National Park Service
U.S. Department of the Interior

Air Resources Division

Air Quality in the National Parks
Second Edition

Air Quality in the National Parks - Second Edition

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Second Edition

National Park Service Air Resources Division
Lakewood, Colorado

U.S. Department of the Interior
Washington, DC

(Cover) Grand Canyon National Park, Arizona

(Left) Crater Lake National Park, Oregon

Acknowledgments

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Disclaimer

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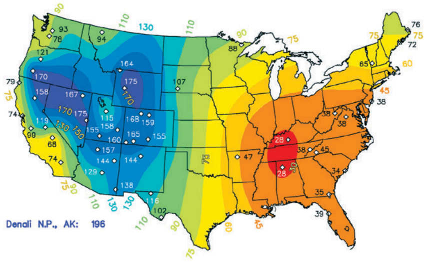
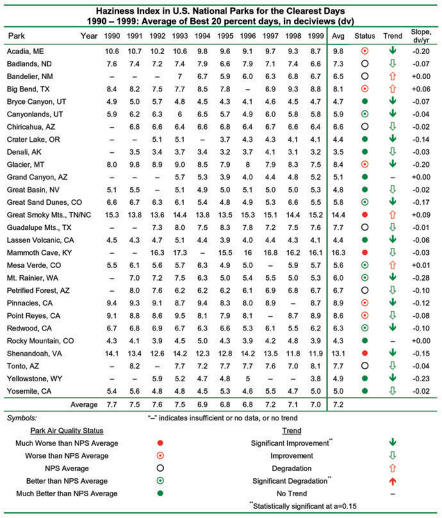
> *"Mount Rainier is the undisputed icon of the Pacific Northwest and the public is passionate about 'their' park and its protection. Mount Rainier dominates the horizon and can be seen daily by millions of people. When the mountain is out, the people come and they expect clean air and panoramic vistas. The views, however, are often tarnished by the haze generated in the Puget Sound area. Because of this unique position, the quality of the air around Mount Rainier National Park serves to galvanize support among all the interest groups, governments, and the general public into actions that protect the entire region."*
>
> *Jon Jarvis, Superintendent*
> *Mount Rainier National Park, Washington*

Contents





Haziness Index in U.S. National Parks for the Clearest Days
1990 – 1999: Average of Best 20 percent days, in deciviews (dv)

Park	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, dv/yr
Acadia, ME		10.6	10.7	10.2	10.6	9.8	9.6	9.1	9.7	9.3	8.7	9.8	⊙	⬇	-0.20
Badlands, ND		7.6	7.4	7.2	7.4	7.9	6.6	7.9	7.1	7.4	6.6	7.3	○	⇩	-0.07
Bandelier, NM		–	–	–	7	6.7	5.9	6.0	6.3	6.8	6.7	6.5	○	⇧	+0.00
Big Bend, TX		8.4	8.2	7.5	7.7	8.5	7.8	–	6.9	9.3	8.8	8.1	⊙	⇧	+0.06
Bryce Canyon, UT		4.9	5.0	5.7	4.8	4.5	4.3	4.1	4.6	4.5	4.7	4.7	🟢	⬇	-0.07
Canyonlands, UT		5.9	6.2	6.3	6	6.5	5.7	4.9	6.0	5.8	5.8	5.9	◎	⬇	-0.04
Chiricahua, AZ		–	6.8	6.6	6.4	6.6	6.8	6.4	6.7	6.6	6.4	6.6	○	⇩	-0.02
Crater Lake, OR		–	–	5.1	5.1	–	3.7	4.3	4.3	4.1	4.1	4.4	🟢	⬇	-0.14
Denali, AK		–	3.5	3.4	3.7	3.4	3.2	3.7	4.1	3.1	3.2	3.5	🟢	⇩	-0.03
Glacier, MT		8.0	9.8	8.9	9.0	8.5	7.9	8	7.9	8.3	7.5	8.4	⊙	⬇	-0.20
Grand Canyon, AZ		–	–	–	5.7	5.3	3.9	4.0	4.4	4.8	5.2	5.1	🟢	–	+0.00
Great Basin, NV		5.1	5.5	–	5.1	4.9	5.0	5.1	5.0	5.0	5.3	4.8	🟢	⇩	-0.02
Great Sand Dunes, CO		6.6	6.7	6.3	6.1	5.4	4.8	4.9	5.3	6.6	5.5	5.8	◎	⬇	-0.17
Great Smoky Mts., TN/NC		15.3	13.8	13.6	14.4	13.8	13.5	15.3	15.1	14.4	15.2	14.4	🔴	⇧	+0.09
Guadalupe Mts., TX		–	–	7.3	8.0	7.5	8.3	7.8	7.2	7.5	7.6	7.7	○	⇩	-0.01
Lassen Volcanic, CA		4.5	4.3	4.7	5.1	4.4	3.9	4.0	4.4	4.3	4.1	4.4	🟢	⬇	-0.06
Mammoth Cave, KY		–	–	16.3	17.3	–	15.5	16	16.8	16.2	16.1	16.3	🔴	⇩	-0.03
Mesa Verde, CO		5.5	6.1	5.6	5.7	6.3	4.9	5.0	–	5.9	5.7	5.6	◎	⇧	+0.01
Mt. Rainier, WA		–	7.0	7.2	7.5	6.3	5.0	5.4	5.5	5.0	5.3	6.0	◎	⬇	-0.28
Petrified Forest, AZ		–	8.0	7.6	6.2	6.2	6.2	6.1	6.9	6.8	6.7	6.7	○	⇩	-0.10
Pinnacles, CA		9.4	9.3	9.1	8.7	9.4	8.3	8.0	8.9	–	8.7	8.9	⊙	⬇	-0.12
Point Reyes, CA		9.1	8.8	8.6	9.5	8.1	7.9	8.1	–	8.7	8.9	8.6	⊙	⇩	-0.08
Redwood, CA		6.7	6.8	6.9	6.7	6.3	6.6	5.3	6.1	5.5	6.2	6.3	◎	⬇	-0.10
Rocky Mountain, CO		4.3	4.1	3.9	4.5	5.0	4.3	3.9	4.2	4.8	3.9	4.3	🟢	–	+0.00
Shenandoah, VA		14.1	13.4	12.6	14.2	12.3	12.8	14.2	13.5	11.8	11.9	13.1	🔴	⬇	-0.15
Tonto, AZ		–	8.2	–	7.7	7.2	7.7	7.7	7.6	7.0	8.1	7.7	○	⇩	-0.04
Yellowstone, WY		–	–	5.9	5.2	4.7	4.8	5	–	–	3.8	4.9	🟢	⬇	-0.23
Yosemite, CA		5.4	5.6	4.8	4.8	4.5	5.3	4.6	5.5	4.7	5.0	5.0	🟢	⇩	-0.02
	Average	7.7	7.5	7.6	7.5	6.9	6.8	6.8	7.2	7.1	7.0	7.2			

Symbols: "–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	◎	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Air Quality in the National Parks - Executive Summary

Visitors to national parks expect clean, clear air. They cherish the natural resources and majestic vistas associated with parks. Monitoring conducted in national parks over the past 20 years documents that, in most parks, air quality is better than standards set by the Environmental Protection Agency (EPA) to protect public health and welfare. In addition, air quality is improving or remaining stable in about half the parks where monitoring occurs. Some parks occasionally experience essentially pristine air quality conditions unaffected by air pollution. Unfortunately, air quality in national parks is not always as pristine as people may think nor are park natural resources free of noticeable impacts.

Many park resources are affected by air pollution. Some of the air pollutants affecting parks are emitted directly from sources such as industrial facilities and automobiles (primary pollutants) and some are formed as a result of chemical reactions in the atmosphere (secondary pollutants). The National Park Service air quality monitoring program acquires information about air pollutants that can impair visibility, harm human health, injure various species of trees and other plants, acidify streams and lakes, leach nutrients from soils, and erode buildings and monuments. The monitoring program focuses on visibility, acidic precipitation, and gaseous pollutant concentrations.

Among the experiences that visitors to national parks treasure is the breathtaking scenery – majestic mountains contrasted against a pure blue sky or the form, color, and texture of unique landscapes and geologic features. Spectacular scenic views need to be seen to be appreciated. In 1977, Congress specifically recognized this by establishing a national goal of remedying any existing and preventing any future human-caused visibility impairment in most of our largest national parks. Unfortunately, air pollution currently impairs visibility to some degree in every national park.

- The best visibility occurs in Denali National Park in Alaska and in an area centered around Great Basin National Park, Nevada.

- The worst visibility occurs in eastern parks such as Mammoth Cave, Shenandoah and Great Smoky Mountains National Parks.

- Years of visibility monitoring show that seasonal differences in visibility conditions exist in parks. For most areas of the country, visibility tends to be best during the winter months and worst during the summer.

- Sulfate particles formed from sulfur dioxide emissions associated with fossil fuel combustion - mostly for electric generation - account for 60% to 85% of the visibility impairment observed in eastern parks. In contrast, sulfates account for between 30% to 40% of visibility impairment in the western U.S.

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through precipitation or as a result of atmospheric processes, such as settling. Acid deposition changes water and soil chemistry, which in turn, affects algae, aquatic invertebrates and soil microorganisms, and can lead to impacts higher on the food chain.

- High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and the upland areas of the eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition.

- Streams in both Shenandoah and Great Smoky Mountains National Parks are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected.

- Rocky Mountain National Park is currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition.

- Other sensitive areas include the upper Midwest, New England, and Florida, including shallow bays and estuaries along the Atlantic and Gulf Coasts.

Ground-level ozone, produced by the reaction of nitrogen oxides and volatile organic compounds in the presence of sunlight, is one of the most widespread pollutants affecting vegetation and public health throughout the world. Plants are generally more sensitive to ozone than humans. Effects range from visible injury on leaves and needles to premature leaf loss, reduced photosynthesis, and reduced growth in sensitive plants species.

- Most parks where ozone is monitored experience ozone levels high enough to cause foliar injury.

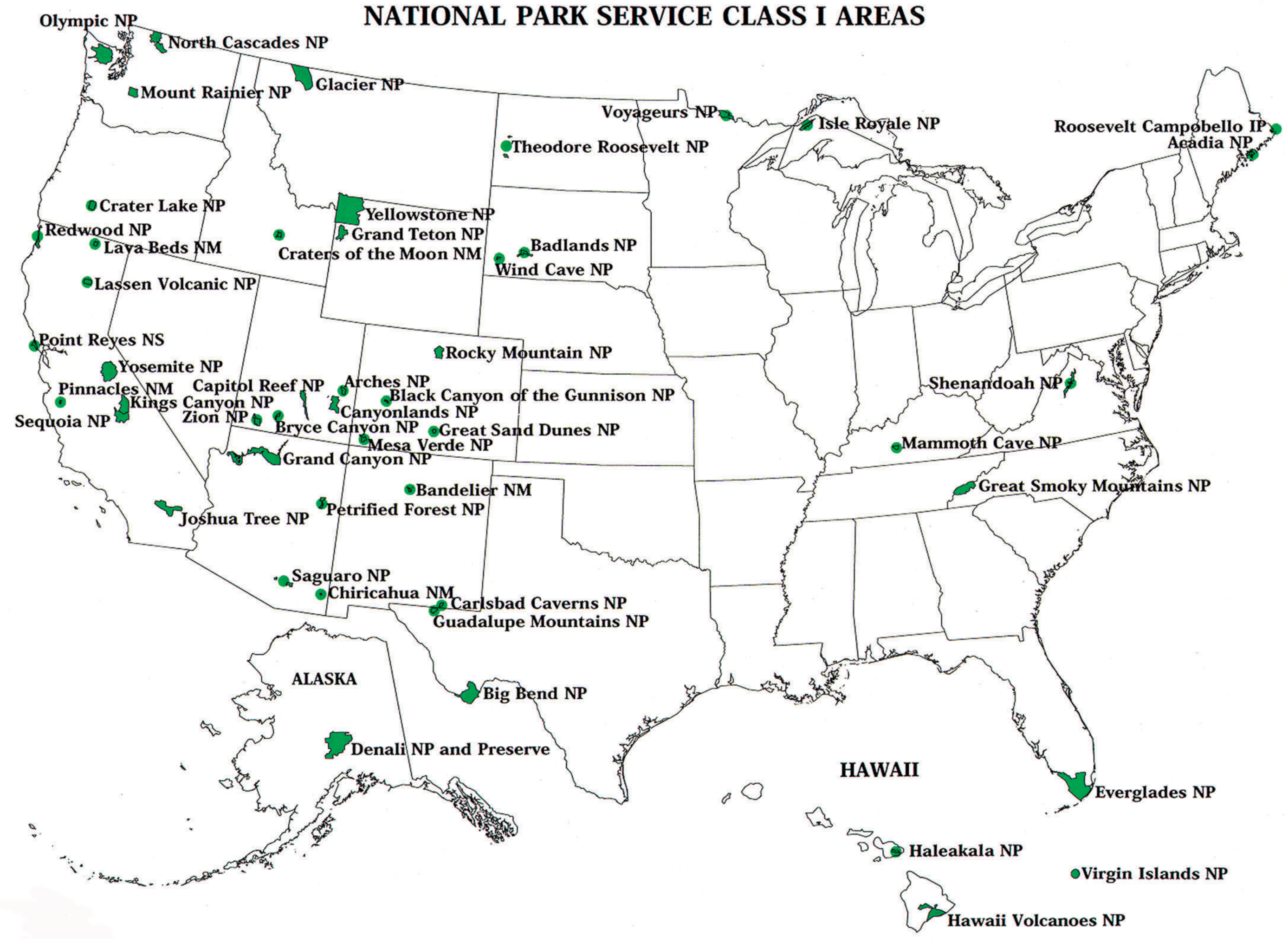
- Field surveys have documented injury in Shenandoah, Great Smoky Mountains, Sequoia, Kings Canyon, Yosemite and Lassen Volcanic National Parks.

- NPS has found that, in general, higher ozone exposure levels occur at high elevation sites and, therefore, high elevation vegetation is possibly more at risk to injury.

- In some parks in the Southeast, Northeast and California, ozone concentrations have exceeded standards set by EPA to protect human health. Concern for the health and safety of visitors and employees has led to an ozone advisory system in several parks where levels are likely to approach or exceed the ozone standard.

- Parks in the Pacific Northwest and Intermountain West experience lower levels of ozone pollution than parks in other regions of the country, but an increasing ozone trend is evident in the Colorado Plateau and Rocky Mountains regions.

Under the Clean Air Act, park managers have an affirmative responsibility to protect "air quality related values (including visibility)" from the adverse effects of air pollution. This responsibility is carried out by communicating information about air quality conditions in parks to the public; providing advice and technical assistance to state, federal, and tribal regulatory agencies; working cooperatively through partnerships with a variety of stakeholders in the development of air pollution control strategies; and promoting pollution prevention practices in parks. The information, expertise, and management concerns that the National Park Service brings to various decision-making arenas have made a difference, but restoring clean air to parks will require concerted, continuing efforts.



NATIONAL PARK SERVICE CLASS I AREAS

> *"The National Park Service has the responsibility to protect and preserve the resources and values of all of the parks in our National Park System and that includes parks in every state and in both urban and rural locations. While air quality statutes are basically designed to protect the parks designated Class I under the Clean Air Act, concern for improved air quality is not so restricted. No one should take for granted and accept the degraded air quality in urban and industrial areas like the Indiana Dunes National Lakeshore. We need to continue to express our concern for the health of the visiting and resident public and the survival of the living resources of the park at places like this as well."*
>
> *Dale B. Engquist, Superintendent*
> *Indiana Dunes National Lakeshore*

Chapter One
Preserving Air Quality in National Parks

Our mandate
Since the establishment of Yellowstone National Park in 1872 as the first national park, people from all over the world have come to experience America's national parks. In the year 2000 alone, an estimated 286 million visitors came to national parks, nearly a 40 percent increase since 1979 and a number roughly equal to the U.S. population.

People come to national parks for a variety of reasons such as their desire to experience the natural beauty of, or be inspired by, these icons of our nation's natural and cultural heritage. Many see parks as places of solace and refuge from an increasingly complex, technological, and fast-paced society. Visitors to national parks expect clean, clear air as part of their park experience. They cherish the natural resources and majestic vistas associated with parks, such as those found at Glacier, Grand Canyon, Shenandoah, and Yosemite National Parks. Even those who do not visit national parks recognize the importance of parks as part of our national heritage, and they place a high value on preserving these areas.

Monitoring conducted in national parks over the past 20 years documents that, in most parks, air quality is better than standards set by the Environmental Protection Agency (EPA) to protect public health and welfare. In addition, air quality is improving or remaining stable in about half the parks where monitoring occurs. Some parks occasionally experience essentially pristine air quality conditions unaffected by air pollution. Unfortunately, air quality in national parks is not always as pristine as people may think nor are park natural resources free of noticeable impacts.

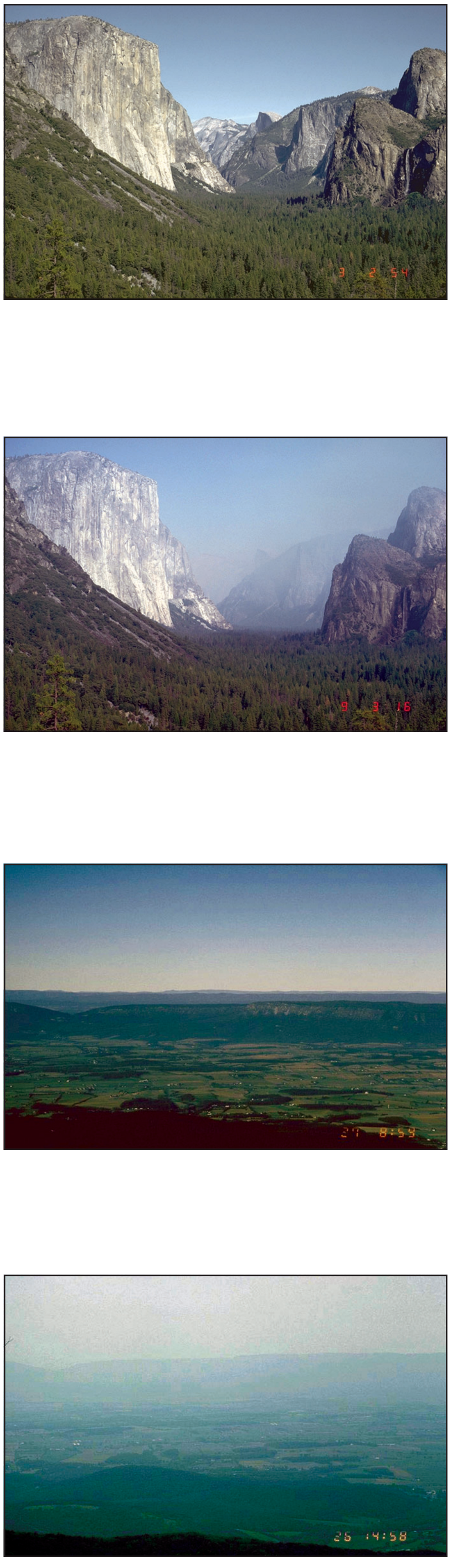
Air pollution effects
Many park resources and values are affected by air pollution. For example, the ability to appreciate scenic vistas is highly dependent on good visibility. Poor visibility caused by air pollution can indicate that there may be other impacts occurring to resources that cannot be readily observed. Human-made pollution can injure various species of trees and other plants, acidify streams and lakes, leach nutrients from soils, and erode buildings and monuments. Air pollution may also be causing or exacerbating respiratory symptoms for some of the visitors and employees at several of our national parks. The harmful effect of air pollution on the park visitor's visual and recreational experience is particularly relevant given the increase in visitor use of the national parks.

