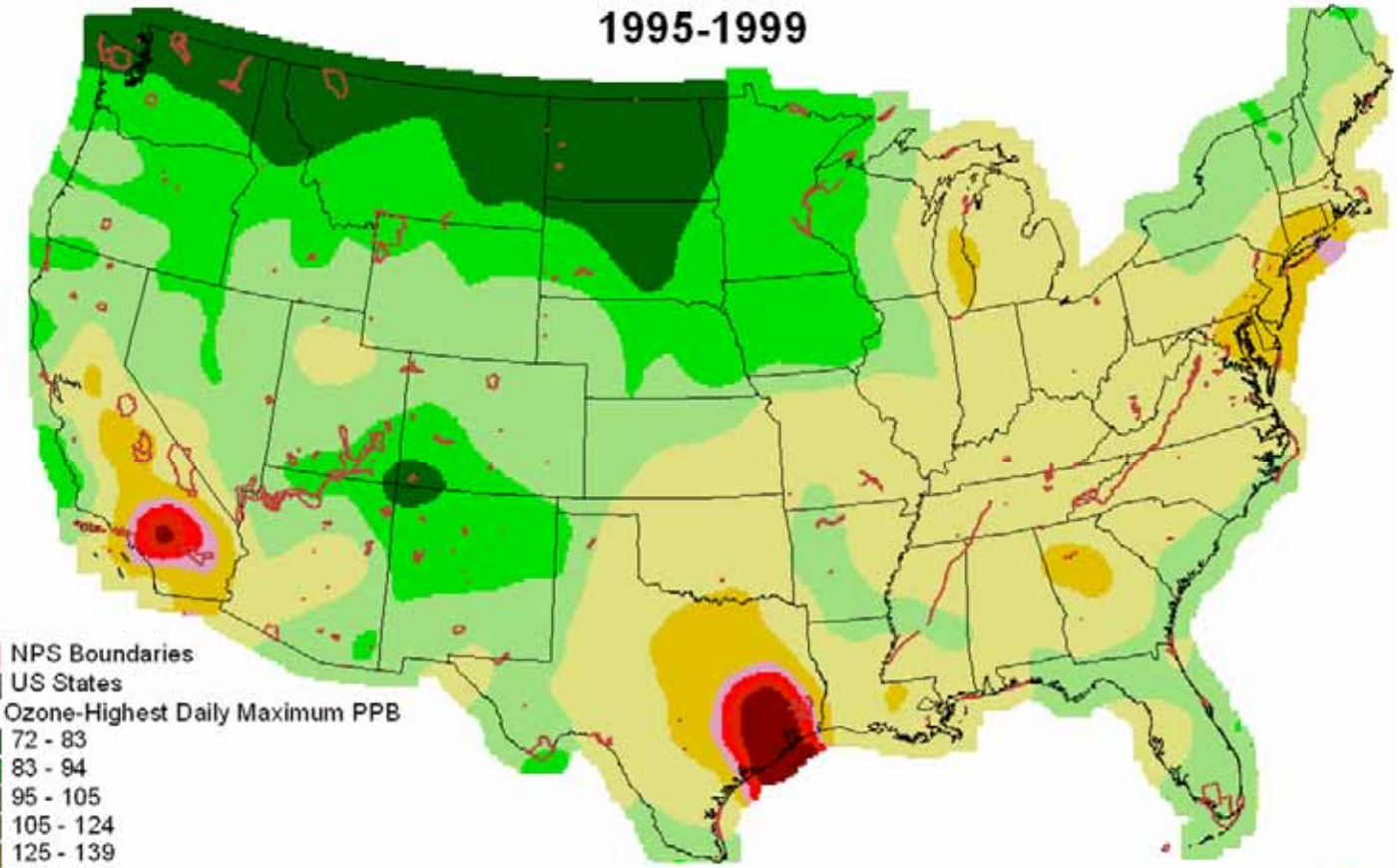
Light extinction is averaged for the 20 percent clearest and the 20 percent haziest days in an area. The Environmental Protection Agency's 1999 Regional Haze Regulations require that reasonable progress be made to restore visibility to natural background conditions within 60 years. States are to establish goals for each Class I area to improve visibility on the haziest days (defined as the 20 percent haziest day) and ensure no degradation occurs on the clearest days (defined as the 20 percent clearest days). Emissions reductions that benefit visibility in Class I areas are also expected to benefit visibility in all other areas.