These are hardly the conditions that Congress foresaw in 1916 when it created the National Park Service (NPS) and established as its fundamental mission

> *"... to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."*

Included in this mission is the mandate to preserve the air quality of our national parks. Congress also emphasized the need to preserve air quality in our nation's special places, including large national parks and wilderness areas, when it amended the Clean Air Act in 1977. Congress mandated that air quality in these areas be protected and enhanced, and not be allowed to deteriorate significantly. It also established a national goal of restoring natural visibility in these areas.

Progress has been made in improving air quality across the country since the enactment of the Clean Air Act in 1970. Nonetheless current air quality in many national parks is far from what can be considered natural conditions. Parks continue to have noticeable impacts on their resources and in some cases their air quality is deteriorating significantly. Air pollution associated with this country's increased industrialization and urbanization over the last several decades is adversely affecting sensitive natural and cultural resources, including visibility, at



Images of some of the clearest days and haziest days experienced at Yosemite and Shenandoah National Parks. Visibility conditions in national parks are being affected by air pollution. Human-caused air pollution in the form of fine particles can wash out the views that visitors come to experience.

Source: NPS Air Resources Division

Panoramic view at Yellowstone National Park

Source: NPS Air Resources Division

> *"The value of clean air, the pay-off for cleaning up our dirty airsheds will be measured both in the aesthetics of better views, and clearer night skies, but also in the economics of our entire planet. The threat of global warming and a wholesale shift in the productivity of our environment can be managed if we manage the bubble of air that envelops us."*
>
> Ellis Richard, Superintendent
> Guadalupe Mountains National Park,
> Texas

> *"... to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value."*
>
> *From the 1977 Clean Air Act Amendments, Part C, Prevention of Significant Deterioration of Air Quality*

many NPS areas. To prevent or remedy any harmful effects from air pollution the NPS must understand how air quality affects park resources and visitor enjoyment, and work cooperatively with regulatory agencies to prevent or reduce air pollution. In light of current population and economic growth trends; restoring and maintaining good air quality in national parks will continue to be a challenge.

Management policies

NPS management policies address the need to protect units of the National Park System from the adverse effects of air pollution stating that NPS

> *"...will seek to perpetuate the best possible air quality in parks because of its critical importance to visitor enjoyment, human health, scenic vistas, and the preservation of natural systems and cultural resources...and will assume an aggressive role in promoting and pursuing measures to safeguard these values from the adverse impacts of air pollution."*

These policies reflect the mission of the National Park Service and other authorities and responsibilities under various federal statutes, such as the Wilderness Act, which help protect NPS areas from the adverse effects of air pollution (see Table 1-1). Foremost of these is the Clean Air Act. In enacting the *Prevention of Significant Deterioration of Air Quality* provisions of the 1977 amendments to the Clean Air Act, Congress provided increased protection to certain national parks and wilderness areas designated as *Class I areas*. The Act gives park managers an affirmative responsibility to protect "air quality related values (including visibility)" from the adverse effects of air pollution. The NPS administers 49 Class I areas including one Class I international park jointly with Canada (Roosevelt-Campobello).

Although the Clean Air Act gives Class I areas the greatest protection against air quality deterioration, NPS management policies make no distinction in the level of protection afforded to any unit of the National Park System. Protecting air quality in NPS areas is reflected in the NPS' Strategic Plan, and progress in achieving air quality goals is one of the results-oriented measures used under the Government Performance and Results Act.

Understanding the impact of air pollution on national parks

Protection of air quality in national parks requires extensive knowledge about the origin, transport, and fate of air pollution, as well as its impacts on resources. In order to be effective advocates for the protection of park air resources, NPS managers need to know such things as the air pollutants of concern, existing levels of air pollutants in parks, park resources at risk, and the potential or actual impact on these resources. Through the efforts of park personnel, support office staff, and the NPS Air Resources Division, the NPS is meeting its clean air affirmative responsibilities by obtaining this critical infor-

Table 1-1. Legislative Requirements Protecting Park Air Resources

Statute	Year	Summary
NPS Organic Act	1916	Requires the NPS to conserve scenery and other park resources and to provide for the enjoyment of such resources by such means as will leave them unimpaired for the enjoyment of future generations.
Wilderness Act	1964	Requires wilderness areas to be administered "for the use of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness."
National Environmental Policy Act	1969	Establishes national environmental policy and goals to protect, maintain, and enhance the environment; requires all federal agencies to examine the environmental consequences of major proposed actions, and to conduct a decision-making process that incorporates public input.
Clean Air Act	1970 1977 1990	Establishes: (1) health- and welfare-based national air quality standards; (2) a national visibility goal of no human-caused impairment; (3) a Prevention of Significant Deterioration of Air Quality program, one purpose of which is to "preserve, protect, and enhance the air quality in national parks, national wilderness areas" and other areas of special value; and (4) acid rain control.
Park Enabling Legislation	Various	Requires parks to be managed by such means and measures to conform to their fundamental purpose.

> *"Today the park is faced with an increasing number of potential air pollution impacts from up-wind sources...."*
>
> *Bill Supernaugh, Superintendent*
> *Badlands National Park, South Dakota*

mation and using this information in regulatory-related activities. Much of this effort focuses on monitoring the levels of air pollution in parks, documenting its effects on park resources through scientific studies, and identifying principal contributors to poor air quality in our national parks.

Pollutants of concern, their impact, and resources at risk Various air pollutants can cause detrimental effects on sensitive resources. These include pollutants emitted directly from sources such as industrial facilities and automobiles (primary pollutants) and those that are formed as a result of chemical reactions in the atmosphere (secondary pollutants). The Environmental Protection Agency (EPA) has set ambient air quality standards for several pollutants. These include fine particles, sulfur dioxide, nitrogen oxides, ozone, carbon monoxide, and lead. Ozone and some fine particles are secondary pollutants. Other particulate and gaseous pollutants of concern include heavy metals (for example, mercury), volatile organic compounds (VOC), ammonia, and toxic organic compounds.

Pollutants of most concern are ozone, sulfate, nitrate, and ammonium compounds formed in the atmosphere from the emissions of primary pollutants. Ozone has been shown to cause visible foliar injury to a variety of trees and other plants in several parks. Growth reductions in several species have also been documented. At some parks where levels of ozone have approached or exceed the ambient air quality standard, visitors sensitive to ozone have likely experienced aggravated respiratory symptoms.

Sulfates and nitrates are the principal constituents of acid rain, which leads to acidification of lakes, streams, and soils, as well as higher level ecosystem effects such as the reduction of fish populations and other aquatic organisms in streams. Sulfate fine particles are also the primary cause of visibility impairment in parks nationwide with nitrates and other pollutants playing a smaller but significant role. Pollutants can be emitted locally near parks or from distant sources but transported long distances in the atmosphere prior to their arrival in parks.

Toxic air contaminants are deposited on ecosystems where they can bioaccumulate in fish and other wildlife. Mercury, a toxic metal, accumulates in fish and wildlife tissue and is a potent neurotoxin. Thirty states have consumption advisories for specific waterbodies to warn consumers about mercury-contaminated fish and shellfish. High concentrations of mercury have been measured in sediments and fish tissue even in certain remote parts of the high Arctic. Pesticides and PCBs have been documented in lakes

Resources at Risk:

Pollutants of Concern

- *Visibility, Night Sky:*
  Fine particles (primarily sulfates)
- *Aquatic and Terrestrial Ecosystems:*
  Acid rain (primarily sulfates and nitrates) toxic air contaminants, ammonium
- *Forest Ecosystems:*
  Ozone, acid rain, sulfur dioxide, ozone precursor emissions, nitrogen deposition
- *Cultural Resources:*
  Acid rain (primarily sulfates and nitrates)
- *Fish and Wildlife:*
  Toxic air contaminants, acid rain
- *Visitor Enjoyment:*
  Visibility impairing fine particles, ozone

NPS Principal Monitoring Objectives

- *Determine levels of air pollutants in parks and correlate to observed effects*
- *Identify and assess trends in air quality*
- *Determine compliance with National Ambient Air Quality Standards*
- *Provide data for the development and revision of national and regional air pollution control policies*
- *Provide data for atmospheric model development and evaluation*
- *Use information to inform public about conditions/trends in national parks*
- *Determine which air pollutants in parks contribute to visibility impairment*

and fish in isolated areas such as Isle Royale National Park in Lake Superior. Toxic organics include persistent organic pollutants, such as pesticides, dioxins, and PCBs, that "mimic" estrogens and can affect reproductive systems in wildlife and humans.

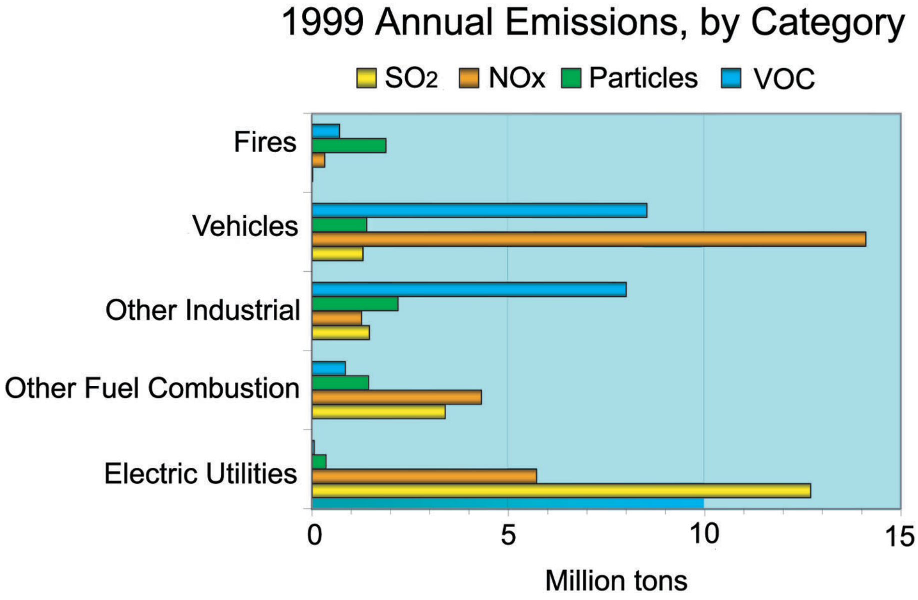
Sources of air pollutants Sources of air pollution include: "stationary sources" such as factories, power plants, dry cleaners, and degreasing operations; "mobile sources" such as cars, buses, planes, trucks, and trains; and "natural sources" such as wind-blown dust and wildfires (see figure below).

Power plants in the U.S. account for 65 percent of sulfur dioxide, a primary cause of acid rain and visibility degradation; 23 percent of nitrogen oxides, a principal precursor to smog and acid rain; and 21 percent of mercury, a heavy metal which poisons fish in freshwater lakes. In addition to coal-fired power plants, other emitters of mercury include chlorine and lye manufacturing (chlor-alkali) plants and waste incinerators; mercury is also emitted during forest fires and from degassing of soils.

Measuring air pollutant levels in parks Historically, air pollution monitoring conducted by local, states, and other federal agencies had been inadequate in documenting levels of air pollution in national parks. As a result, in the late 1970s, the NPS initiated an extensive air quality monitoring network to gather vital information about air quality conditions in national parks. The network has grown over time through collaborative partnerships with other federal agencies and states. The map on the following page shows the location of NPS air monitoring stations, illustrates its extensiveness, and identifies those parks where some type of air monitoring is being conducted. The network includes gaseous pollutant, meteorology, visibility, and deposition monitoring components.

Visibility monitoring Visibility monitoring documents current visibility conditions and the composition of particles in the air that contribute to visibility impairment. This information is used to determine how much of the impairment is human-caused and what types of sources may be responsible for this impairment. Analyses of the monitoring data and research on the transformation and transport of pollutants in the air help NPS identify the region and sources of the pollutants that cause impairment.

Atmospheric deposition monitoring The atmospheric deposition monitoring component gathers information on both wet (acid rain) and dry atmospheric deposition as part of two nationwide monitoring networks: the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for wet deposition and the Clean Air Status and Trends Network (CASTNet) for dry deposition. This information is critical in evaluating aquatic and terrestrial ecosystem effects.



Annual emissions of air pollutants from different major source categories for 1999, in millions of tons. Particle emissions include fine and coarse particles.

Source: U.S. EPA

Location of air quality monitoring stations in U.S. national parks. Parks identified on the map routinely monitor one or more of the following: visibility, fine particles, ozone, sulfur dioxide, atmospheric deposition (wet and/or dry), or meteorology. Monitoring at most of these locations is conducted by NPS, with some stations operated by states or other federal agencies. Measuring air pollution levels in parks is an essential part of the NPS air resource management program and provides vital information to Congress, academia, air pollution control agencies, and the public on air pollution levels in national parks, as well as in rural America.

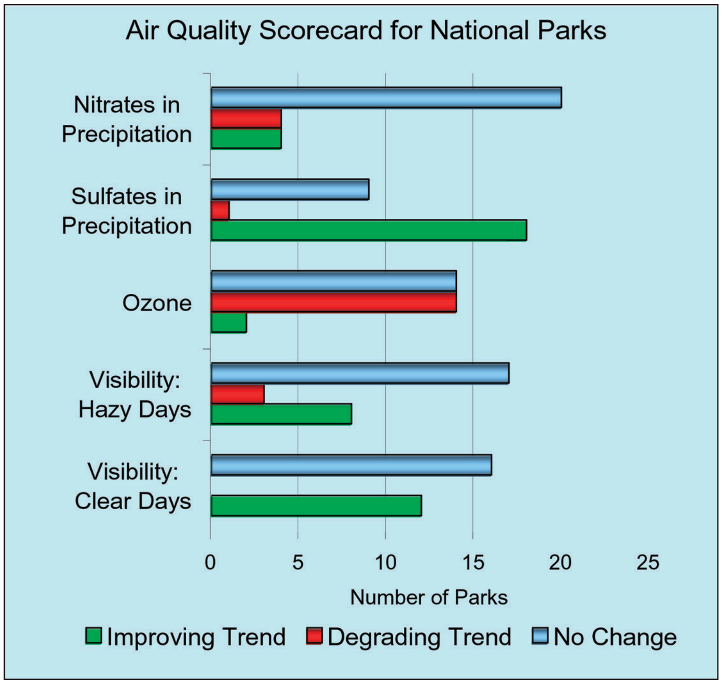
In addition to the monitoring described above, NPS conducts snow, fog, and cloudwater sampling in a few parks and is establishing a network to monitor levels of toxic air contaminants, such as airborne persistent organic pollutants and mercury in precipitation, on a routine basis.

Gaseous pollutant and meteorological monitoring The gaseous pollutant monitoring program concentrates primarily on determining the levels of ozone and sulfur dioxide in the parks primarily because of their toxicity to native vegetation at or below the levels of the National Ambient Air Quality Standards (NAAQS). Ozone has been measured in several parks at levels exceeding the NAAQS raising concerns about potential human health effects to visitors and employees. Meteorology monitoring complements gaseous pollutant monitoring by providing data useful in assessing measured levels of air pollutants.

Pollutant transport Sources contributing to air pollution problems in parks need to be identified so that appropriate remedial actions can be recommended to regulatory agencies. NPS often uses EPA-approved air quality dispersion and other accepted mathematical models to simulate the atmospheric and chemical mechanisms that transform and transport pollutants to national parks. The NPS uses models to identify sources, source areas, or source types that result in elevated pollutant concentrations in national parks or to predict their impact on park air quality.

Source-oriented mathematical models simulate the transport, dispersion, and fate of pollutants in the atmosphere from known emission sources to specific locations. Air pollutant emissions from known industrial facilities are coupled with meteorological data to simulate the transport of pollutants such as sulfur dioxide, nitrogen dioxide, and reactive hydrocarbons. The models also simulate the chemical reactions that form secondary pollutants, such as ozone, sulfates, and nitrate particles. The models then estimate the amount of pollutants that are deposited on the ground as acid rain particles or as gaseous deposition, and the

Number of national parks showing a statistically significant trend for various air quality indices over the 10-year period, 1990-1999. A majority of parks show improvements in visibility on clear days and in the concentration of sulfates present in precipitation. Nearly all parks show degradation or no change in nitrate levels in precipitation. Almost half of the parks show significant degradation in ozone levels, with only few showing an improvement. Hazy conditions persist in most parks. Refer to Chapter Two for additional information on air quality status and trends.



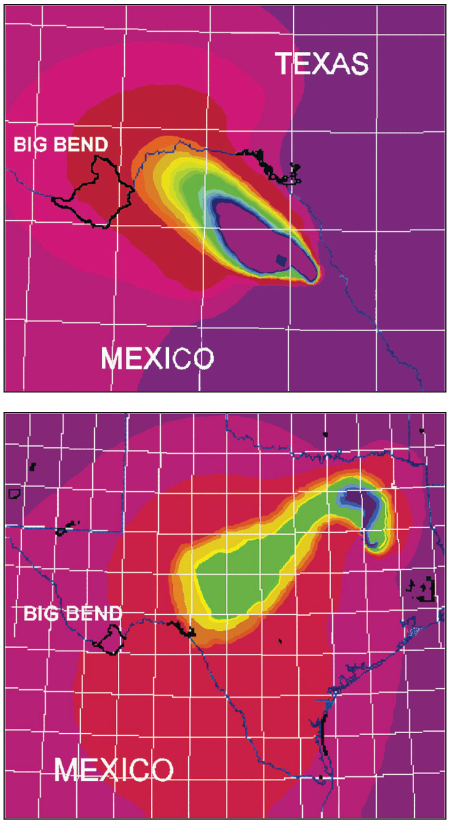
amount that remains in the atmosphere. These estimates are used to assess the impact on resources, such as visibility impairment or the acidification of lakes or streams.

Receptor-oriented models trace the path that clean or polluted air masses traveled in the atmosphere prior to arriving at a park. These models can be used to estimate the likelihood that an area may have contributed to clean or polluted events. From the analysis of these "back trajectories" for all measurements made at a park, clean and polluted transport "corridors" can be identified. Combining the results of these analyses with information on the actual location of source areas or type of sources, the relative contribution of each source area or source type to air pollution at a park can be determined.

Meeting our affirmative responsibilities Protection of air quality in national parks presents interesting challenges, because the NPS has no direct authority to control sources of pollution located outside park boundaries. Nonetheless, many actions are being taken to ensure that progress will continue to be made in meeting clean air goals for our national parks.

Communication Information about air quality conditions in parks is shared with the public in a variety of ways. Over 50 park units have exhibits with air quality related information. Several parks have real-time information about current air quality conditions available through Web sites and in visitor centers. Air quality data and issues are discussed in park brochures, newspapers, fact sheets, audio-visual programs, interpretive talks, and community-oriented educational outreach. The NPS Air Resources Division also maintains a Web site with information about air quality in parks throughout the country, including access to databases, images, and reports.

Consultation The Clean Air Act requires states to consult with the NPS prior to issuing permits for construction or modification of facilities that might affect air quality in Class I areas. During the "new source review" process, the NPS shares information about air quality conditions, potential effects on park resources, assessment techniques, and the most efficient pollution control technology. In cooperation with the U.S. Forest Service and Fish and Wildlife Service, the NPS has also developed guidance for permit applicants to help streamline the review process while at the same time ensuring that new sources will not contribute significantly to air quality deterioration in parks. As a result of NPS involvement in permit application reviews, the permitting agency and public are made aware of how new facilities might affect park air quality, and emissions from proposed new sources have been reduced.



Source-oriented simulation modeling shows how emissions from sources in the U.S. and Mexico can combine to impact air quality at Big Bend National Park, Texas, on the same day. Park boundaries are outlined on the map.

"The whole arena of observable sky phenomena-- daytime as well as nights -- is a spectacular resource at Cedar Breaks. Any diminution of air quality combined with increased light pollution will have devastating effects on the quality of this fast-diminishing resource."