Visual range (VR) is another index used to describe visibility. Because VR is not particularly useful for assessing the quality of scenic vistas (clarity, color), light extinction is used in Air Atlas. However, VR is sometimes useful for describing visibility to the general public. VR is expressed as length; extinction is expressed as 1/length. The relationship between VR and extinction is:

$$VR = \frac{3.912}{bext(km^{-1})} = \frac{3912}{bext(Mm^{-1})}$$

# OZONE - HIGHEST DAILY MAXIMUM PPB

## 1995-1999

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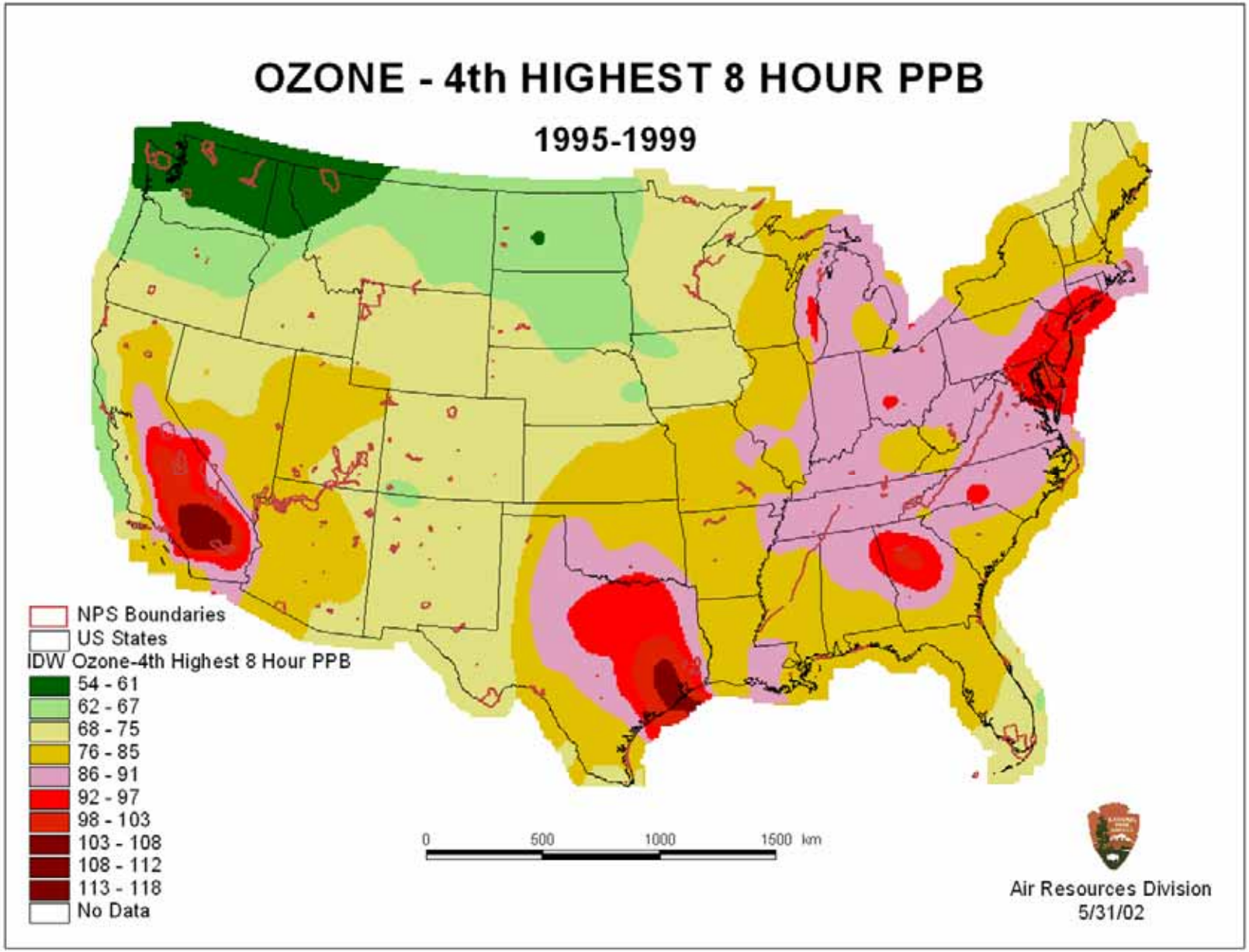
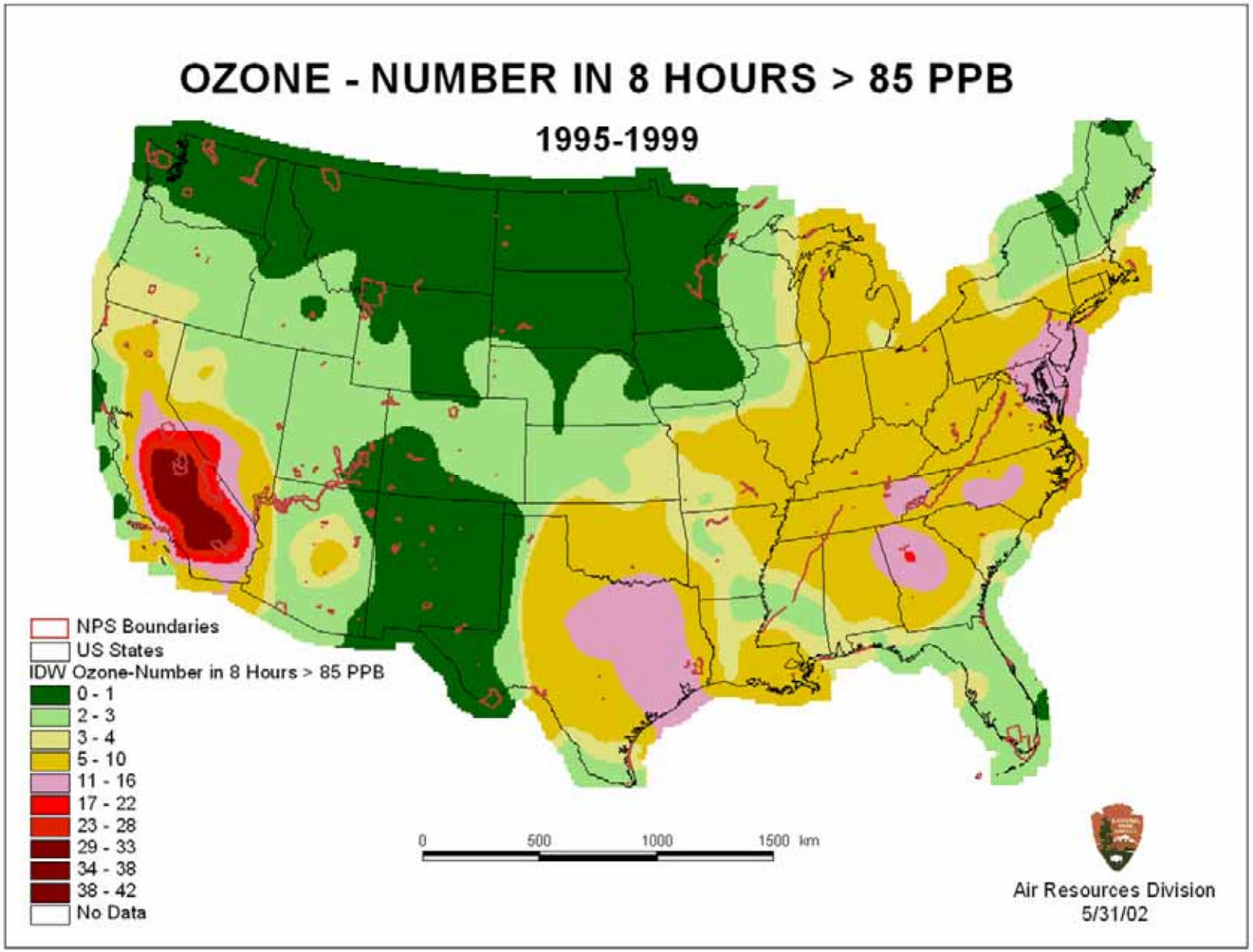
5/31/02