Denny Davies, Superintendent
Cedar Breaks National Monument, Utah

Once night falls, the equally magnificent night sky in national parks emerges replacing the daytime scenic views. Light pollution and air pollution combine to diminish the spectacular night sky that attracts numerous visitors to national parks.

Source: NASA

The NPS also actively promotes and supports national and regional initiatives to reduce air pollutant emissions. NPS provides advice and technical assistance to state and federal regulatory agencies that are responsible for developing air pollution control programs. Current air quality standards and regulations do not appear to have been sufficient to fully protect sensitive park resources, so the NPS has been an advocate for new standards and cost-effective pollution reduction and prevention programs, including the following items.

Motor vehicle standards The NPS endorsed the EPA's issuance of "Tier 2" mobile source emission reduction standards and gasoline sulfur standards for refineries that would significantly reduce emissions from cars and light trucks, including sports utility vehicles, minivans, and pickup trucks. Tier 2 standards will decrease emissions of hydrocarbons and nitrogen oxides, which will have numerous benefits such as reduced levels of ambient ozone, decreased particulate matter and carbon monoxide emissions, improved visibility, reduced acid rain problems, and reduced greenhouse gases and toxic air pollution. The new emissions standards will take effect in 2006 with the full effect on pollution levels expected by 2020. These standards will result in decreases in emissions even with expected increases in the number of vehicles and miles traveled. The NPS also testified in favor of new standards for heavy-duty diesel engines and off-road vehicles. EPA issued regulations for diesel engines in January 2001.

Eastern states nitrogen oxides state implementation plan order In the eastern U.S., ground-level ozone pollution routinely exceeds health standards. After a multi-year technical study on the effects of nitrogen oxide emissions across the eastern region, EPA issued a requirement that 20 eastern states must reduce emissions of nitrogen oxides to levels determined to help bring the region into compliance with health standards. NPS publicly supported this rule. This reduction should lead to less formation of ozone and nitrate and, by reducing oxidants in the atmosphere, should lead to lower formation of sulfate as well. These expected outcomes will reduce ozone levels and acid deposition in eastern parks while also improving visibility.

Regional haze regulations The NPS provided technical information and consulted closely with EPA in the development of new visibility protection regulations, which were issued in 1999. The regulations require states to make "reasonable progress" toward restoring "natural" visibility conditions in mandatory federal Class I areas. Improving visibility in Class I areas will improve visibility nationally, thereby benefiting all NPS units as well as urban areas. One of the key components of the program is that older, major stationary sources such as power plants, smelters, and oil refineries, must install best available retrofit technology (BART) if they are found to contribute to regional haze. This will result in a significant reduction in visibility-reducing pollutant emissions. The NPS helped EPA develop and publicly endorsed a rule proposed in June 2001 outlining the BART process.

EPA estimates that roadway vehicles emitted 8.6 million tons of nitrogen oxides and 5.2 million tons of volatile organic compounds during 1999.

Air quality related value restoration and protection rulemaking In July 2000, the NPS, through the Department of the Interior, asked the EPA for rulemaking to restore and protect air quality related values in Class I areas, and for more immediate actions to reverse deteriorating air quality trends at Great Smoky Mountains and Shenandoah National Parks, and the Blue Ridge Parkway. The EPA solicited public input on the NPS request for new tools to mitigate adverse impacts from air pollution in national parks.

Cooperation The air pollution problems in parks are often the result of pollution transported regionally, nationally, or even internationally. Therefore, the NPS must work in partnership with states, tribes, other federal agencies, non-governmental organizations, academic institutions, scientists, and a wide variety of stakeholders. These partnerships facilitate the acquisition of information, such as monitoring and research data, or help build consensus on air quality protection goals and strategies.

The NPS participates in regional partnerships, such as the Western Regional Air Partnership (WRAP), a voluntary organization of western states, tribes, and federal agencies. The WRAP was formed in 1997 as the successor to the Grand Canyon Visibility Transport Commission, which made over 70 recommendations in June 1996 for improving visibility in 16 national parks and wilderness areas on the Colorado Plateau. The WRAP is implementing regional planning processes to improve visibility in all western Class I areas by providing the technical and policy tools needed by states and tribes to implement the federal Regional Haze Regulations.

Recognizing the regional nature of many air pollution problems — including regional haze that degrades visibility in parks — regional planning organizations have been convened around the country to coordinate air quality planning efforts among states and tribal governments. In particular, these organizations are facilitating the implementation of the visibility protection regulations. The NPS is actively participating in these regional partnerships by lending technical expertise, assisting in the development and evaluation of various strategies, and helping inform and involve the public in the consensus-building process.

Conservation Air quality in parks is also affected by activities and facilities within parks. Parks contribute to air pollution control efforts through energy conservation, use of alternative or renewable fuels, development of alternative transportation systems, and smoke management practices. Promoting the use of energy efficiency and renewable energy technologies and educating the public about our nation's energy options are at the heart of the Green Energy Parks program. The national parks are ideal places to showcase the federal government's commitment to both promoting energy efficient and renewable energy technologies and practices, and reducing the environmental impacts associated with pollution and global climate change. To this end the Department of the Interior has partnered with the Department of Energy (DOE) whereby parks use a variety of DOE programs designed to provide technical assistance and financial resources to federal agencies interested in establishing on-site energy and water conservation and renewable energy projects. Replacing diesel generators with photovoltaic arrays at Glen Canyon National Recreation Area and Joshua Tree National Park, for example, have replaced the use of 81,000 gallons of diesel fuel and reduced annual air pollution emissions (e.g., sulfur dioxide, nitrogen oxides) by 35 tons and carbon dioxide emissions by over 900 tons at these parks.

These are some of the national and regional activities NPS is engaged in to make progress toward meeting its air quality preservation mandates. The information, expertise, and management concerns that the NPS brings to various external decision-making arenas has made a difference. Air quality-related interpretive and educational programs implemented by parks have also contributed to public understanding and support for air pollution control programs. Efforts to reduce and prevent pollution from activities and operations within parks will also help us meet this goal. However, more public participation and advocacy for the preservation of clean air in our national parks is needed if we are to:

> "... *leave them unimpaired for the enjoyment of future generations.*"

Chapter Two

Current Air Quality Conditions and Trends

Visibility

Among the experiences that visitors enjoy, treasure, and remember are the breathtaking scenes of majestic mountains contrasted against a pure blue sky or the form and texture of unique landscapes and geologic features. Our national parks are often referred to as the "crown jewels" and represent some of the finest of nature's "cathedrals." The enjoyment and appreciation of these are inextricably linked to one's ability to see clearly. The atmosphere plays a key role in this, and so does air pollution. Fine particles suspended in the atmosphere, mostly as the result of human-caused air pollution, have dropped a veil over these scenes, robbed the visitor's appreciation of the scenes' colors, forms, and textures, and the experience of seeing "forever". Haze conditions in parks have diminished the visitor experience to our national parks.

There are still a few days a year in parks where visibility is unimpaired by pollution. These opportunities, however, are infrequent. And, if we're not careful in protecting America's national parks from human-caused air pollution, these opportunities could become even less frequent.

Current visibility conditions Air pollution currently impairs visibility to some degree in every national park. Congress recognized the importance of visibility in national parks and wilderness areas when it established a national goal in 1977 of preventing any future visibility impairment, and remedying any existing visibility impairment due to human-caused air pollution. EPA has developed rules addressing visibility impairment, and in 1999 issued *regional haze* regulations to address the hazes degrading the scenic resources of specially designated national parks and wilderness areas, or Class I areas. These regulations require that reasonable progress be made to restore current visibility conditions to natural conditions within 60 years. States are to establish goals for each affected area to improve visibility on the haziest days and ensure no degradation occurs on the clearest days.

EPA estimates annual average natural visibility conditions for parks in the eastern U.S. are between 113 and 117 miles (182 and 189 kilometers) and parks in the western U.S. are between 141 and 158 miles (228 and 255 kilometers). For eastern parks, such as Great Smoky Mountains and Shenandoah National Parks, annual average visibility has been about 24 miles (38 kilometers) based on 1996-1999 data. This indicates that an improvement of nearly 100 miles in visual range must occur if visibility in these parks is to be restored to natural conditions. Western parks enjoy much better visibility than eastern parks, yet in parks like the Grand Canyon and Big Bend, annual visual ranges must be improved by 60 and 90 miles, respectively, to achieve natural visibility conditions.

The map on page 13 shows the distribution of visibility conditions across the country based on data collected in national parks and wilderness areas. It illustrates the large differences that exist in visibility conditions between the eastern and western United States, with western visibility conditions generally being substantially better than eastern conditions. Climatic factors such as higher relative humidities and the greater density, quantity and mix of emissions in the East are some of the reasons for this difference. The best visibility in the contiguous U.S. occurs in an area centered around Great Basin National Park, Nevada, where visibility ranges seasonally between 97 and 122 miles (156 and 196 kilometers) with summer having the haziest conditions. In contrast, summertime visibility conditions at Acadia National Park in Maine average only 32 miles (52 kilometers), considerably worse than at Great Basin National Park. Conditions at Mammoth Cave, Shenandoah, and Great Smoky Mountains, which together account for almost 12.4 million recreational visits annually, are even worse than those found at Acadia.

Years of visibility monitoring show that seasonal differences in visibility conditions exist in parks. For most areas of the country, visibility tends to be best during

National Visibility Goal

> *"Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution."*
>
> *1977 amendments to the Clean Air Act*

Big Bend National Park, Texas.

> *"Because we don't have the long history in the US as they have in Europe and other countries, the National Parks are the cathedrals and our great works of arts; the equivalent of what is in other countries. We need to preserve them so we can be inspired by them."*
>
> *Frank Deckert, Superintendent*
> *Big Bend National Park, Texas*

View from Great Basin National Park under near pristine conditions (left) and current annual average conditions (right). Light scattering caused by microscopic fine particles resulting from human-caused air pollution result in the whitish hazes that obscure scenic views at national parks. The goal of the EPA's Regional Haze Regulations is to restore NPS areas to natural visibility conditions.

Source: IMPROVE Monitoring Network Permanent Photographic Archive

the winter months and worst during the summer. These differences can be large with winter visual range in some parks, (e.g., Lassen Volcanic and Yosemite), being as much as 70 percent better than during the summer. Unfortunately, summer also coincides with the period of highest visitation in most national parks, and haze is likely diminishing visitor enjoyment of the spectacular vistas found in national parks.

Causes of visibility impairment The scattering and absorption of light by particles and gases emitted by, or formed as a result of, natural and human-caused activities causes visibility impairment. In addition to limiting the distance one can see, air pollution can also degrade the color, clarity, and texture of a scene. Light scattering by fine particles approximately one millionth of a meter (micrometer, or micron) in size causes most of the whitish hazes that one often sees obstructing scenic views.

The concentration and size of the particles in the air play an important role in reducing visibility, as does the humidity of the air. Small particles the size of molecules are inefficient scatterers of light, however, as particle size gets larger—to about 0.1 micron in size—they scatter light more efficiently causing a greater reduction in visibility. The same mass of larger particles (greater than 2.5 microns) are much less efficient in scattering light and contributes less towards visibility reduction. Particles such as sulfates and nitrates are hygroscopic (have an affinity for absorbing water) and the scattering properties can change as a result of the air's humidity. As relative humidity increases so does the scattering efficiency of these particles, sometimes by as much as five times or greater.

Chemical signatures contained in fine particle samples are used to determine the amount that certain chemical constituents and source types (for example, smelters or power plants) contribute to visibility impairment. Knowing the chemical constituents responsible for visibility impairment allows scientists to infer the probable causes for the observed impairment and the reductions in emissions that must occur to remedy this impairment. Years of monitoring and research by NPS and others have found fine particles in the form of sulfates, nitrates, organics, elemental carbon, and soil particles are primarily responsible for visibility degradation. In fact, actual light extinction can be estimated fairly accurately just knowing the amount of these chemical compounds contained in fine particle samples.

Sulfate particles formed from sulfur dioxide emissions associated with fossil fuel combustion—mostly for electric genera-

Parks with Best Annual Average Visibility, in miles

Denali NP & Preserve	*122*
Great Basin NP	*109*
Crater Lake NP	*105*
Yellowstone NP	*102*
Mesa Verde NP	*99*

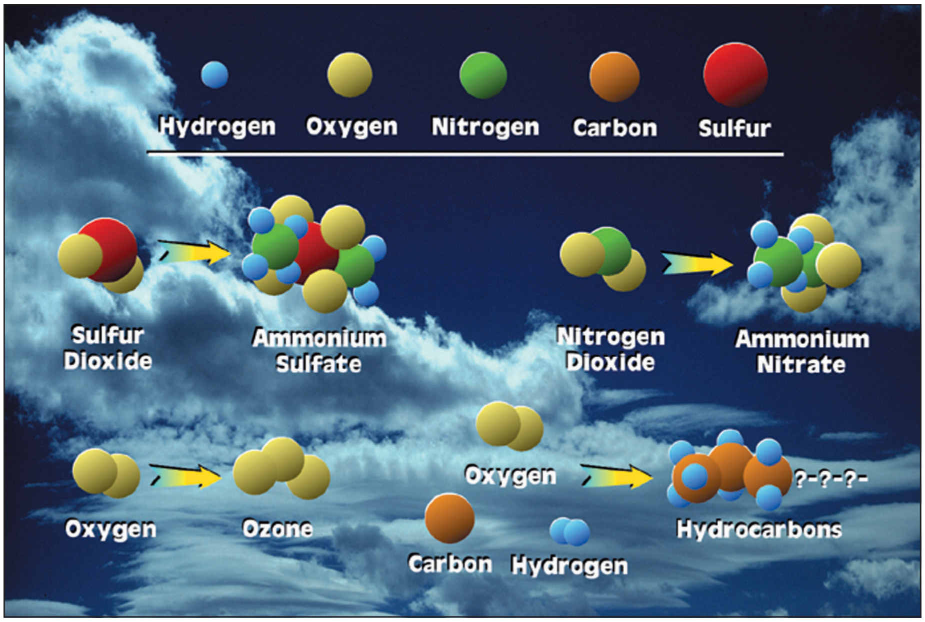
Parks with Worst Annual Average Visibility, in miles

Mammoth Cave NP	*17*
Great Smoky Mtns. NP	*24*
Shenandoah NP	*24*
Sequoia NP	*42*
Acadia NP	*45*

Source: IMPROVE Program 1996 - 1999

Seasonal differences in visibility at Lassen Volcanic National Park, California. Left photo represents average conditions during winter months, while right photo represents average conditions during summer. For most parks, visibility is best during winter and worst during summer.

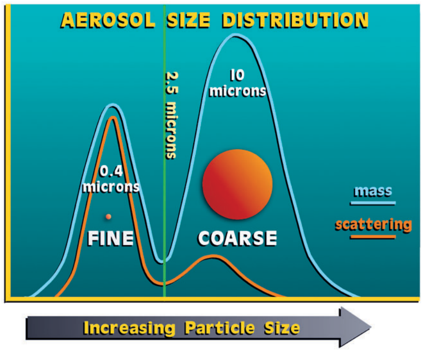
Source: IMPROVE Monitoring Network Permanent Photographic Archive



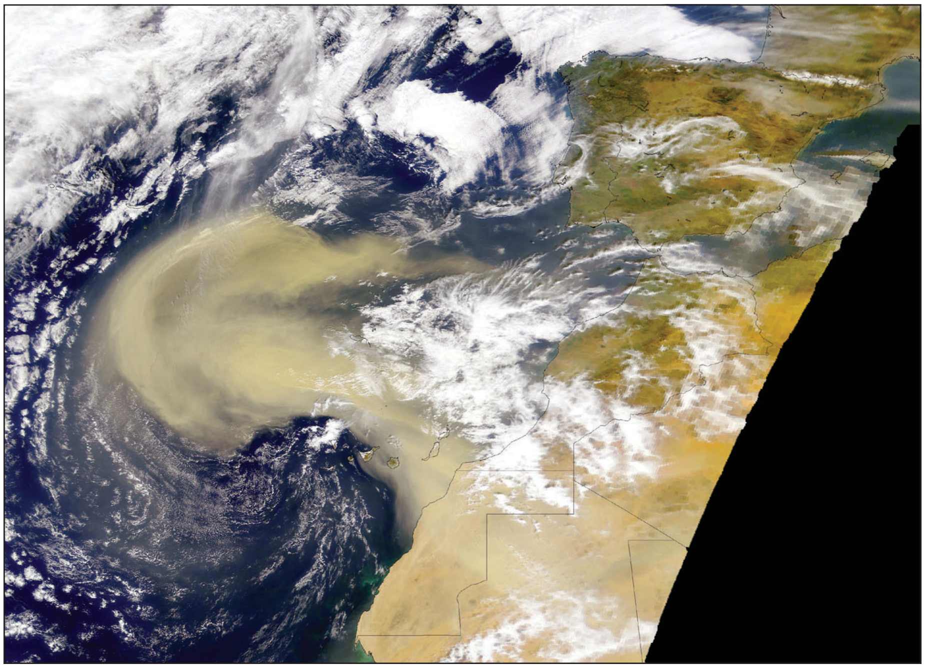
Five atoms, hydrogen, oxygen, nitrogen, carbon, and sulfur, play a significant role in determining air quality. Through complex sets of chemical reactions, gases are formed that, in some cases, react to form visibility reducing particles. Sulfur dioxide reacts to form ammonium sulfate, nitrogen oxide forms ammonium nitrate, oxygen is converted to ozone, and carbon, hydrogen, and oxygen complexes react to form other hydrocarbon gases and particles.

tion—account for 60 to 85 percent of the visibility impairment observed in eastern parks. In contrast, sulfates account for between 30 to 40 percent of visibility impairment in the western U.S. The contribution of the other chemical constituents is typically less than that of sulfates as illustrated in the figure on the following page. Organics and elemental carbon play a much greater role in visibility impairment in certain regions of the West and Pacific Northwest. This is thought to be in part the result of a greater contribution of emissions from agricultural and forest fires to overall visibility reduction.

Soil particles can be important contributors to visibility impairment in the western U.S. primarily due to the greater occurrence of wind-blown dust. On occasion, wind-blown dust from as far away as the Sahara (Africa) and Gobi (China) Deserts is transported in the upper atmosphere affecting visibility conditions in parks. Smoke from forest fires, sometimes from Central America and southern and central Mexico, can impact visibility substantially during some episodes, typically during late spring and early summer.



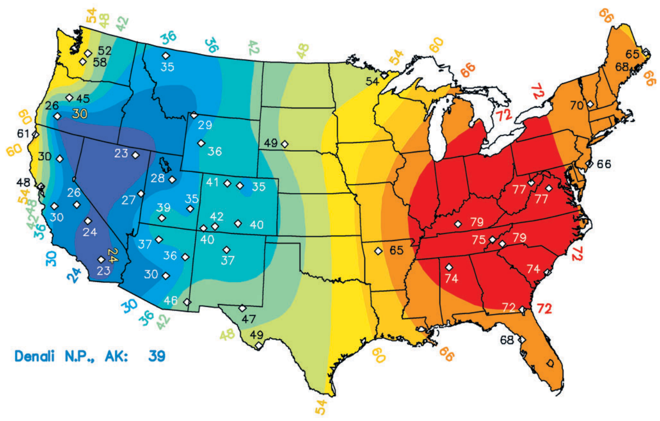
The size of particles affects visibility due to light scattering. The blue line shows the relative amount of mass typically found in a given particle size range. The orange line shows the relative amount of particle scattering associated with that mass. Note that even though mass is associated with coarse particles, the fine particles are more efficient for light scatter.



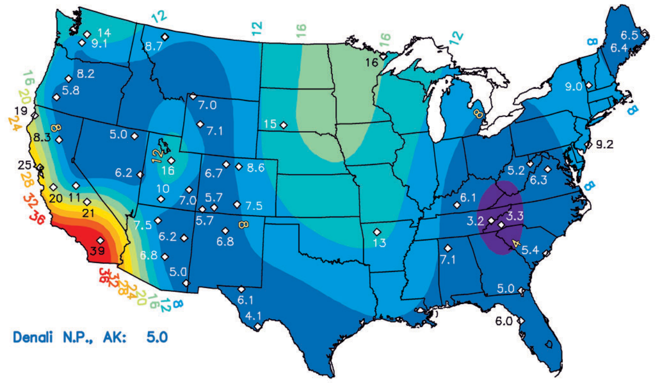
A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand, which reached over 1,000 miles into the Atlantic. These storms and the rising warm air can lift dust 15,000 feet or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean. Recent studies by the U.S.G.S. have linked the decline of the coral reefs in the Caribbean to the increasing frequency and intensity of Saharan Dust events. Fine particle sampling conducted by the NPS has documented evidence of Saharan dust reaching national parks in the U.S.

Provided by the SeaWiFS Project, NASA/GSFC and ORBIMAGE

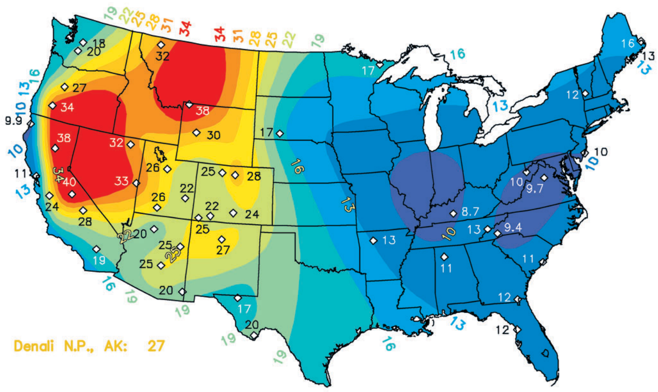
Sulfates



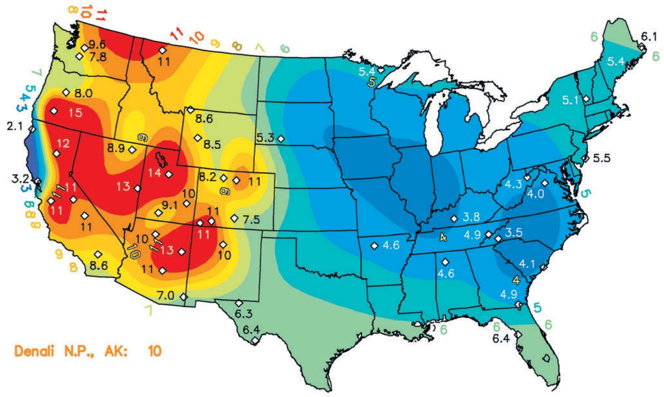
Nitrates



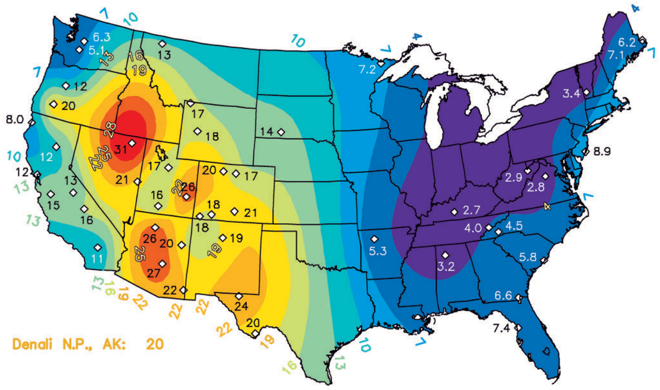
Organics



Light Absorbing Carbon



Coarse Mass



Maps illustrating the percent contribution of the primary chemical constituents of fine particle mass to visibility impairment in national parks across the United States. Sulfates formed from emissions of sulfur oxides, mostly from coal-fired power plants, are the primary contributor to visibility reduction throughout most of the U.S. In the eastern U.S., sulfates can contribute to more than 75 percent of the impairment at some locations. Organics and light absorbing carbon (elemental carbon), emitted in part by agricultural and forest fires, can contribute significantly over large areas of the country.

Visibility trends Seasonal haze patterns and trends based on airport visibility records since 1950 are illustrated in the maps shown on the following page. The maps show two large contiguous haze regions, one over the eastern United States and the other along the Pacific coast. Between these two haze regions lies an area with better visibility that spans from the Rocky Mountains to the Sierra-Cascade mountain ranges in the Pacific Northwest. Although this general pattern has been preserved over the last 45 years, notable trends have occurred over both the western and the eastern U.S.

Increased haze conditions occurred throughout the Pacific coast of the United States, particularly in central and southern California where the highest haze levels occurred during the winter and fall seasons. The haze increased from the 1950s to the 1960s and remained relatively constant through the 1980s. During the period 1980-1994, however, the haze levels declined about 10 percent throughout the Pacific coast, including the San Joaquin and Los Angeles basins.

Haze in the eastern U.S. extends from the Great Plains states to the East Coast. Significant seasonal variations and long-term trends over different sub-regions are exhibited. In the 1950s, the greatest haze occurred during the winter and fall seasons, particularly over the Midwestern and Great Lake states. During the 1960s and 1970s, the haze during winter decreased slightly in New England and in the Midwest but increased in the Southeast. The summertime haze increased significantly throughout the eastern U.S., and by the 1970s the summer became the haziest season in the eastern U.S. From 1980-1994 the haze decreased almost 10 percent throughout the eastern U.S. The largest decreases occurred in the southeastern U.S. (12 percent) compared to the northeastern U.S. (8 percent).

Prior to 1990, visibility degradation in the southeastern U.S. coincided with the increase in sulfur dioxide emissions associated with increased fossil fuel combustion primarily for electric generation, which accounts for 65 percent of total sulfur dioxide emissions in this country. Emissions from fuel combustion in the electric utility industry increased nearly fourfold between 1950 and 1980 from 4.5 million to 17.5 million tons.

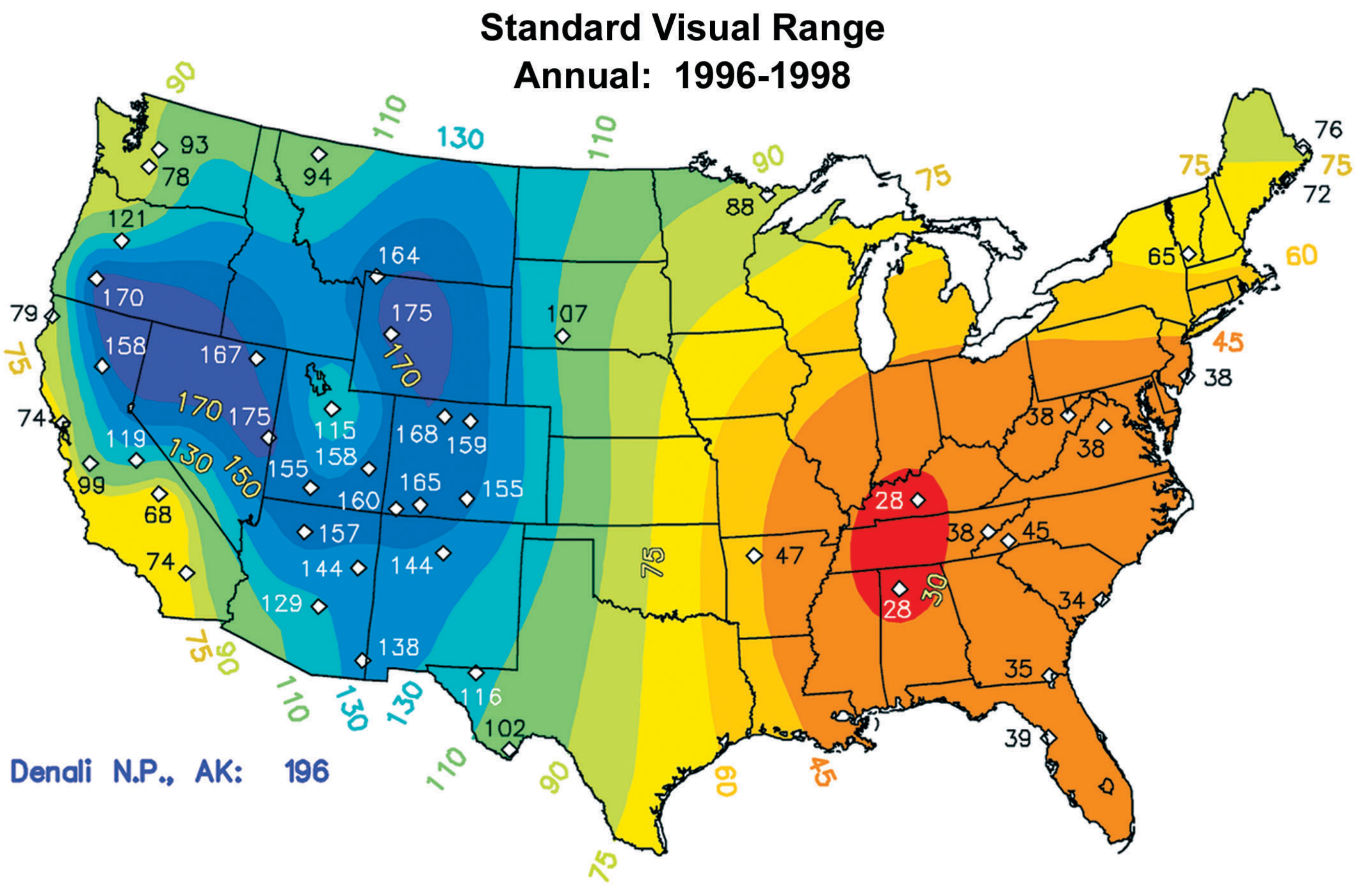
Sulfur Dioxide Reduction

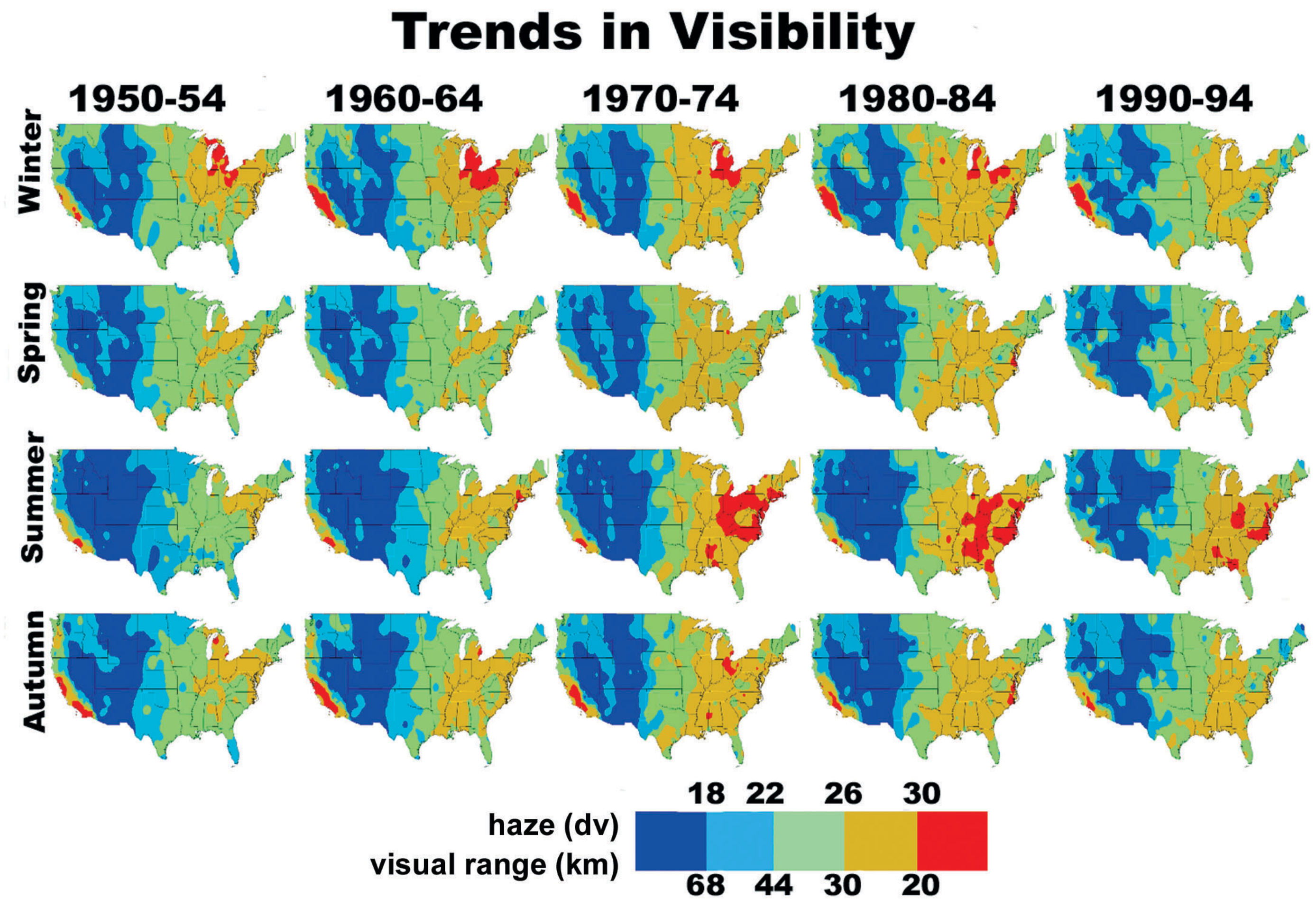
The 1990 amendments to the CAA required a 10 million ton reduction in sulfur dioxide emissions from electric utilities by 2010. From 1990 through 2000, EPA estimates that nearly five million tons of sulfur dioxide emissions have been reduced by the electric utility industry.

> **"...the loss of quality viewing is apparent through increased haze and many fewer days when Wheeler Peak in Great Basin National Park is visible."**
>
> *Denny Davis, Superintendent*
> *Cedar Breaks National Monument, Utah*

Visibility conditions (visual range) throughout the United States, in kilometers. Visibility conditions in the eastern U.S. are substantially worse than those in the western U.S. primarily due to the high concentration of sulfur dioxide emissions in the eastern U.S. These emissions are transformed in the atmosphere into sulfate fine particles, or aerosols, which account for most of the visibility impairment in the eastern U.S.

Source: IMPROVE

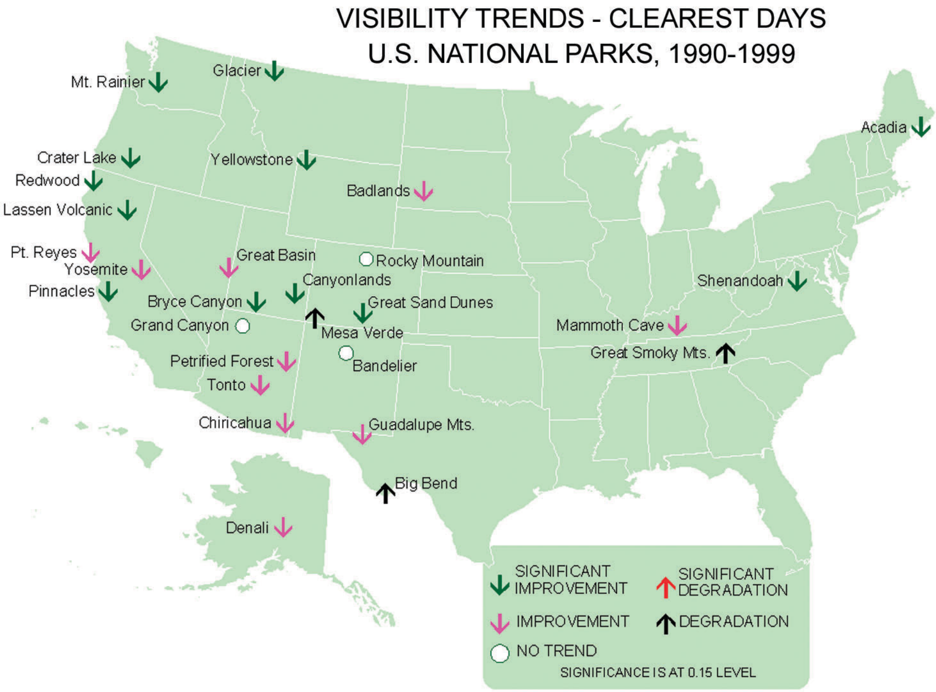




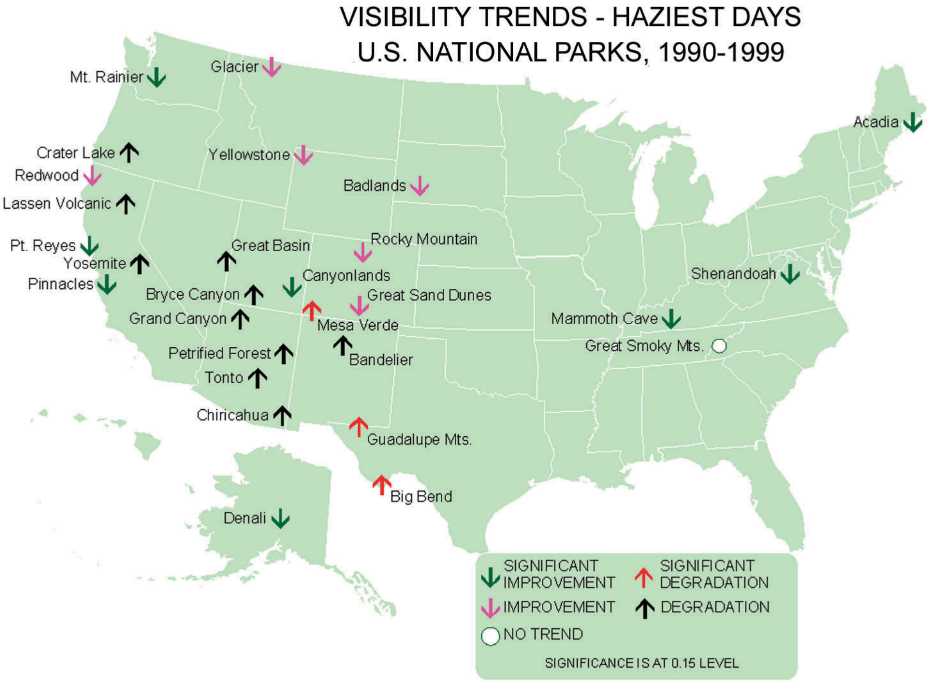
Trends in seasonal visibility across the United States from 1950 through 1994 based on the analysis of airport visibility records. Visibility declined steadily between 1950 and 1984, particularly in the eastern U.S. Some improvements occurred in most areas of the country between 1984 and 1994.

Over the 10-year period 1990 through 1999 visibility conditions have improved for some regions of the country, particularly for days with the best visibility, (i.e., the clearest days). Although there have been large reductions in sulfur dioxide emissions from electric utilities in the eastern and southeastern U.S. required by the 1990 amendments to the Clean Air Act, not all parks show an improvement in visibility. Although Acadia and Shenandoah National Parks show a significant improvement in visibility on the clearest days, clear and hazy conditions at Great Smoky Mountains have failed to show an improvement in spite of these reductions. The two maps on the page at right illustrate these trends in national parks over the last 10 years for the clearest and haziest conditions, respectively.