OZONE - 4th HIGHEST 8 HOUR PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-4th Highest 8 Hour PPB
54 - 61
62 - 67
68 - 75
76 - 85
86 - 91
92 - 97
98 - 103
103 - 108
108 - 112
113 - 118
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02


OZONE - NUMBER IN 8 HOURS > 85 PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-Number in 8 Hours > 85 PPB
0 - 1
2 - 3
3 - 4
5 - 10
11 - 16
17 - 22
23 - 28
29 - 33
34 - 38
38 - 42
No Data
0
500
1000
1500 km
Air Resources Division
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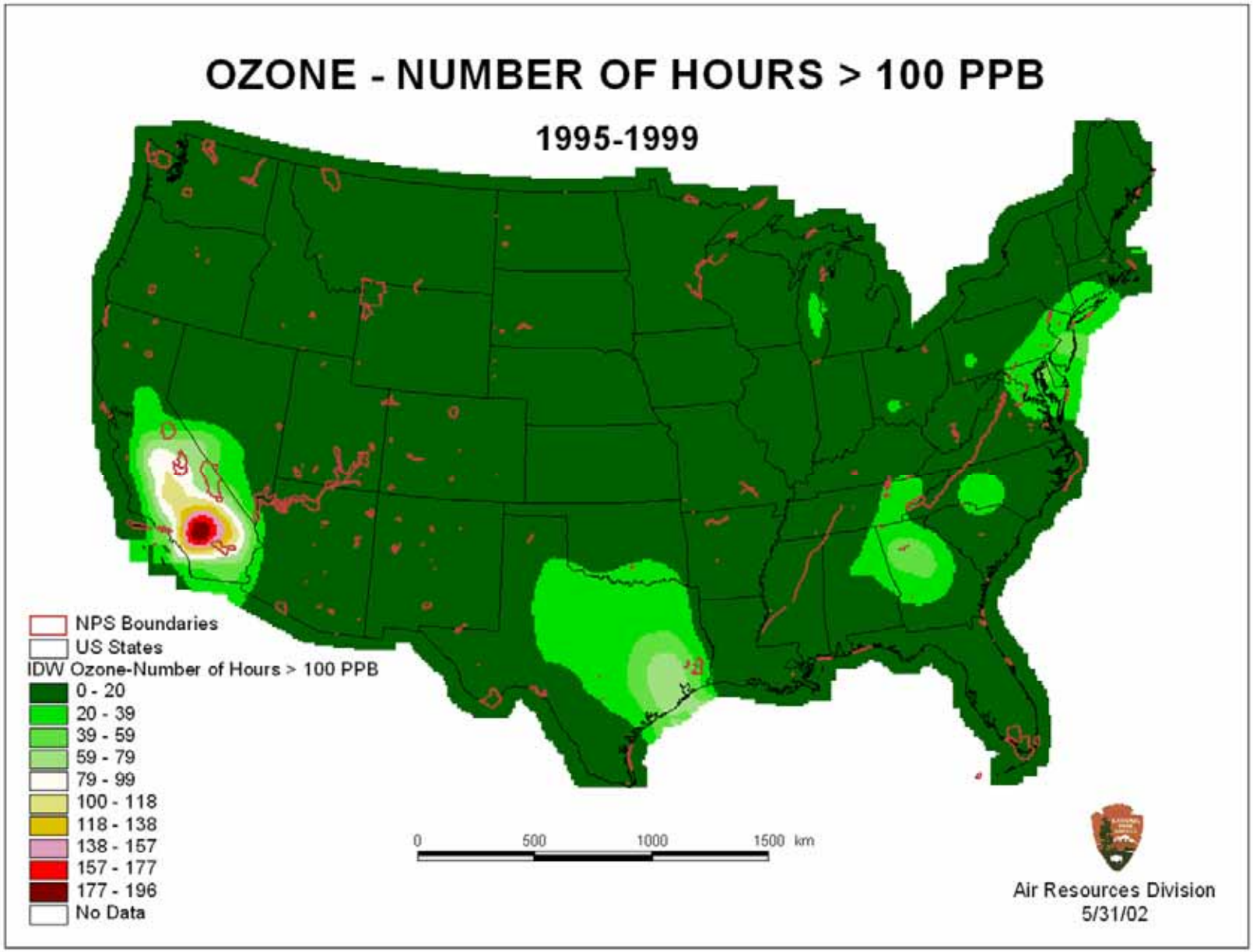
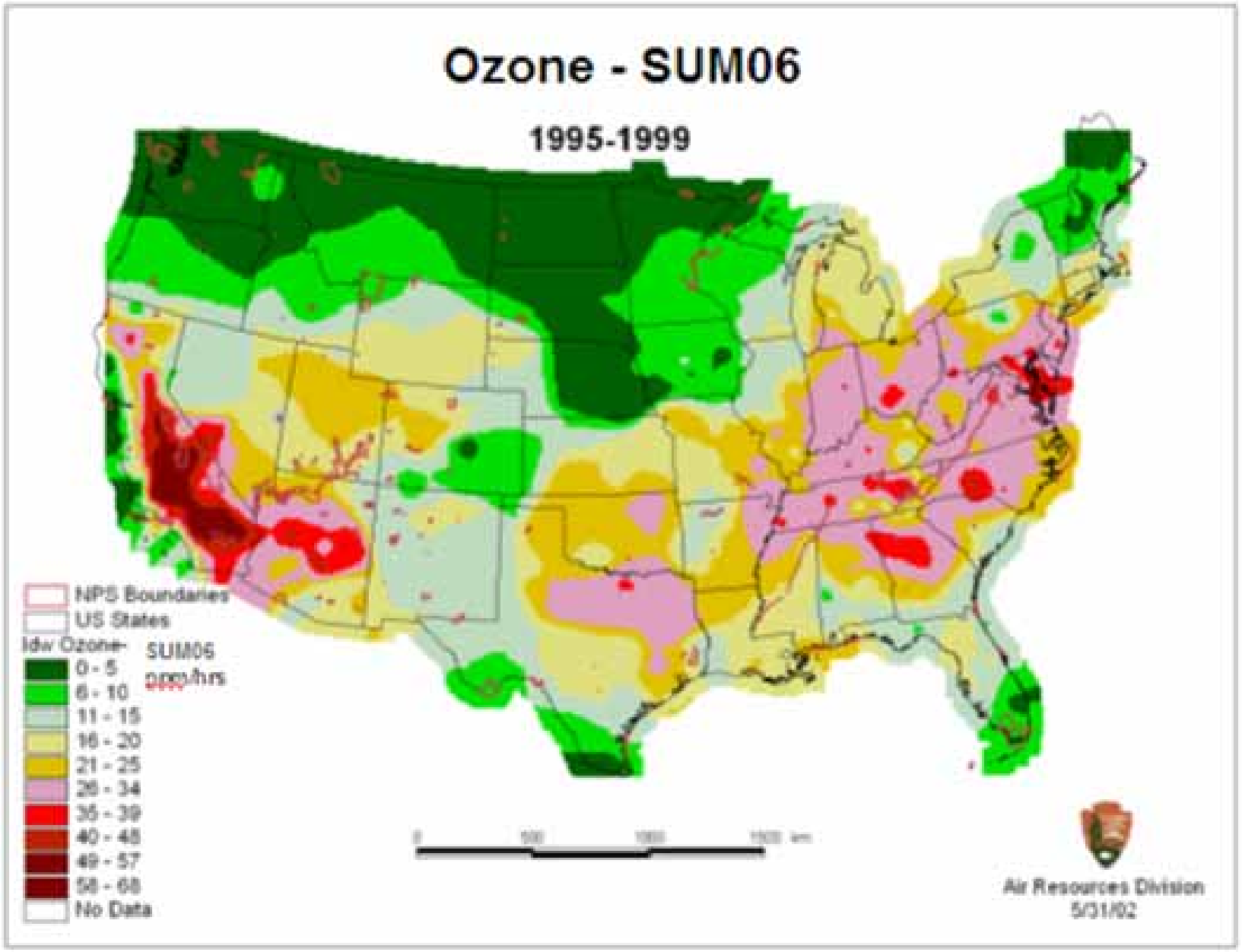
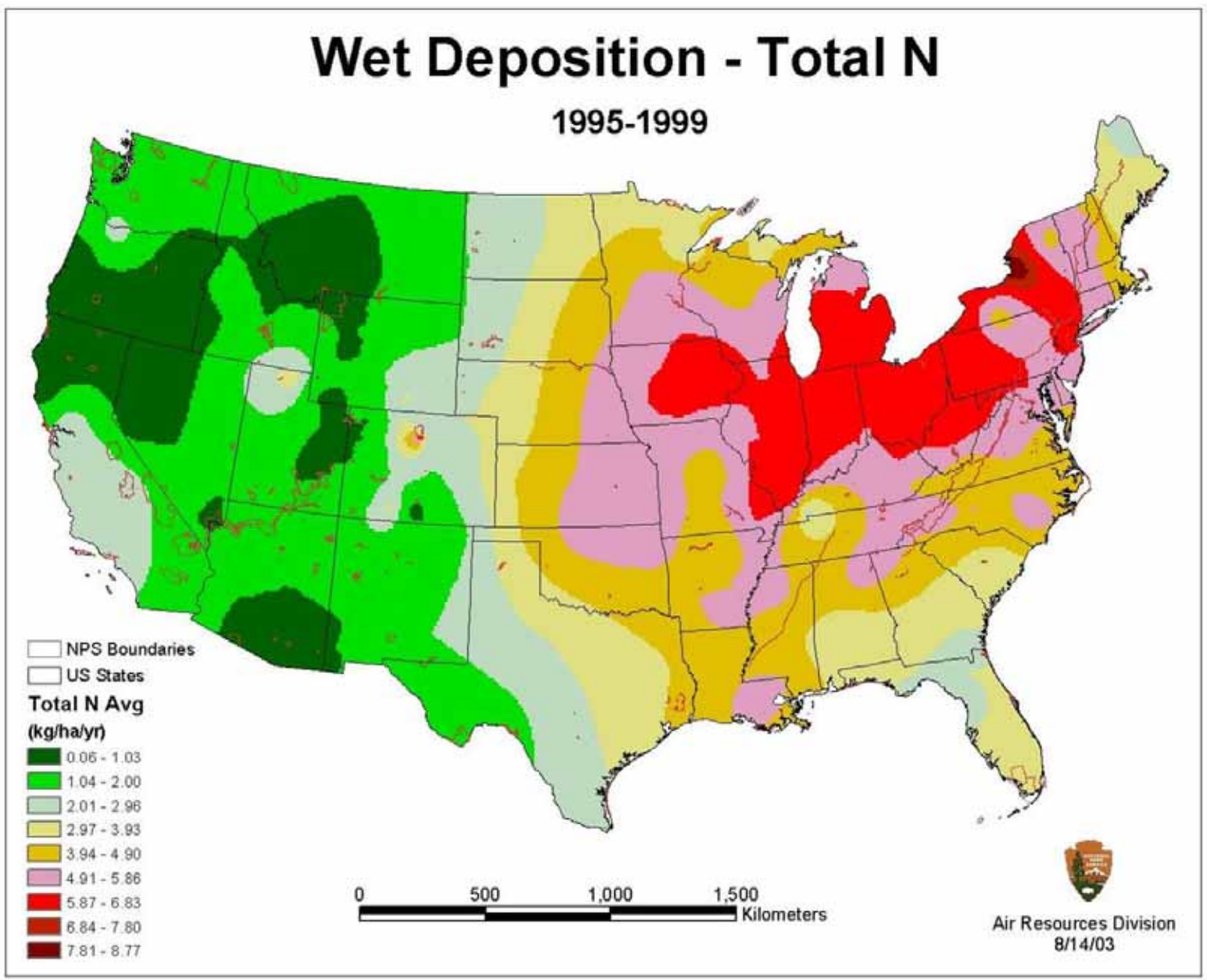