NPS assessed the changes for days with the best visibility (20 percent clearest days) and poorest visibility (20 percent haziest days) based on fine particle measurements made in national parks. Improvements on the clearest days have occurred in numerous parks in the western U.S. over the last 10 years as well. Nonetheless there are still numerous western parks where visibility conditions have degraded significantly on the haziest days. In most of these cases, the haziest days are becoming much hazier, with parks in the Southwest and on the Colorado Plateau being the most affected, as illustrated in the bottom figure on the page at right.



Trends in best visibility conditions (annual average haze levels of the 20 percent clearest days, in deciviews), at national parks during 1990-1999. Nearly all parks show some improvement in visibility conditions, with 12 showing significant improvement. Three parks continued to show degradation on the clearest days (Big Bend, Great Smoky Mountains, and Mesa Verde), however, the trends are not statistically significant.



Trends in the worst visibility conditions (annual average haze levels of the 20 percent haziest days, in deciviews), at national parks during 1990-1999. Most parks show at least some degradation or worsening of visual conditions, especially in the southwestern U.S., where haze conditions at three parks (Big Bend, Guadalupe Mountains, and Mesa Verde) show significant degradation.

Deposition of Toxic Pollutants

Atmospheric deposition of toxic compounds such as metals, pesticides, and industrial chemicals can also cause ecosystem impacts. One example is the accumulation of mercury in the food web, resulting in human health risks from eating mercury-contaminated fish.

Acidic deposition also speeds the decay of buildings, statues, sculptures, and petroglyphs that are part of our national heritage.

Spruce-fir Forests Under Stress

Great Smoky Mountains National Park contains 74 percent of the spruce-fir forests in the Southern Appalachians, making the park the largest remnant red spruce-Fraser fir ecosystem in the world.

Spruce-fir forests in the park are undergoing greater stress, possibly as a result of atmospheric deposition inputs to forest-water chemistry.

It is currently unknown how much sulfur and nitrogen emissions would have to be reduced before atmospheric deposition impacts would cease to cause ecosystem changes at Great Smoky Mountains National Park.

Atmospheric deposition

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through precipitation (rain, snow, clouds, and 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 and dry deposition) to park ecosystems, usually only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Wet deposition, often referred to as *acid rain,* occurs when nitrogen and sulfur gases and particles in the atmosphere are washed out in precipitation. Acid deposition affects freshwater lakes, streams, ponds, and the watersheds surrounding these surface waters. Effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. These changes can result in higher food chain impacts in park ecosystems. Deposition can also cause chemical changes in soils that affect soil microorganisms, plants, and trees. Some tree species may experience growth reductions, and alpine plant community compositions may change where high deposition occurs. The deposition of nitrogen contributes to nutrient enrichment in coastal and estuarine ecosystems, the symptoms of which include toxic algal blooms, fish kills, and loss of plant and animal diversity.

High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and the upland areas of the 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 National Parks are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain National Park is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition.

Critical loads and target loads In assessing the risk to park ecosystems from atmospheric deposition it is important to know the amount of pollutants that an ecosystem may be able to tolerate in order to prevent or remedy any adverse effects. *Critical loads* are threshold amounts of pollutants at which harmful effects on sensitive resources begin to occur. Critical loads for sulfur and nitrogen deposition are science-based and vary by ecosystem because soils, water, and biota tolerate acidic and nutrient inputs differently. A *target load* is the amount of deposition that will result in an "acceptable level" of resource protection. NPS would set target loads lower than critical loads (i.e., more protective) in order to protect very sensitive ecosystem components to prevent unnatural changes to these ecosystems. Although few critical loads have been established thus far in the United States, the NPS views establishing critical and target loads for park ecosystems as effective management tools to guide pollution reduction efforts and assess their effectiveness in mitigating adverse effects attributable to atmospheric deposition.

There are several parks in the U.S. where these "critical loads" are likely being exceeded. Ecosystem impacts from atmospheric deposition have been documented at Great Smoky Mountains, Shenandoah, and Rocky Mountain National Parks. In Great Smoky Mountains NP, sulfur and nitrogen deposition impacts high elevation spruce-fir forests by creating chemical changes that produce soil nutrient imbalances and forest health concerns in red spruce. Current deposition amounts of around 43 kilograms per hectare per year (kg/ha/yr) total sulfur, and around 33 kg/ha/yr total nitrogen are well above what could be considered the critical load level for the park. A kilogram is about 2.2 pounds and a hectare is about 2.5 acres.

Research studies indicate that chronic and episodic acidification related to sulfur deposition has affected fish in Shenandoah's aquatic ecosystems (see

Stream Acidification, at top right). Current total sulfur deposition is around 8 kg/ha/yr and would likely have to be reduced substantially (by some estimates more than a 70 percent reduction from current levels) in order to see even a small improvement in park water chemistry. It is unknown how much reduction in sulfur would be needed to reach a level where fish were no longer impacted. Recent studies suggest that critical loads for total (wet and dry) nitrogen in high elevation ecosystems in the central Rocky Mountains are around 3-5 kg/ha/yr. These loads are being experienced currently at Rocky Mountain National Park and there is strong evidence that nitrogen deposition associated with human activities has resulted in changes to aquatic and terrestrial chemistry and biota in the park's high elevation ecosystems.

There may be other national parks where critical loads have been exceeded. Unfortunately, most parks lack sufficient monitoring and research information to document with certainty any ecosystem responses that may be occurring as a result of atmospheric deposition.

Atmospheric deposition levels National parks generally lack complete information on *total* atmospheric deposition levels, as typically only precipitation samples are collected in parks. Cloudwater, and fog deposition, which at some locations can contribute significantly to total deposition, is sampled only rarely as part of research projects. Snow is collected as part of a regional network, such as the one in the Rocky Mountains. Dry deposition data have only been available recently at 26 parks as part of the joint NPS-EPA Clean Air Status and Trends monitoring effort.

The primary source of long-term information on wet deposition is the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), which began operation in 1978 and currently consists of more than 240 stations nationwide. NPS is a major sponsor of this network and has 42 NTN sites located in national park units. This network provides information based on weekly precipitation samples that are analyzed for several chemical constituents, such as acidity (pH), sulfates, nitrates, ammonium, and calcium.

In the following assessment of wet atmospheric deposition to park ecosystems, data are presented in terms of concentrations and deposition measured in precipitation samples for several pollutants of interest. Concentration data are useful in determining spatial and temporal trends because they are not dependent on the amount of precipitation at each site, which can vary substantially from year to year. Deposition is calculated by taking into account both the amount of precipitation and the concentration at each location. Years with higher amounts of precipitation will yield higher levels of deposition. Deposition data provide the total amount of pollutants actually deposited on the ground and quantify wet deposition inputs to ecosystems.

Sulfate, nitrate, and ammonium in precipitation Sulfate concentration and deposition levels across the U.S. show very similar patterns. Highest concentrations of sulfate range from 1.75 to greater than 2.5 mg/l and are centered over the highly industrialized Ohio River Valley, where sulfur emissions are highest in the country. Concentrations generally decline to the west, where they are less than 1.0 mg/l. Alaska's Denali National Park and Preserve measured 0.1 mg/l, the lowest concentration measured. Similarly, the highest deposition occurs over the Ohio River Valley and the eastern U.S., ranging from 18 to greater than 27 kg/ha/yr. Wet sulfate deposition is much lower in the West, generally less than 9 kg/ha/yr, due to fewer sulfur emissions and a dryer climate. Wet sulfate deposition across the U.S. for 1999 is shown in the top map on the following page.

Highest concentrations of nitrate range from 1.35 to greater than 1.8 mg/l, and occur from the Midwest to the Northeast. Relatively high concentrations also extend into the Great Plains and appear in the Southwest. The lowest concentrations, less than 0.4 mg/l, are found in the Northwest and Alaska. Ammonium concentrations are also of interest because they contribute to the total nitrogen deposited on ecosystems from precipitation. High ammonium concentrations also occur in the upper Midwest and extend south through the center of the country, where ammonia emissions associated with livestock wastes and fertilizer applications are high. Two other "hot spots"

Stream Acidification

Indicators of fish declines at the community, population, and organism level related to chronic and episodic stream acidification at Shenandoah National Park:

- *Reduced growth in black-nosed dace fish in streams with a lower ability to neutralize acids.*
- *Decline in fish survivorship (from 80 percent to 0 percent) at Paine Run during an "acute acidification" event in 1993.*
- *Trout populations (production and density) are smaller in streams with a poor ability to neutralize acids.*

Unfortunately, most parks lack sufficient monitoring and research information to document with certainty any ecosystem responses that may be occurring as a result of atmospheric deposition.

Great Smoky Mountains National Park, North Carolina/Tennessee, in the autumn. Streams such as these are being threatened by atmospheric deposition.

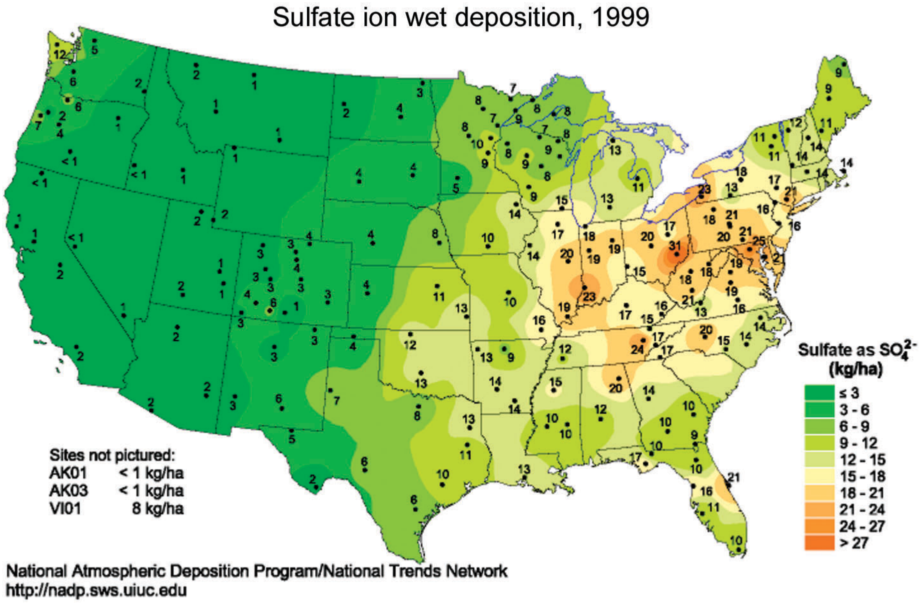
are in northern Utah and northern California. Lower concentrations occur in the Northwest, Southeast, and Alaska.

Nitrogen deposition, which accounts for nitrogen in both nitrate and ammonium, is shown in the bottom map below. The area of highest nitrogen deposition encompasses the Midwest and most of the eastern U.S. Nitrogen deposition in this area in 1999 is estimated at 5 to greater than 7 kg/ha/yr, whereas in the western U.S. it is generally less than 3 kg/ha/yr.

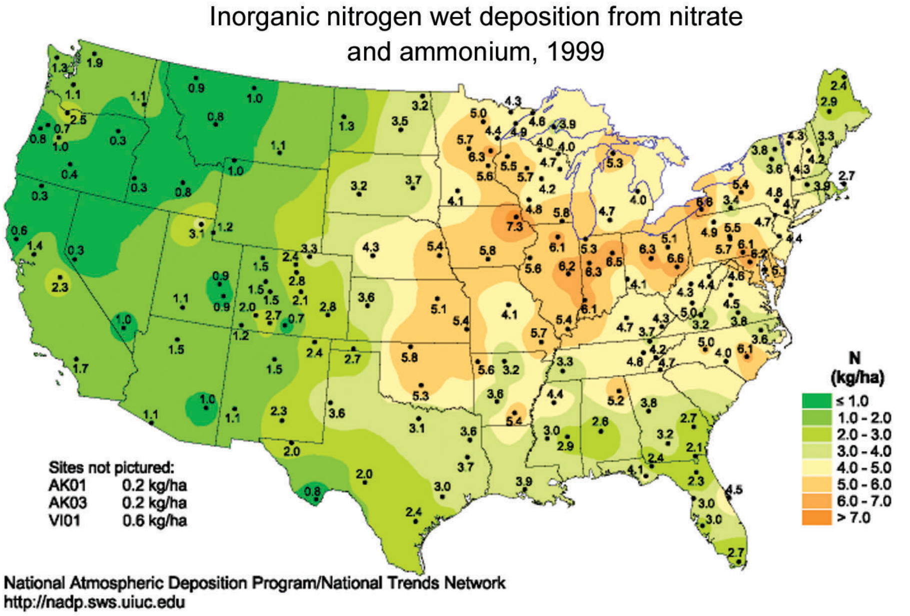
Acid Clouds and Fog

Deposition from clouds and fog plays an important role in many high elevation and coastal areas across the country adding significant amounts of pollutants and nutrients to ecosystems. Clouds are a significant source (30 percent to 38 percent) of nitrogen and sulfur at Great Smoky Mountains.

Concentrations of sulfate and nitrate in clouds at Shenandoah are 7 to 43 times as high as those in precipitation.



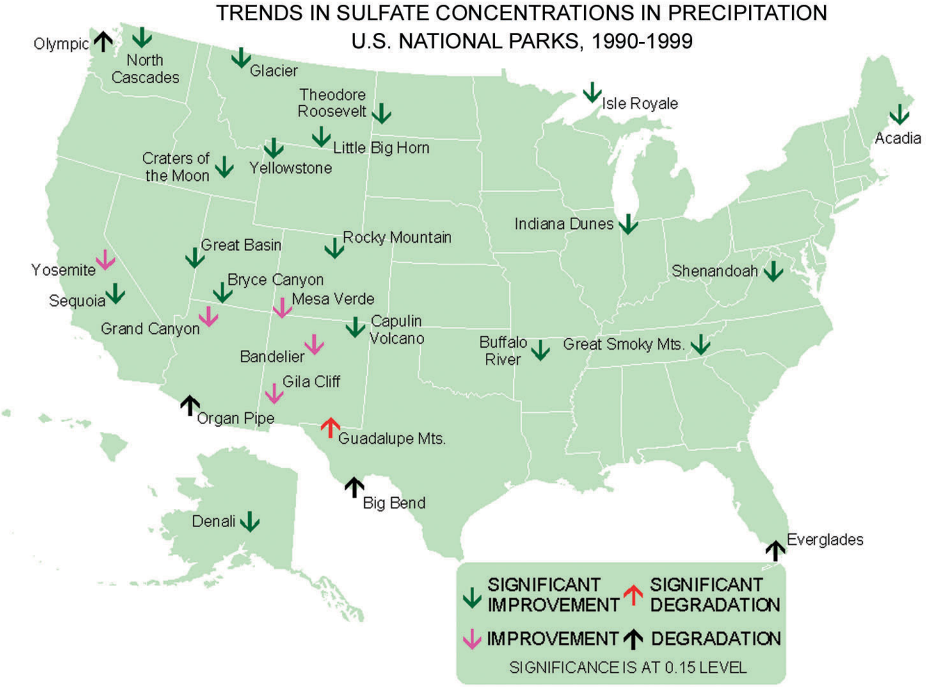
Wet sulfate deposition in 1999 shows the highest levels are in the Ohio River Valley, with most of the western U.S. showing levels less than or equal to 3 kg/ha/yr. In spite of recent reductions in deposition levels across the eastern U.S., sulfur deposition to some park ecosystems exceeds levels that these ecosystems can tolerate.



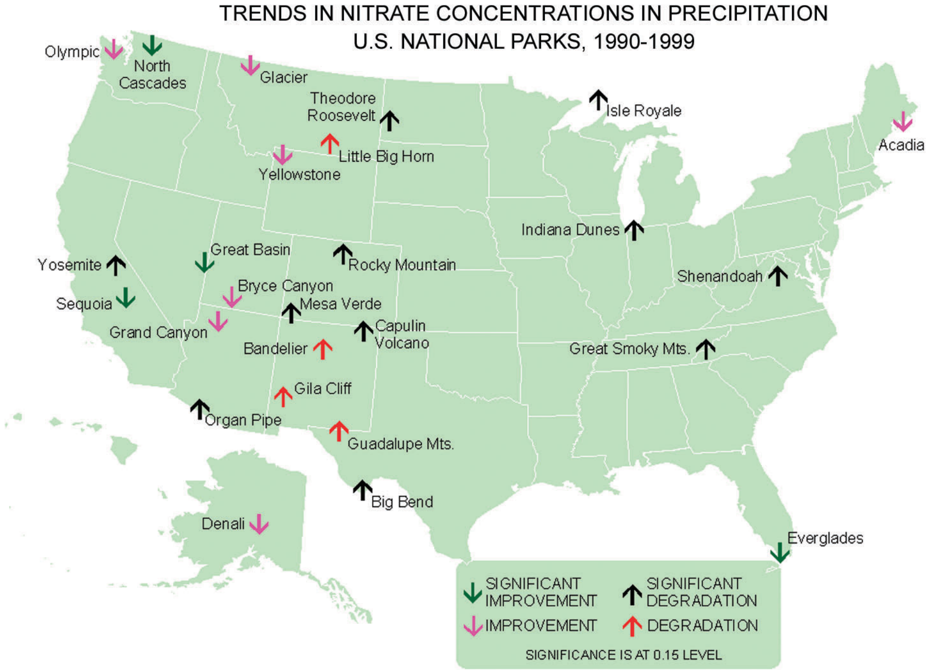
Nitrogen deposition in 1999 shows the highest levels are in the Midwest. In spite of lower nitrogen deposition levels in the West, some high elevation ecosystems in the Rocky Mountains are being affected.

Trends in sulfate and nitrogen concentrations in precipitation Precipitation chemistry in the U.S. has changed significantly over the past two decades. In general, sulfate levels are showing a downward trend but nitrogen is increasing at many parks. There are various ways of determining trends depending on the intended use of the information. The NPS prepares annual performance reports for Congress based on a methodology that only assesses trends in the annual average of sulfate and nitrate levels over the most recent 10 years.

Over the past 10 years, annual average sulfate concentrations have decreased at most parks, reflecting the 1995 sulfur emission reductions required under the Clean Air Act. Only five parks failed to show a downward trend, including those located near the U.S.-Mexico border, and



Trends in sulfate concentrations in precipitation from 1990-1999 show generally significant improvement in most national parks. The reduction of sulfate levels in precipitation have been attributed to the reduction of sulfur oxide emissions from electric utilities required by the 1990 amendments to the Clean Air Act.



itrate concentrations in precipitation increased at ıost parks from 1990 to 1999, with some parks howing significant increases. An issue that has ained in importance is the growing evidence of itrogen saturation in high-elevation forest cosystems of the Southern Appalachians and ther regions and the influence this condition may ave on terrestrial and aquatic chemistry in lational Park Service areas.

Measurements obtained from this air quality monitoring station at Rocky Mountain National Park, Colorado, and other stations located in national parks are used to estimate dry deposition levels of acidic air pollutants to park ecosystems.

Precipitation collectors such as this one at Virgin Islands National Park are used at 42 park locations to measure the chemical composition of rain.

at Everglades and Olympic National Parks. Of these five parks, Guadalupe Mountains had the only statistically significant increasing trend. Additional emissions reductions are likely necessary to reverse the trends for these five parks, including possibly a reduction from sources in other regions and countries.

In contrast, annual average nitrate concentrations have increased at many parks across the nation, with four parks in the western U.S. having statistically significant increases over the past 10 years. At the same time, concentrations of nitrate decreased significantly at four other parks, illustrating how local variability in nitrogen emissions may affect precipitation chemistry in parks. The NPS can use this information to determine where emissions reduction strategies would produce the highest benefit for specific park units.

Additional analyses of deposition trends have been conducted by others using methods designed to incorporate seasonal cycles and data over longer periods. This type of assessment yields useful information about changes in precipitation chemistry that may be more subtle (occur at certain times of year) and about long-term changes that may reflect decades of changes in emissions.

A recent analysis completed by the U.S. Geological Survey looked at seasonal averages to determine trends in precipitation chemistry from 1981 to 1998 for 147 sites in the NADP/National Trends Network, 21 of which are located in national parks. The analysis also showed most park sites having significantly decreasing trends in sulfate concentrations (see Table 2-1). The analysis also confirmed that concentrations of nitrate and ammonium have increased at many parks in the western U.S. over this period. The increasing trend in nitrogen is a cause for concern because of the changes associated with the addition of nutrients to ecosystems. The problem of increasing nitrogen does not seem limited to any specific region of the country suggesting that a national emissions reduction strategy may be necessary to prevent any further increase.

Overall, the reduction of sulfur emissions called for by the Clean Air Act has resulted in the reduction of sulfate concentrations in precipitation and surface waters in the northeastern U.S. Unfortunately, there has not been a recovery of pH and acid neutralizing capacity (ANC) in streams and lakes in this region. It has been suggested that more sulfur emission reductions are necessary to protect these ecosystems and there is currently an effort underway to begin to set "critical loads" in federal lands for sulfur and nitrogen as a means to doing this.

Table 2-1. National parks showing statistically significant changes in precipitation chemistry from 1981 to 1998 based on an analysis of seasonal averages

Source: USGS

Park	Sulfate	Nitrate	Ammonium
Acadia National Park	↓		
Bandelier National Monument	↓		
Big Bend National Park		↑	↓
Buffalo National River			↑
Everglades National Park			↑
Glacier National Park	↓	↑	
Great Basin National Park			↑
Great Smoky Mountains National Park	↓		
Indiana Dunes National Lakeshore	↓		
Isle Royale National Park (Chassell)	↓		
Little Big Horn National Monument			↑
Mesa Verde National Park	↓	↑	↑
North Cascades National Park	↓	↑	↑
Olympic National Park	↓	↑	↑
Rocky Mountain National Park	↓		
Sequoia National Park	↓		

Green, down arrow indicates a decrease in concentrations
Red, up arrow indicates an increase in concentrations
No arrow indicates no significant change in concentrations

Ozone and its effects
Of the various air pollutants that the EPA recognizes as problems, ozone (the principal component of urban smog) is one of the most widespread. Unlike most pollutants, ozone is not emitted directly from smokestacks or motor vehicles. Emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) from these sources react in the atmosphere in the presence of sunlight to create ozone, usually during the warmer summer months.

Although ozone is principally an urban problem, ozone and its precursor emissions (NOx and VOCs) can travel long distances resulting in elevated ozone levels in national parks. High levels of ozone can injure vegetation and affect the health of park visitors and employees. For some national parks, ozone concentrations have exceeded EPA standards set to protect public health and welfare. These parks are generally near major urban or industrial areas, but can also be a substantial distance from these areas, as in the case of Acadia and Joshua Tree National Parks.

Ozone and its ecological effects Ozone is one of the most phytotoxic air pollutants, and causes considerable damage to vegetation throughout the world. Data show that plants are more sensitive to ozone than humans. Most ozone effects research has concentrated on crops and large economic losses have been documented for U.S. agriculture. Many native plants in natural ecosystems are also reported to be sensitive to ozone. The effects of ozone range from visible injury to the leaves and needles of deciduous trees and conifers to premature leaf loss, reduced photosynthesis, and reduced growth in sensitive plant species. These physiological changes can occur in the absence of foliar injury, and vice versa. In a natural ecosystem, many other factors, such as soil moisture, presence of other air pollutants, insects or diseases, genetic make-up, topographical locations, and other environmental stresses, can lessen or magnify the extent of ozone injury.

The EPA's new 8-hour standard for ozone may better serve to protect vegetation compared to the older 1-hour standard, however, many scientists believe that a more biologically-relevant statistic is necessary to ensure protection of vegetation. Some scientists believe that the SUM06 statistic (the sum of hourly average ozone concentrations greater than or equal to 0.06 parts per million, or ppm) calculated over a 3-month period is a better statistic because it is well correlated with vegetation impacts. They recommend SUM06 effects endpoints of 8 to 12 ppm-hrs for foliar injury to vegetation and 10 to 15 ppm-hrs for growth effects on tree seedlings in forest stands. Ozone concentrations below these endpoints would, in most cases, protect against foliar injury and/or growth loss.

Ecosystem Effects of Ozone and its Precursors

- *Ozone interferes with the ability of plants to produce and store food, so that growth, reproduction, and overall plant health are compromised.*

- *Ozone makes plants more susceptible to disease, pests, and environmental stresses.*

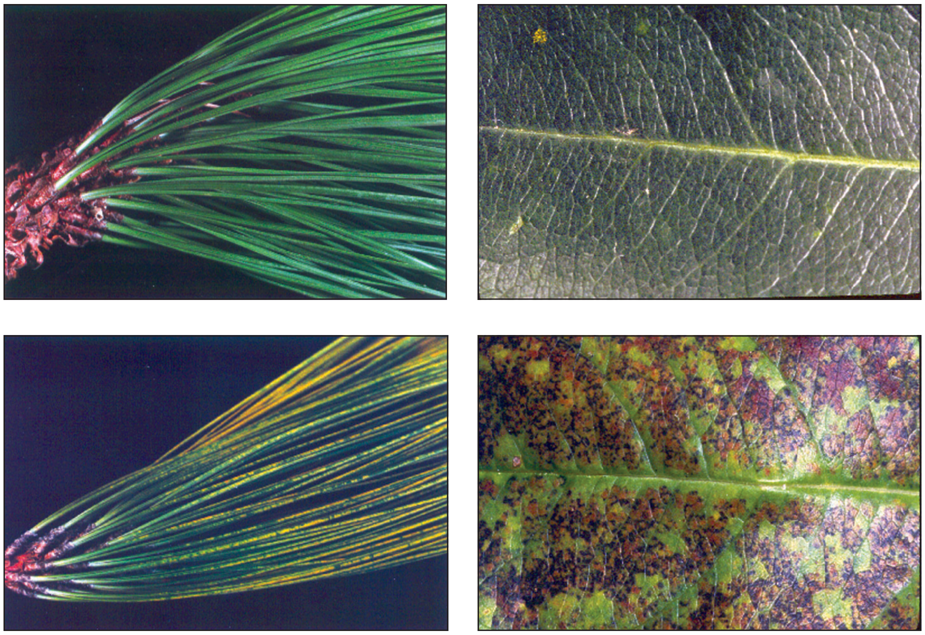
- *Ozone reduces agricultural yields for many economically important crops like soybeans, kidney beans, wheat, and cotton.*

- *Ozone effects on trees are believed to add up over many years so that whole forests or ecosystems can be affected.*

- *Ozone can kill or damage leaves so that they fall off the plants too soon or become spotted or brown. These effects can significantly decrease the natural beauty of an area, such as in national parks and recreation areas.*

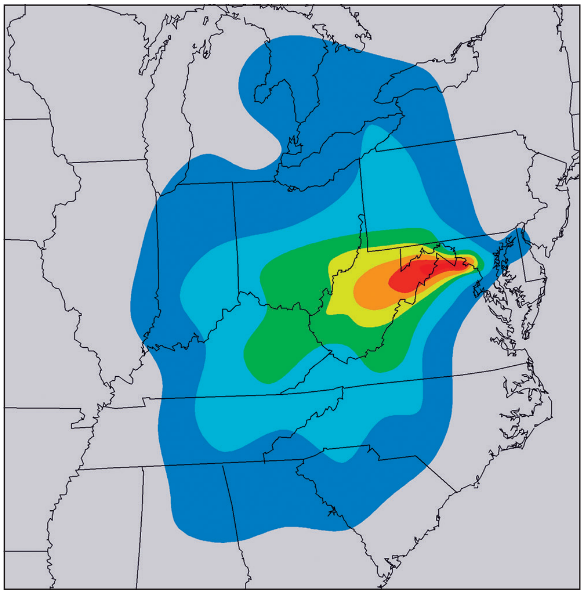
- *Nitrogen oxides, an ozone precursor, contributes to fish kills and algae blooms in sensitive waterways, such as the Chesapeake Bay.*

Source: U.S. EPA



Examples of healthy (top) and injured (bottom) foliage from ozone exposure are illustrated by the two species pictured: ponderosa pine (left) and black cherry (right). Ozone injury causes chlorotic mottling (yellow spots) in pine needles and stippling on the leaves of deciduous vegetation.

Back trajectory models allow NPS to identify the transport regions associated with elevated ozone levels in parks. This figure shows that high ozone levels at Shenandoah National Park are most likely associated with air masses transported through regions west and southwest of the park, including the Ohio River Valley.



The map below shows the distribution of maximum 3-month SUM06 values at various national parks for the period 1995 to 1999. SUM06 values range from 0 to 77 ppm-hrs, with most parks having values above the foliar injury endpoint. Field surveys conducted at various sites in Shenandoah and Great Smoky Mountains National Parks found foliar injury on black cherry trees ranged from about 30 to nearly 100 percent at ozone values at or above 25 ppm-hrs. Between 15 and 30 percent of black cherry were injured at one survey site in Great Smoky Mountains at SUM06 values less than 5 ppm-hrs. Foliar injury on Jeffrey and Ponderosa pines in surveyed plots at Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite National Parks range from about 15 to 50 percent at ozone values between 25 and 30 ppm-hrs. In two plots in Lassen Volcanic National Park injury was about 20 percent and SUM06 values were less than 10 ppm-hrs. More than 80 percent of surveyed trees at Sequoia National Park showed injury at SUM06 levels greater than 60 ppm-hrs. The maximum SUM06 values at Sequoia and Yosemite were 77 and 57 ppm-hrs, respectively, during this time period. NPS has found that, in general, higher ozone exposure levels occur at higher elevation

Ozone: Good or Bad?

Ozone occurs in two layers of the atmosphere. The layer surrounding the earth's surface is the troposphere. Here, ground-level or "bad" ozone is an air pollutant that damages human health, vegetation, and many common materials. It is a key ingredient of urban smog.

The troposphere extends to a level about 10 miles up, where it meets the second layer, the stratosphere. The stratosphere or "good" ozone layer extends upward from about 10 to 30 miles and protects life on earth from the sun's harmful ultraviolet rays (UV-B).

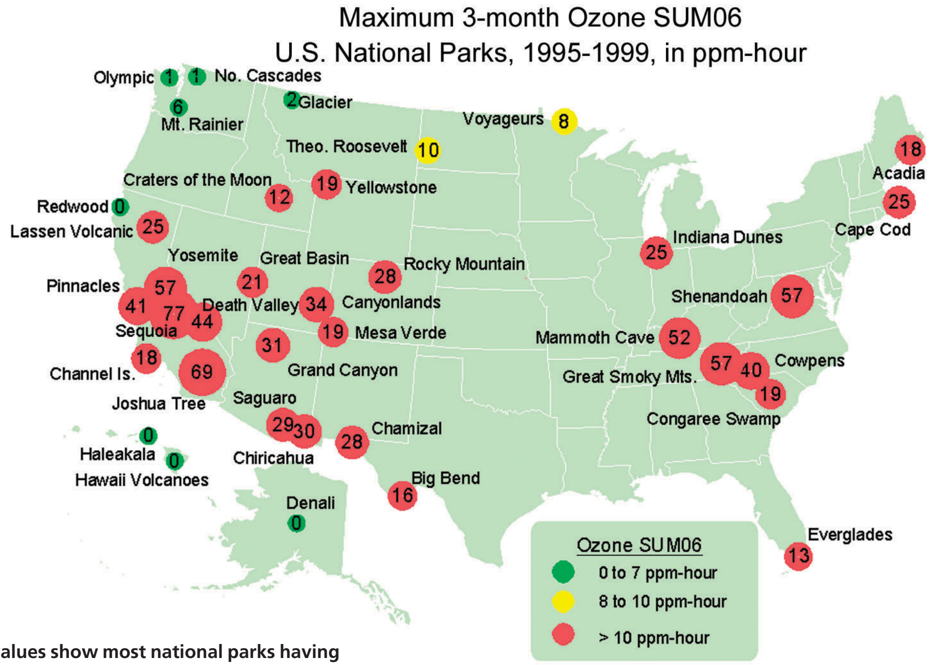
Sources of Ozone Precursor Emissions

Nationwide fossil fuel combustion and motor vehicles[1] emit 40 percent and 55 percent of annual nitrogen oxides emissions, respectively.

Of human sources of VOC emissions, the largest are motor vehicles (49 percent) and solvent utilization (28 percent). Fuel combustion accounts for only 5 percent of VOC emissions nationwide.

Natural VOC emissions from vegetation (biogenic emissions) exceed human-caused emissions on an annual basis.

[1] Motor vehicles include on-road and non-road vehicles and engines.



SUM06 values show most national parks having ozone values >10 ppm-hr, which can harm foliage.

sites (topographically-exposed ridge tops) and, therefore, vegetation is possibly more at risk to injury. Higher ozone at these sites is probably the result of ozone being trapped above the nightly inversion layer; thereby being separated from emissions that tend to scavenge ozone. Studies at Great Smoky Mountains confirm a dramatic increase in visible foliar injury to some plant species with increasing elevation.

Ozone and visitor and employee health The EPA has well documented the human health effects associated with acute and chronic exposures to air pollutants, including ozone. Because of these health effects and concern for the health and safety of its visitors and employees, NPS has developed an ozone advisory system in several parks where levels are likely to approach or exceed the ozone standard. Whenever ozone levels exceed or are predicted to exceed the ozone standard at these parks, the park personnel post health advisories cautioning visitors of the potential health risks associated with exposures to elevated levels of ozone. Health symptoms from ozone exposure are generally exacerbated in most individuals under strenuous exercise, such as hiking at higher elevations than what one is accustomed to, as is typical in many national parks. The need to post pollution health advisories in national parks is disconcerting, given the values and purposes for which the parks were established, as well as what visitors expect in their national parks.

EPA revised the National Ambient Air Quality Standard for ozone in 1997 setting the standard at 0.08 parts per million (ppm), or equivalently 80 parts per billion (ppb), averaged over an 8-hour period. Compliance is based on a 3-year average of the annual 4th-highest daily maximum 8-hour ozone concentration measured at a location. Prior to 1997 the standard had been set at 0.12 ppm, or 120 ppb, on an hourly basis. The 1-hour standard continues to apply in a given area until it has met the standard for three consecutive years, whereupon it is replaced with the new 8-hour standard.

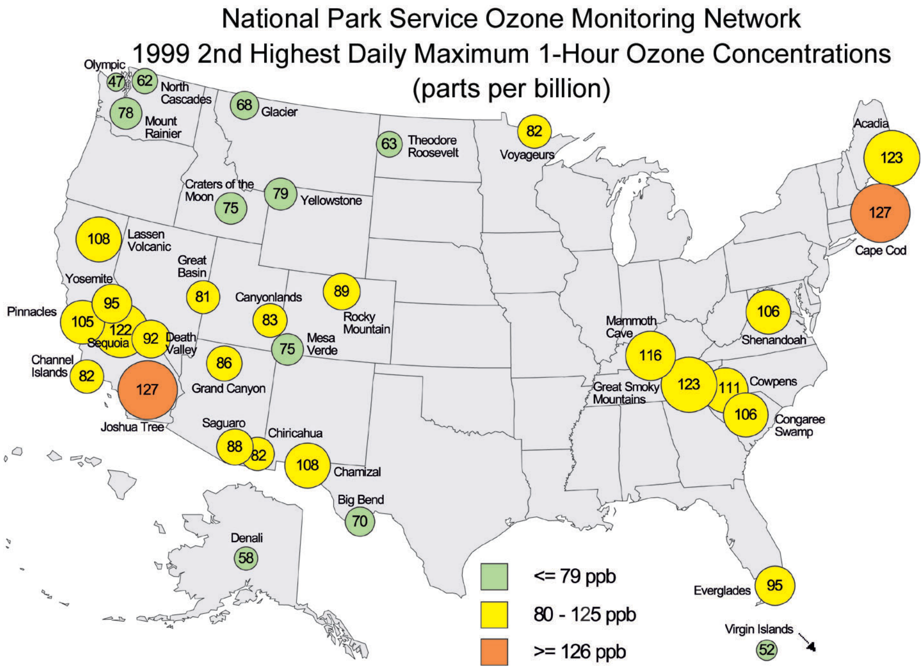
The map below shows the 2nd highest 1-hour average ozone concentrations measured in national parks for 1999. Several parks, primarily in the southeast, Northeast Coast, and California, exceeded or approached this standard. Since 1992, nine parks have measured at least one 1-hour ozone value above the one-hour standard. Joshua Tree National Park (California) has exceeded the standard a total of 46 days between 1992 and 1999. Most other parks only occasionally exceed the 1-hour ozone standard.

Interpretive display at the Sugarland Visitor Center in Great Smoky Mountains National Park allows visitors to view current ozone levels and visibility conditions and air quality data.

Health Effects Associated with Exposures to Ozone

- *Acute respiratory problems*
- *Aggravation of asthma*
- *Significant temporary decreases in lung capacity of 15 percent to over 20 percent in some healthy adults*
- *Inflammation of lung tissue*
- *Impair the body's immune system defenses, making people more susceptible to respiratory illnesses, including bronchitis and pneumonia*

Source: U.S. EPA



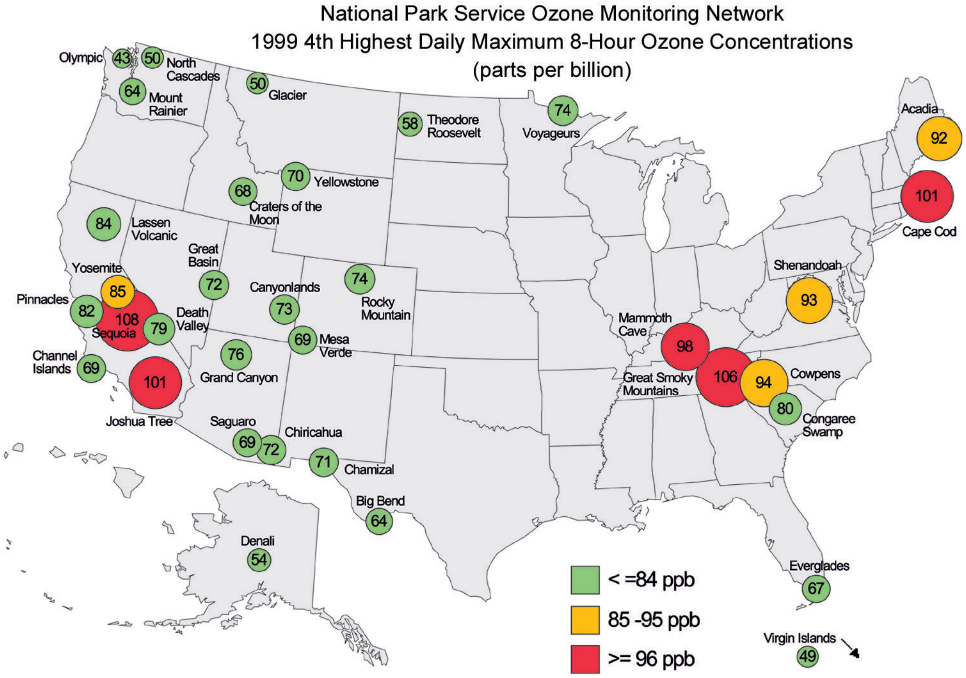
Spatial distribution of second maximum 1-hour ozone concentration, in parts per billion, in U.S. national parks for 1999. Circles are proportional to concentration, with circles in orange identifying the two parks exceeding EPA's 1-hour standard. Parks in the eastern U.S. and in California generally experience the highest short-term ozone concentrations.

Air quality technicians at Yosemite National Park perform routine servicing on air quality monitoring instrumentation. Periodic training of park personnel in the proper operation of air quality monitoring equipment is part of the NPS' quality assurance program.