OZONE - NUMBER OF HOURS > 100 PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-Number of Hours > 100 PPB
0 - 20
20 - 39
39 - 59
59 - 79
79 - 99
100 - 118
118 - 138
138 - 157
157 - 177
177 - 196
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02


Ozone - SUM06
1995-1999
NPS Boundaries
US States
Idw Ozone
SUM06
ppm-hrs
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 34
35 - 39
40 - 48
49 - 57
58 - 68
No Data
Air Resources Division
5/31/02

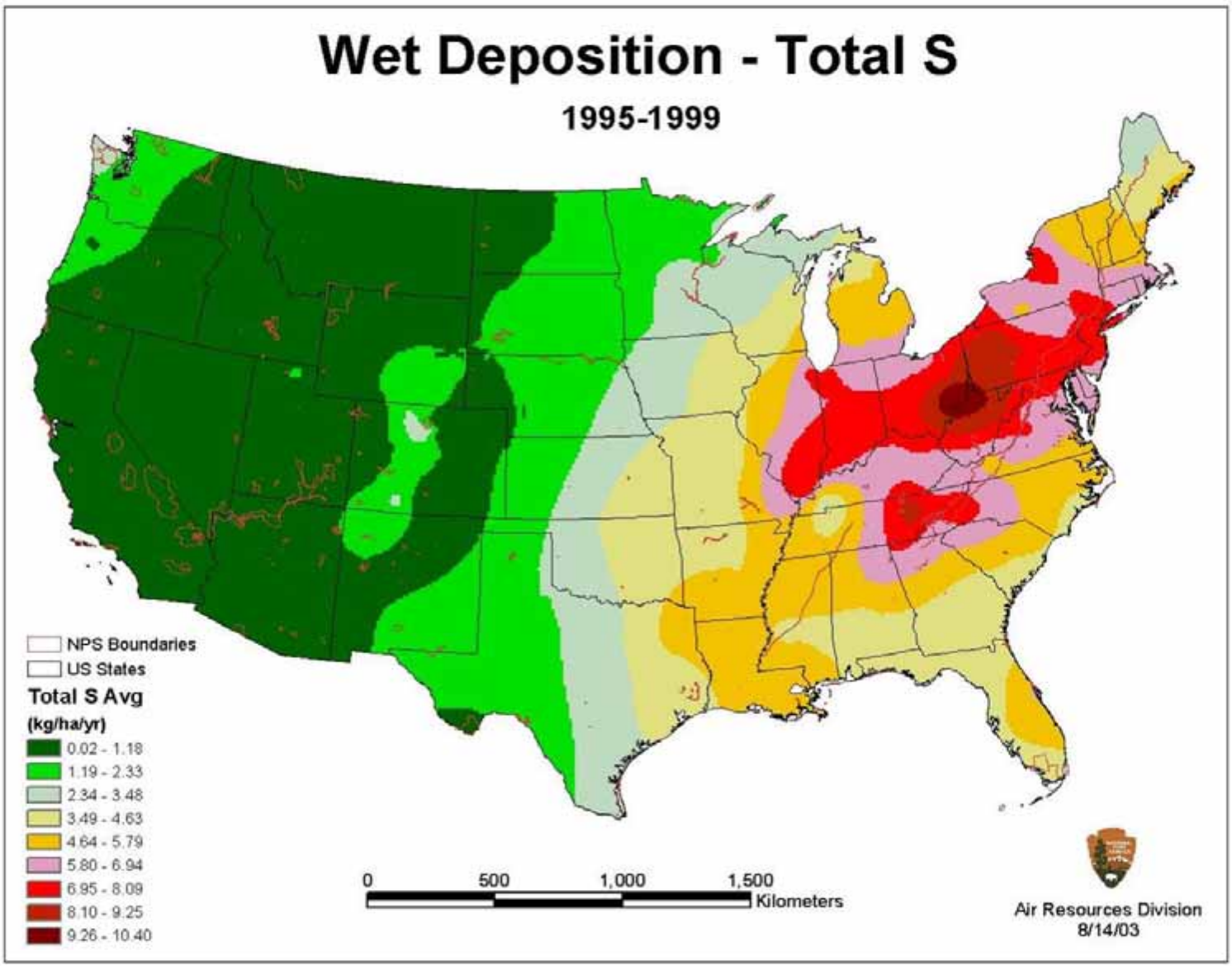
# Wet Deposition - Total N

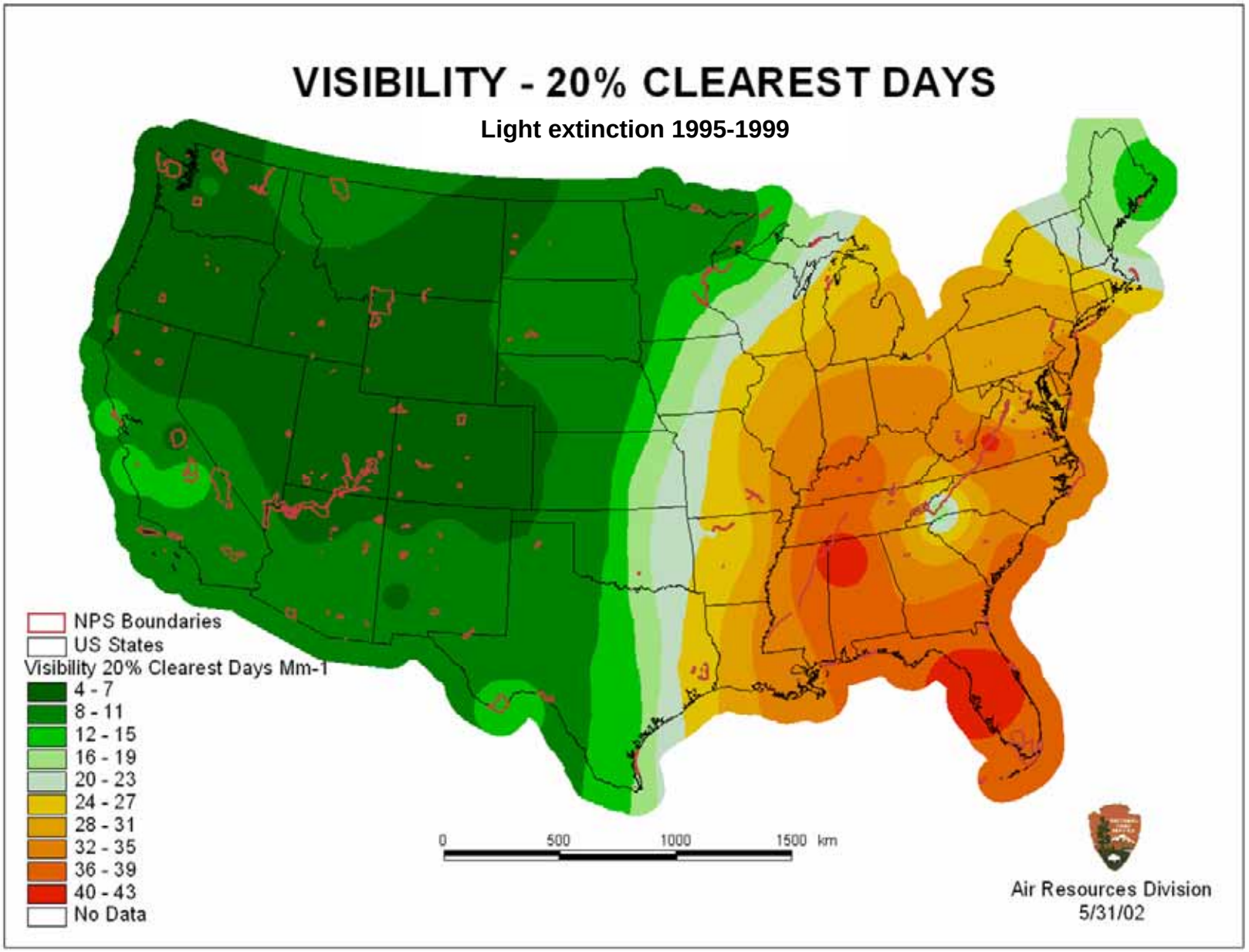
## 1995-1999

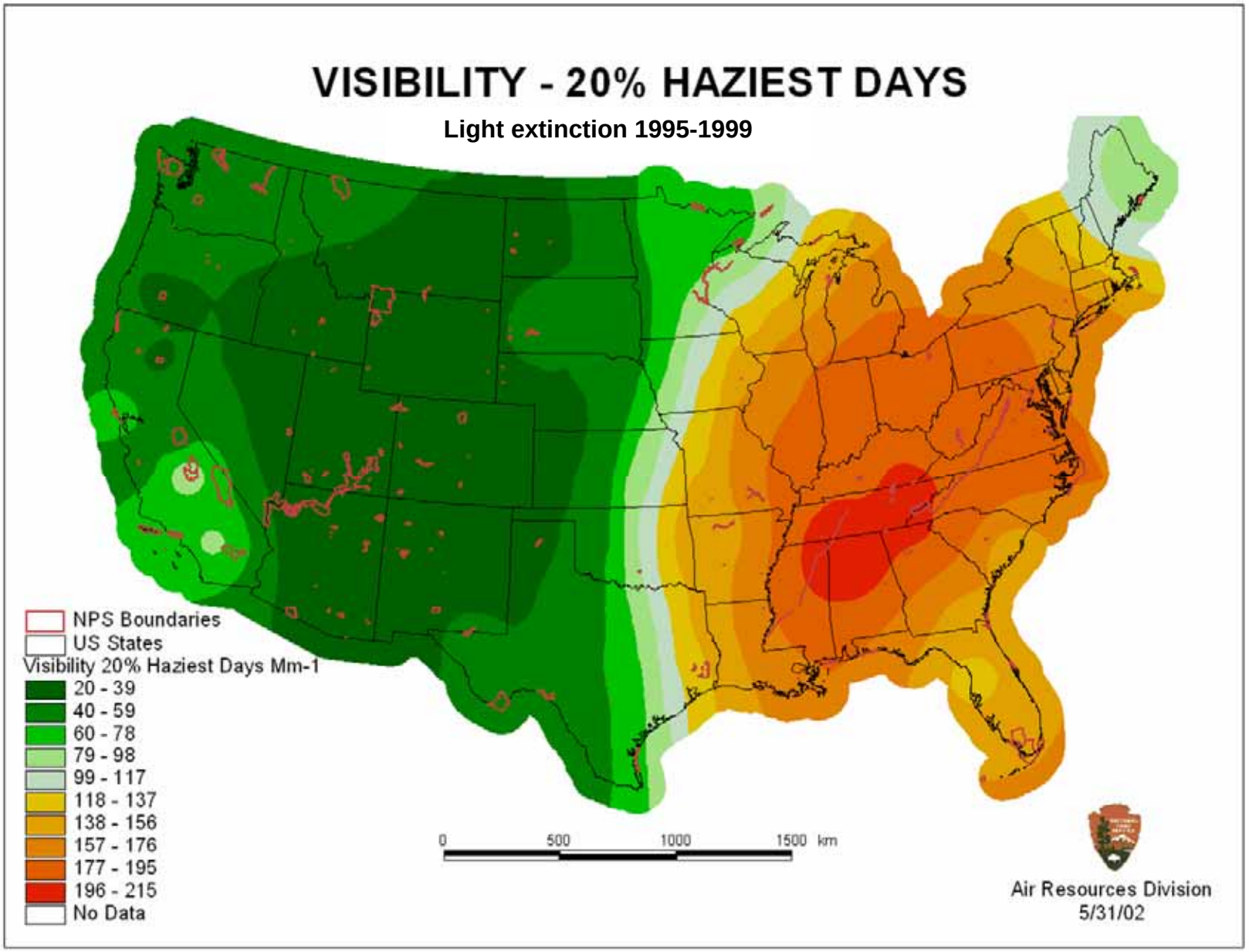


# Wet Deposition - Total S

## 1995-1999




VISIBILITY - 20% CLEAREST DAYS
Light extinction 1995-1999
NPS Boundaries
US States
Visibility 20% Clearest Days Mm-1
4 - 7
8 - 11
12 - 15