In contrast, the number of times that parks exceed the new 8-hour standard is substantial. For example, at Joshua Tree the level of the 8-hour standard was exceeded on 68 days in 1994 alone and 38 days in 1999. Nine parks currently do not meet EPA's new 8-hour standard based on the most recent three years of data (1997-1999). These parks are: Joshua Tree, Sequoia, Great Smoky Mountains, Cape Cod, Shenandoah, Yosemite, Mammoth Cave, Cowpens, and Acadia. The map below shows the 4th highest 8-hour ozone average for all parks where measurements are made and shows the location of the nine parks currently not meeting the ozone standard. The map also shows the general spatial distribution of ozone levels measured in parks. Parks in the Intermountain West and the Pacific Northwest experience lower levels of ozone pollution than parks in other regions of the country.

The preceding assessment of the number of parks exceeding the ozone standard is limited to the relatively small number of parks where ozone is measured. Numerous parks are located in or near large urbanized areas that do not currently meet the ozone standard (non-attainment areas). As a result, these parks are likely to be experiencing unhealthy ozone levels and exposures as well.

Ozone trends Knowing whether air pollution levels throughout the National Park System are getting better or worse helps park managers in framing and resolving air resource management issues specific to individual parks. Ozone concentrations exhibit large variability from year to year due to daily and seasonal cycles primarily associated with changes in emissions and climate. This makes the interpretation of trends difficult. Even without meteorological influences, the complex photochemistry associated with the formation of ozone and other oxidants further complicates the interpretation of trends. The following assessment looks only at the observed trend in measured concentrations at each park, without accounting for changing emissions or meteorology. To smooth out some of this variability, the ozone daily maximum concentrations have been averaged annually for the months of May through September, which coincides with the period when ozone concentrations are highest, plants are usually most active, and park visitation is highest.

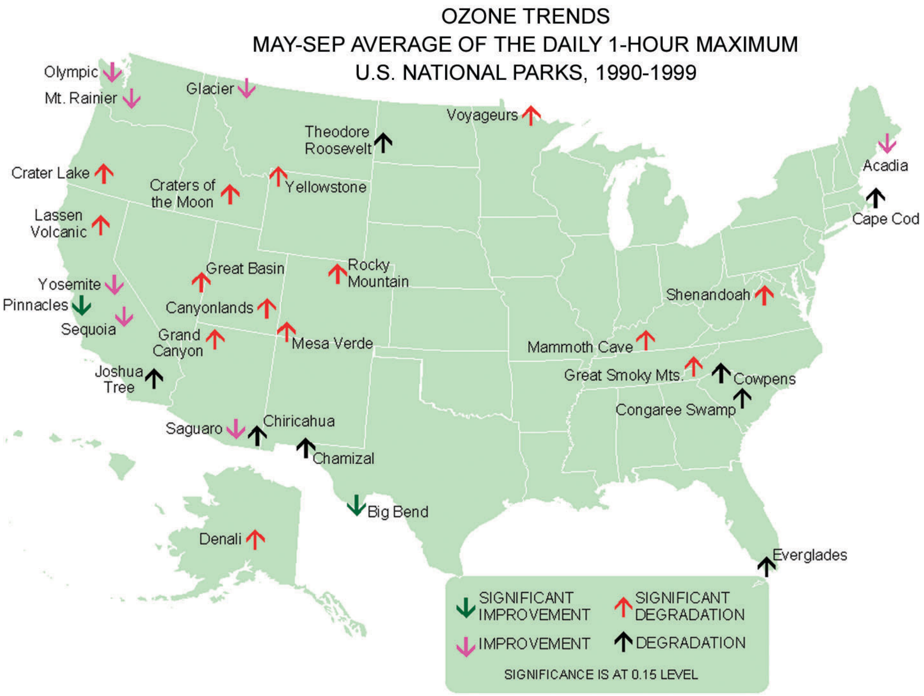


Spatial distribution of maximum 8-hour ozone averages in U.S. national parks for 1999. Circles are proportional to concentration, with circles in red and orange identifying the nine parks exceeding EPA's 8-hour standard. High ozone levels in parks present a threat to native vegetation, as well as to employees and visitors.

The figure below illustrates the current 10-year trend in ozone concentrations in national parks showing ozone levels have gotten progressively worse in many national parks during the period 1990-1999. The annual rate of increase in some parks is substantial in some cases. For example, on average the daily 1-hour maximum ozone (May-September) concentration increased by almost 2 ppb each year at Great Smoky Mountains, a park that has numerous documented effects due to ozone. This equates to an alarming increase of 20 ppb in the average of the daily ozone maximum over this 10-year period. Parks in the Intermountain West and the Colorado Plateau, such as Rocky Mountain and Grand Canyon, are showing annual increases of 1 ppb. All but one park in the eastern U.S. (Acadia) show ozone levels increasing over this time period, with most of these increases being statistically significant. The average of the ozone daily maximum is not the only ozone statistic on the rise. A trend analysis of 8-hour ozone levels in national parks conducted by EPA shows almost identical results. EPA's analysis showed seven parks with a statistically significant increasing trend in the 4th highest 8-hour ozone concentration indicating a greater potential for parks exceeding the new ozone standard. Rising ozone levels in national parks is contrary to the generally decreasing trends EPA reports for most urban areas of the country.

Clearly, strategies to reduce ozone levels in urban areas are not having the same effect in reducing what in some cases are unacceptable high levels of ozone in national parks. Further studies are necessary to understand the reasons why ozone levels in parks have increased and to determine the appropriate strategies to reverse these trends. Increasing ozone levels in parks are of serious concern to NPS because vegetation in some of the parks already show signs of visible injury. Physiological effects and research show, and EPA acknowledges, that there are numerous adverse effects that can occur as a result of acute and chronic exposures to ozone.

> *"East Coast vacationers flock to Acadia National Park each summer. Unseen by them, urban air pollution also heads 'downeast' on the wind. Smog doesn't take a vacation, it just goes to work in other places downwind."*
>
> Deb Wade, Chief of Interpretation
> Acadia National Park, Maine



Ozone concentration trends at national parks in the U.S., 1990-1999. With few exceptions, ozone levels increased significantly over this 10-year period.

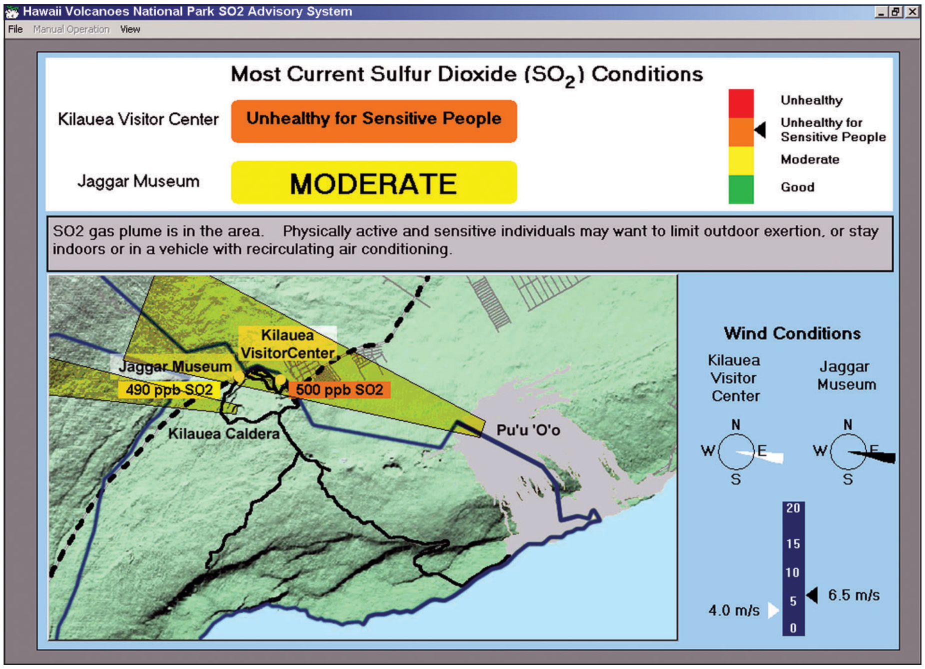
Volcanoes are a source of SO_2 emissions which pose a threat to human health, animal health, and plant life.

Source: USGS/Cascades Volcano Observatory

Other gaseous pollutants

Other gaseous pollutants are monitored in the parks, including sulfur dioxide (SO2), carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs). These are usually monitored for very specific purposes, such as understanding the reaction chemistry of various air pollutants. Monitoring levels of nitrogen oxides and VOCs in parks, such as Great Smoky Mountains, Mammoth Cave, and Shenandoah, allows NPS to understand the chemistry and potential sources of emissions associated with high levels of ozone in these parks. Of these other gaseous pollutants, however, only SO2 is monitored routinely at a large number of parks, mostly on a weekly-integrated basis. Monitoring has shown that all these pollutants are generally present at low ambient levels in national parks. For example, sulfur dioxide is generally below 5 ppb at most parks. Only Hawaii Volcanoes National Park experiences SO2 concentrations high enough to pose a human health threat and damage vegetation, as a result of emissions from volcanic activity. SO2 levels there can often rise above the level of EPA's short-term National Ambient Air Quality Standards (NAAQS). Since 1987, the number of times that SO2 levels have risen above EPA's 24-hour standard has ranged from 2 to 20 times annually. High SO2 levels are dependent on the wind direction and the intensity of volcanic activity. When prevailing winds carry the volcanic plume away from the monitoring stations, concentrations drop to zero. However, locations that are directly downwind of the plume are likely to see as high, if not higher, SO2 levels than those being measured at the monitoring stations. High SO2 presents a significant health threat for visitors, residents, and park employees. When inhaled, SO2 reacts with lung tissue and causes coughing, wheezing, and breathing difficulty even in healthy adults. Children and asthmatics are even more at risk. Since controlling volcanic activity is not possible, NPS has developed a health advisory program and issued warnings to limit the exposure of people to unhealthy levels of sulfur dioxide and other potentially hazardous gases associated with volcanic eruptions.

A pollution advisory program has been put in place at Hawaii Volcanoes National Park accessible by visitors, island residents, and park personnel via the Internet. Using data from park SO2 monitors and weather stations, graphical displays alert visitors and employees of the areas where the volcano's SO2 emissions are being transported and, therefore, should be avoided.



Most Current Sulfur Dioxide (SO_2) Conditions

Kilauea Visitor Center: Unhealthy for Sensitive People

Jaggar Museum: MODERATE

SO2 gas plume is in the area. Physically active and sensitive individuals may want to limit outdoor exertion, or stay indoors or in a vehicle with recirculating air conditioning.

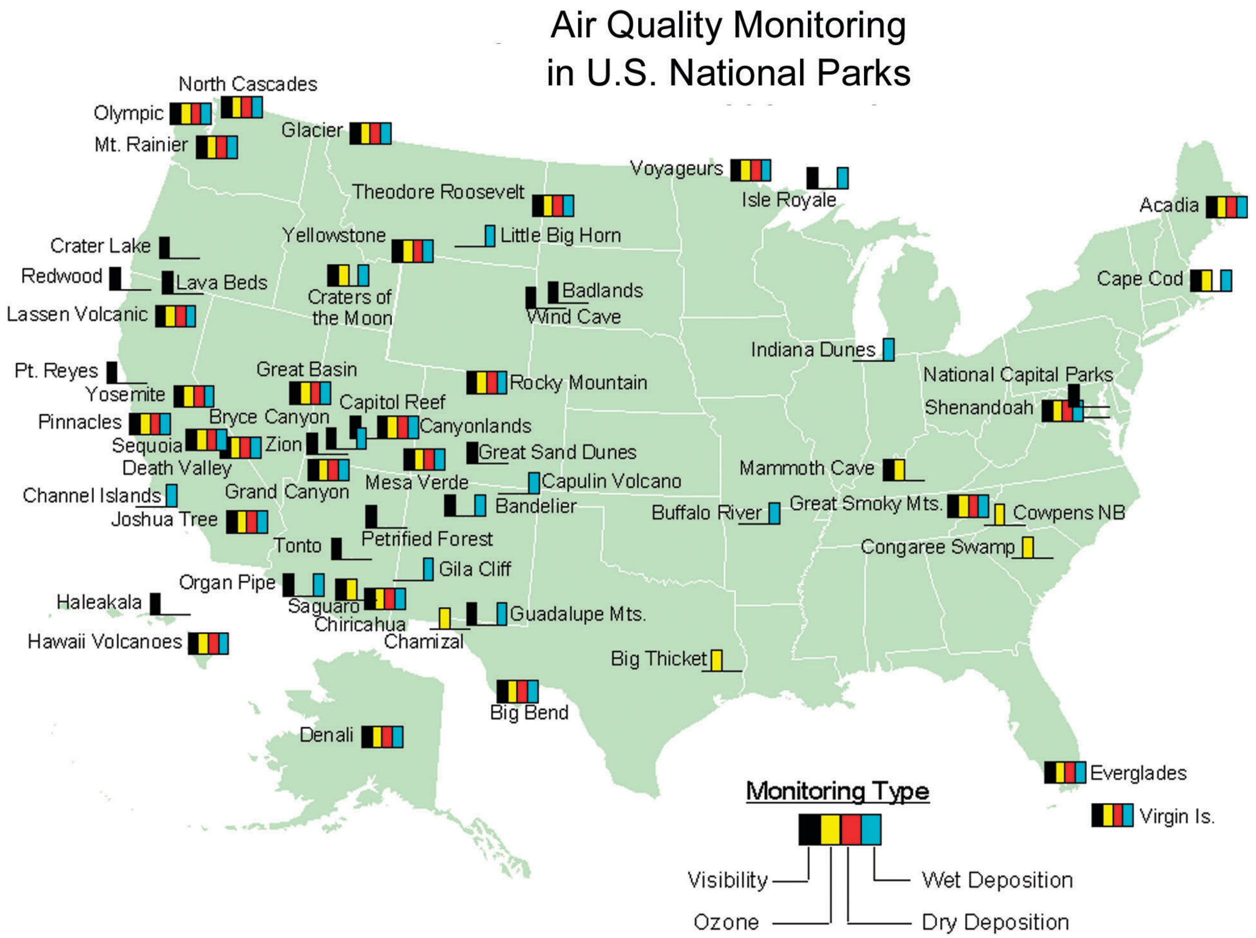
Air quality display at Hawaii Volcanoes National Park alerting island residents and visitors of current SO_2 levels at the park's monitoring stations. The display also alerts visitors of those areas that should be avoided due to toxic volcanic plumes. On this particular day easterly winds are transporting toxic gases toward the Kilauea Visitor Center, where unhealthy levels of sulfur dioxide are being measured.

Chapter Three
Measuring Air Quality in National Parks

The National Park Service's comprehensive air quality program encompasses a wide range of activities, many of which are dedicated to measuring levels or effects of air pollution in parks. The NPS Air Resources Division has established an extensive network of air quality monitoring stations to characterize air quality in national parks, as illustrated in the figure below.

The NPS air quality monitoring program has three primary components: visibility, acidic precipitation, and gaseous pollutant monitoring. In addition, meteorological monitoring is conducted at many locations to aid in the interpretation of measured air pollution levels. Within each monitoring component are various elements addressing special NPS monitoring needs. In most instances, NPS monitoring efforts complement air pollution monitoring efforts conducted by other federal, state, and local agencies.

Although there are extensive air pollution monitoring networks in this country operated by state and local air pollution control agencies as a result of the enactment of the Clean Air Act, few of these networks measure air pollution levels in national parks. The primary objective of state and local air pollution monitoring networks was the characterization of air quality in large, urbanized or heavily industrialized areas to determine compliance with the primarily health-based national air quality standards. People generally assumed that the designation of areas as national parks implied that the air resources of these areas were protected and remained unaffected by air



Locations of National Park Service air quality monitoring sites in the United States, that were active in 1999. Parks identified on the map routinely monitor one or more of the following: visibility, fine particles, ozone, sulfur dioxide, atmospheric deposition (wet and/or dry), or meteorology. Monitoring at most of these locations is conducted by the NPS, with some stations operated by states or other federal agencies. Measuring air pollution levels in parks is an essential part of the NPS air resource management program and provides vital information to Congress, academia, air pollution control agencies, and the public on air pollution levels in national parks, as well as rural America.

pollution due to their distance from major urban and industrial areas. Hence, few people saw the need to monitor air quality in national parks. As a result, these networks were incapable of satisfying NPS monitoring objectives.

Visibility monitoring

In 1979, the NPS, cooperating with the U.S. EPA, established long-term visibility monitoring sites at various remote locations throughout the continental United States. These sites were equipped with fine particle samplers (stacked filter units), optical monitors (teleradiometers), and 35mm cameras to document how scenes are affected by air pollution. Particle samples were collected on a 72-hour basis twice per week, in two nominal size ranges: 0 to 2.5 micrometers (μm) and 2.5 to 15 μm. Teleradiometer and scene monitoring was conducted three times daily at 9 a.m., noon, and 3 p.m. by park resource managers or rangers.

Over the years, this monitoring effort was supplemented by the efforts of the U.S. Forest Service, Bureau of Land Management, the U.S. Fish and Wildlife Service, and the EPA to include other areas such as national wildlife refuges and national forests that were designated as Class I areas under the Clean Air Act. In 1985 this effort was enhanced further by establishing a national visibility monitoring program, referred to as the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. Beginning in 1987 the stacked filter units were replaced with new fine particle samplers consisting of four modules that collected samples in two particle sizes ranges: 0 to 2.5 μm in diameter and 0 to 10 μm in diameter. Samples were collected for a 24-hour duration (midnight-to-midnight) on Wednesdays and Saturdays (as of 2000, sampling is conducted on an every third-day basis). Transmissometer systems were also added to collect continu-

Table 3-1. IMPROVE Network Visibility Measurements

Component	Instrumentation	Parameter		
Scene	35mm remote camera system or high-resolution digital camera system (8mm time-lapse cameras or video systems can also be applied to document the dynamics of specific events)	Qualitative documentation of visual appearance of a scene on 35mm slides or digital images		
Optical	Transmissometer system	Hourly values of total extinction (b_{ext})		
	Ambient nephelometer	Hourly values of the scattering component of total extinction (b_{scat})		
Aerosol	IMPROVE modular aerosol sampler	Three samples of fine particles (smaller than 2.5 μm) and one of respirable particles (smaller than 10 μm) 24-hour samples collected every 3 days:		
		Module	Filter	Parameter
		A	25mm Teflon	fine mass, sulfur, soil elements, organic mass, absorption (b_{abs}), and trace elements (Na-Pb)
		B	47mm nylon	nitrate, sulfate, and chloride ions
		C	25mm quartz	tandem filters for organic and elemental carbon
		D	25mm Teflon	PM_{10} mass (may also be followed by an impregnated filter to measure SO_2 gas concentrations)

Scene monitoring camera system at Tonto National Monument, Arizona. The photographic documentation of how scenic views associated with national parks are affected by air pollution has been a very effective tool in the regulation of air pollutants at the national level.

Transmissometer transmitter component at Canyonlands National Park, Utah. Transmissometers measure atmospheric extinction (total visibility reduction due to particles and gases). Measurements can be converted to visual range.

Nephelometer monitoring system at Great Smoky Mountains National Park, Tennessee/North Carolina. Nephelometers measure the amount of light scattering, and hence visibility reduction, caused by fine particles, and are used routinely in many national parks.

Aerosol samplers at Big Bend National Park, Texas. The chemical analysis of sample filters allows scientists to determine the contribution of various chemical species to visibility reduction in parks.

ous measurements of atmospheric total extinction. Transmissometer measurements are reported on an hourly basis. Nephelometer systems were added at a few sites to measure extinction due to only light scatter by particles in the atmosphere. Nephelometers operate continuously with measurements of light scattering reported on an hourly basis.