16 - 19
20 - 23
24 - 27
28 - 31
32 - 35
36 - 39
40 - 43
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02


VISIBILITY - 20% HAZIEST DAYS
Light extinction 1995-1999
NPS Boundaries
US States
Visibility 20% Haziest Days Mm-1
20 - 39
40 - 59
60 - 78
79 - 98
99 - 117
118 - 137
138 - 156
157 - 176
177 - 195
196 - 215
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02

# Air Quality Pollutant Estimates

## Northern Great Plains Network

| | Ozone | | | | | Wet Deposition NADP | | Visibility Mm-1 | Mm-1 |
|---|---|---|---|---|---|---|---|---|---|
| **Park** | **2nd_Hi_1hr** | **#1hr_>_100** | **4th_Hi_8hr** | **#8hr_>_85** | **Sum06_3_Mo** | **Total_S_kg/Ha** | **Total_N_kg/Ha** | **bext_Clear** | **bext_Hazy** |
| Agate Fossil Beds NM | 99 | 2 | 73 | 2 | 16 | 1.59 | 2.77 | 7 | 32 |
| Badlands NP | 90 | 1 | 69 | 1 | 9 | 1.30 | 2.70 | 10 | 46 |
| Devils Tower NM | 88 | 1 | 68 | 1 | 7 | 1.02 | 1.89 | 7 | 33 |
| Fort Laramie NHS | 98 | 2 | 73 | 2 | 16 | 1.59 | 2.68 | 6 | 28 |
| Fort Union Trading Post NHS | 77 | 0 | 63 | 0 | 3 | 0.74 | 1.46 | 7 | 35 |
| Jewel Cave NM | 93 | 2 | 70 | 1 | 14 | 1.28 | 2.37 | 8 | 38 |
| Knife River Indian Village NHS | 73 | 0 | 61 | 0 | 2 | 1.05 | 2.36 | 8 | 38 |
| Missouri NRR | 111 | 12 | 86 | 6 | 26 | 4.91 | 3.78 | 34 | 190 |
| Mount Rushmore NMem | 92 | 2 | 70 | 1 | 10 | 1.25 | 2.42 | 9 | 41 |
| Niobrara NSR | 111 | 12 | 86 | 6 | 26 | 4.91 | 3.78 | 34 | 190 |
| Scotts Bluff NM | 99 | 2 | 73 | 2 | 15 | 1.62 | 2.83 | 7 | 29 |
| Theodore Roosevelt NP | 76 | 0 | 63 | 0 | 3 | 0.91 | 1.85 | 7 | 36 |
| Wind Cave NP | 94 | 2 | 71 | 1 | 15 | 1.34 | 2.53 | 9 | 40 |