The program is managed by the IMPROVE Steering Committee that consists of representatives from the EPA, the four federal land managers (National Park Service, U.S. Forest Service, U.S. Fish and Wildlife Service, and Bureau of Land Management), the National Oceanic and Atmospheric Administration, four organizations representing state air quality organizations (State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials, Western States Air Resources Council, Northeast States for Coordinated Air Use Management, and Mid-Atlantic Regional Air Management Association), and an associate member, the State of Arizona Department of Environmental Quality.

The goal of IMPROVE is to monitor at enough locations to represent all of the Class I areas to which the Regional Haze Regulations apply. The IMPROVE network began with 30 monitoring sites in Class I areas, 20 of which began operation in 1988 with the others starting in the early 1990s. Beginning in 1998 the EPA provided additional resources to expand the network to as many Class I areas as practical to meet the needs of the then anticipated Regional Haze Regulations. Of the 110 IMPROVE sites in operation in 2000, 44 are located in NPS units (*http://vista.cira.colostate.edu/improve*).

Acid precipitation and deposition monitoring

The NPS participates in several networks that currently monitor atmospheric deposition, as listed in Table 3-2.

The National Atmospheric Deposition Program (NADP) was formed in 1978 to investigate atmospheric deposition and its effects on the environment. It is a cooperative effort between federal and state governments, universities, and private organizations, and provides the only long-term record of precipitation chemistry in the U.S. The program began with 22 original sites and has grown to over 240 primarily non-urban sites. National parks operate 42 of these sites, stretching from Alaska to the Virgin Islands. In 1982, the NADP was renamed the NADP/National Trends Network. Today the program includes three sub-networks: the National Trends Network (NTN), the Atmospheric Integrated Research Monitoring Network (AIRMoN), and the Mercury Deposition Network (MDN).

The National Trends Network monitors wet deposition using an Aerochem precipitation collector and a Belfort rain gauge. Weekly precipitation samples are gathered every Tuesday and sent to the Central Analytical Laboratory of the Illinois State Water Survey, where they are analyzed for hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and

NPS Monitoring Objectives

- *Identify air pollutants which may injure or damage park natural resources, measure these pollutants, and correlate observed effects on resources to ambient levels of pollutants*
- *Establish baseline visibility conditions, deposition, and air pollutant concentrations in national parks*
- *Identify and assess trends in air quality*
- *Determine compliance with National Ambient Air Quality Standards*
- *Provide data for the development and revision of national and regional air pollution control policies that are protective of park resources*
- *Provide data for atmospheric model development and evaluation*
- *Determine the relative importance of various atmospheric constituents to visibility impairment*
- *Determine the sensitivity of individual areas or views to variations in visual air quality*

Table 3-2. Atmospheric Deposition Monitoring Networks

Network	Initial Year	Total # Network Sites	# NPS Sites	Parameters Measured	Sampling Frequency
National Atmospheric Deposition Program (NADP)					
National Trends Network (NTN)	1978	240	42	major ions in wet deposition	weekly
Atmospheric Integrated Research Monitoring Network (AIRMoN)	1992	10	1	major ions in wet/dry deposition	daily
Mercury Deposition Network (MDN)	1996	70	7	mercury in wet deposition	weekly
Snow Sampling in the Rocky Mountains (USGS)	1992	52	4	major ions in snow deposition	seasonally
Clean Air Status and Trends Network (CASTNet)	1987	70	26	ambient air concentrations and meteorological conditions	weekly
Mountain Acid Deposition Program (MADPro)	1993	3	1	major ions in cloud deposition	hourly/continuously
National Dioxin Air Monitoring Network (NDAMN)	1999	29	7	dioxin in wet/dry deposition	variable

NPS employees collect snow samples in the Rocky Mountains to determine the amount of air pollutants deposited throughout the winter.

University of Denver researchers measure snowmobile emissions at Yellowstone National Park. Snowmobiles emit significant amounts of carbon monoxide and hydrocarbons during the 3 months that they are allowed in the park. Between 60,000 and 70,000 snowmobiles enter the park each winter.

base cations (such as calcium, magnesium, potassium and sodium). These data are available on the NADP Web site at *http://nadp.sws.uiuc.edu*.

The Atmospheric Integrated Research Monitoring Network (AIRMoN) began in 1992 and measures the same chemicals as the National Trends Network. This network samples daily rather than weekly, to obtain higher resolution data, which are used to run computer models that simulate atmospheric transport and removal of pollutants on a storm-by-storm basis.

The Mercury Deposition Network (MDN) began in 1996 with the objective of monitoring the amount of mercury in precipitation on a regional basis. The network has quickly grown to approximately 70 sites. The sampling equipment is similar to the National Trends Network sites, but ultra-clean glassware is used and strict sample handling procedures are required. Concentrations of total mercury, and sometimes methyl mercury, are determined.

Atmospheric deposition has not always been well characterized in high-elevation areas, where as much as 60 to 80 percent of annual precipitation may fall as snow. Few National Trends Network sites exist in these areas due to access difficulties. To complement the National Trends Network, the U.S. Geological Survey in cooperation with other federal, state, and local agencies began a snowpack sampling network in the early 1990s to measure winter atmospheric deposition in the Rocky Mountains. The network consists of 52 core sites that surround the Continental Divide from Montana to New Mexico. Sampling occurs near maximum accumulation when snow-water equivalence is measured, and contiguous columns of snow are collected, and later analyzed for all major ions. Chemical composition and snow-water equivalence measurements allow for calculation of deposition loading to these areas during the winter season (November to March).

The Clean Air Status and Trends Network (CASTNet) provides data on dry deposition, ground-level ozone, and other forms of atmospheric pollution. Established in 1987, CASTNet now comprises over 70 monitoring stations across the U.S. The majority of the monitoring stations are operated by EPA's Office of Air and Radiation; however, 26 stations are operated by the NPS. Each CASTNet station in national parks measures atmospheric concentrations of nitrate, sulfate, ammonium, sulfur dioxide, and nitric acid; ambient ozone; and meteorological conditions. EPA then calculates dry deposition estimates using models that incorporate site-specific atmospheric concen- trations, meteorological data, and information on land use, vegetation, and surface conditions.

The Mountain Acid Deposition Program (MADPro) was initiated in 1993 as part of CASTNet due to questions about the contribution of cloud deposition and total deposition in mountainous areas. MADPro monitoring efforts have focused on an automated cloudwater collection system, continuous measurements of cloud liquid water content, and meteorological parameters relevant to the cloud deposition process. Cloudwater is collected hourly and analyzed for sulfate, nitrate, calcium, and ammonium. Sampling sites include Whiteface Mountain, NY; Whitetop Mountain, VA; and Clingman's Dome, TN/NC in Great Smoky Mountains National Park.

The National Dioxin Air Monitoring Network (NDAMN) began in 1999 and currently monitors vapor and particulate forms of dioxin-like compounds at 29 mostly rural stations, seven of which are located in national parks. These samplers run every third month; standard EPA methods are used for analysis.

Ecosystem monitoring

NPS units serve as sites for a number of ecosystem monitoring networks and index site networks, including the NPS Inventory and Monitoring Program; the small watersheds program (USGS); the Water, Energy, and Biogeochemical Budgets Program (USGS); and the Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet) (EPA and NPS).

PRIMENet is a program jointly funded by the EPA and the NPS to address the linkages between environmental stressors and ecosystem responses. PRIMENet is designed to monitor major environmental stressors such as ultraviolet radiation, air pollution, contaminants, and climate, and to relate changes in these stressors to ecological indicators at 14 parks, representing a range of ecosystems.

Lake, stream, and watershed monitoring Some parks in regions with sensitive natural resources have developed long-term monitoring programs focused on water chemistry measurements and watershed mass balance approaches. Both Great Smoky Mountains and Shenandoah National Parks have well-developed research and monitoring programs to investigate the effects of nitrogen and sulfur deposition on waters, soils, vegetation, and aquatic biota. These parks have recorded some of the highest deposition levels in the NPS system. Western parks in mountainous regions are extremely sensitive to atmospheric deposition inputs. A number of these parks, including Olympic, Glacier, Sequoia-Kings Canyon, and Rocky Mountain National Parks, have monitored small, headwater watersheds to detect changes associated with increasing chemical deposition.

Gaseous pollutant and meteorological monitoring

The gaseous pollutant monitoring program historically concentrated on determining the levels of two gaseous air pollutants, ozone and sulfur dioxide, which are most toxic to native vegetative species found in NPS units at levels at or below the National Ambient Air Quality Standards. Other gaseous pollutants (e.g., other photochemical oxidants, nitrogen compounds, and toxic organic compounds) are also of interest to the NPS because they relate to physiological, morphological, or historical injury to park biological resources, or to global climate change. Currently, only selected, limited studies measure other gaseous pollutants within the National Park System. Ozone and sulfur dioxide monitoring in national parks has been ongoing since the early 1980s using EPA reference or equivalent methods. This allows for the direct comparison of NPS data with data collected by state and local air pollution control agencies and EPA.

The present network is designed to represent air quality conditions for parks in all ecological regions and to not duplicate other existing monitoring efforts. A few states maintain remote stations within park units that serve as "background" sites in their air quality monitoring networks. In addition, NPS has joined with EPA to expand the coverage of the CASTNet network that was established to track changes in air quality associated with the sulfur dioxide emissions reductions required by the 1990 amendments to the Clean Air Act.

Table 3-3 lists the type of monitoring, monitoring methods and the number of gaseous pollutant monitoring stations deployed in national parks. In most cases, monitoring equipment is collocated within a park when more than one type of measurement network is involved.

Once validated, data are reported to individual parks and cooperating agencies and programs, then incorporated into the EPA's Aerometric Information and Retrieval System (AIRS) database, a national database of all air quality data collected throughout the country (*http://www.epa.gov/air/data/index.html*).

Ozone passive sampling The NPS and EPA have investigated and field tested the use of passive sampling devices to obtain air pollution measurements in very remote locations where commercial power is unavailable. NPS uses passive sampling in numerous national parks as an inexpensive way of determining whether high levels of ozone may be present in a park or to assess how ozone concentrations may vary across topographically complex terrain found in many national parks. NPS uses the Ogawa passive sampler for this purpose. This simple device is inexpensive and easy to use. It requires no A/C power, thus, the passive sampler can be placed virtually anywhere and left unattended for days, even weeks. The device has no moving parts (hence the term "passive") and relies solely on the principle of diffusion for the air sample to come in contact with a specially treated filter. NPS has used passive samplers for numerous years to conduct week-long sampling in parks during the summer ozone season. These studies indicated that passive sampling was a reliable method to conduct background surveys and as a screening method to identify locations as potential candidates for continuous monitoring. Examples of ozone spatial distribution interpolations from monitoring that includes both passive and

Fourteen national parks, as part of PRIMENet, measure ultraviolet radiation as part of a cooperative effort with the U.S. EPA. Brewer spectrophotometers, such as the one being serviced, measure different wavelengths of light, with a focus on the ultraviolet spectra (UV-B radiation is in the 300-320 nanometer range of light). These instruments actively track the sun as they monitor the variation in solar irradiance throughout the day; they also record other data, such as total column ozone and optical density.

Table 3-3. Number of stations and monitoring methods used to measure gaseous pollutant levels and meteorological conditions in national parks, as of 1999

Gaseous Air Polllutants	# Sites	Method	Sampling Frequency	Reported as
Ozone	41 28[1]	UV Photometric Passive Sampling (Ogawa samplers)	Continuous Daily to weekly	1-hour average Daily/weekly average
Sulfur Dioxide	5 27	Pulsed Fluorescent Filter Pack	Continuous Weekly	Hourly average Weekly average
Nitrogen Oxides:				
NO/NO$_2$/NO$_Y$	4	Chemiluminescence	Continuous	5-min to 1-hr avgs
NO$_2$	27	Filter Pack	Weekly	Weekly average
Nitric Acid	27	Filter Pack	Weekly	Weekly average
Carbon Monoxide	4	Non-dispersive IR	Continuous	5-min to 1-hr avgs
Volatile Organics[2]	4	Stainless Steel Canisters	Daily to weekly	Daily/weekly average
Meteorological Parameters: Wind speed & direction, Relative Humidity, Solar Radiation, Precipitation, Ambient Temperature	41		Continuous	1-hour average
UV-B	14	Brewer Spectrophotometer	Continuous	1-hour average

[1] Number of passive sampling sites varies annually.
[2] VOC canister sampling conducted as part of special studies only.

NOTE: Continuous monitoring methods and quality assurance procedures are those specified by EPA.

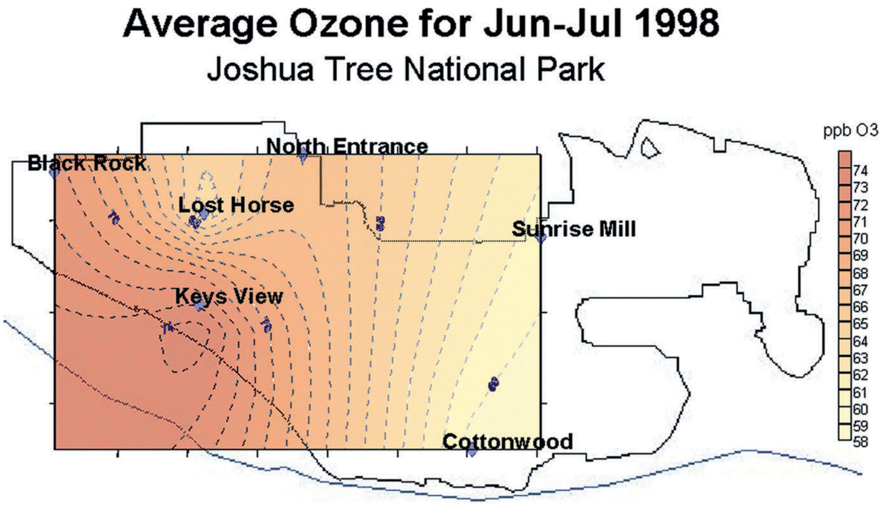
Volunteer places a passive ozone sampler at Great Smoky Mountains National Park.

continuous ozone samplers are provided in the figure below.

Air pollution special studies

In addition to its routine monitoring performed in numerous parks, NPS occasionally conducts or participates in special monitoring studies. The objectives of these studies vary from understanding the chemistry of the formation of ozone and visibility-reducing particles to the identification and quantification of specific sources affecting the air quality at one or more national parks. As a leader in visibility monitoring and research in this country, the NPS has participated in numerous visibility special studies over the last two decades, some of which have resulted in the reduction of air pollution emissions from several sources.

Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) The BRAVO study, conducted during July-October 1999, investigated the causes of haze at Big Bend National Park, Texas. An earlier study conducted jointly with Mexico in 1996 identified coal-fired sources in east Texas and the southeastern U.S., and coal- and oil-fired sources in Mexico contributing to these hazes. In addition to determining the chemical components of fine and coarse particles responsible for the haze, BRAVO will at-



Spatial distribution of ozone concentrations from passive and continuous ozone samplers at Joshua Tree National Park.

tempt to quantify the impacts of sources in the U.S. and Mexico. NPS expects the results of this study to guide air quality management decisions in the state of Texas and in Mexico so that the trend of increasing haziness at Big Bend and Guadalupe Mountains National Parks will be reversed.

Winter Haze Intensive Tracer Experiment (WHITEX) Visibility impairment at Grand Canyon National Park has been a concern for several decades. To assess qualitatively and quantitatively the contribution of two large coal-fired power plants in proximity of the park, the NPS Air Resources Division participated in two air quality field studies. The WHITEX study conducted during Winter 1987 assessed the contribution of the Navajo Generating Station (NGS), located in Page, Arizona, to visibility impairment at the park. The study incorporated the use of a unique chemical tracer emitted from NGS stacks and an extensive field measurement program that included 11 monitoring stations located throughout the Colorado Plateau, including Grand Canyon National Park. Using a variety of statistical models, the results indicated that on average, fine sulfate particles contributed 46 percent to visibility reduction (i.e., aerosol light extinction) at the park. Fine organic, nitrate, soil, and elemental carbon particles contributed the remaining 54 percent. Some models showed that as much as 60 to 70 percent of fine sulfate particles measured at the Grand Canyon could be attributed to NGS and nearly all of the fine sulfate under certain meteorological conditions. As a result of these findings, EPA moved forward in requiring the installation of scrubbers at NGS thereby reducing annual emissions of sulfur dioxide by 90 percent, from 70,000 tons to 7,000 tons. The scrubbers were installed and became operational in 1999.

Measurement of Haze and Visual Effects (MOHAVE) The MOHAVE study, conducted during Winter and Summer 1992, consisted of an extensive monitoring, modeling, and data assessment project designed to estimate the contribution of the Mohave Power Plant, also a coal-fired facility, to haze at Grand Canyon and other national parks and wilderness areas in the southwestern U.S. designated as Class I areas. Several unique chemical tracers were used to track emissions from the power plant and other areas of high emissions to determine their contribution to visibility impairment. The study showed that although the Mohave Power Plant contributes to visibility impairment at Grand Canyon, it is not the major cause of visibility impairment at the park. Air pollution from other areas, including southern California, is also transported to the park. Because the Mohave facility had the largest single contribution to visibility impairment, its proximity to the park and the quantity of its emissions, the facility was required to install scrubbers and reduce SO2 emission by 85 percent, from approximately 45,000 tons to 7,000 tons annually. The facility will also further reduce its particulate matter emissions by adding additional controls.

Pacific Northwest Regional Visibility Experiment using Natural Tracers (PREVENT) To identify the contribution of emission sources to fine particle concentrations and regional haze at Mt. Rainier, North Cascades, and Olympic National Parks, and other Class I wilderness areas managed by the U.S. Forest Service, NPS conducted an intensive field monitoring program in the Pacific Northwest during Summer 1990. Study results showed that sulfates account for 20 to 30 percent of fine particle mass, but contribute over 40 percent of the visibility reduction at these parks. The study also showed that carbon (organics and light absorbing carbon) contributes about 20 percent to visibility reduction and nitrates and coarse mass contribute 10 percent.

The study clearly linked sulfates measured at Mt. Rainier to the Centralia coal-fired power plant in Washington, while most sulfates at North Cascades were associated with transport from Canadian sources. Most of the organic carbon was associated with emissions from the Seattle-Tacoma area rather than with fire-related activity. Fire-related activity accounted for a significant fraction of light absorbing carbon (soot), much of which was transported from the state of Oregon.

Centralia Power Plant Collaborative Decision-Making Process Because the Centralia power plant was found to contribute to visibility impairment at Mt.

The Navajo Generating Station, located in Page, AZ, near Grand Canyon National Park, installed scrubbers in 1999 to reduce annual sulfur dioxide emissions by more than 60,000 tons. These reductions will result in better visibility at the Grand Canyon.


NPS researchers have queried the public on traits of a scene and how this related to their perception of visual air quality and what people value.


Air quality instrumentation are calibrated and serviced in a laboratory prior to deployment for special studies or routine monitoring.

Rainier, it qualified as a potential candidate for Best Available Retrofit Technology (BART) to reduce SO_2 emissions under EPA's visibility regulations. Plant SO_2 emissions were estimated at approximately 69,000 tons annually. To avoid the resource and time intensive BART process, the NPS, the plant owners, the U.S. Forest Service (USFS), the Environmental Protection Agency (EPA), and state and local regulatory agencies formed a Collaborative Decision Making (CDM) group to negotiate additional SO_2 emission reductions at the plant. After a year of negotiations with NPS taking a leadership role throughout the process, the CDM group announced its "final target solution" in December 1996. The solution will result in 90 percent reduction of SO_2 emissions through scrubbing technology, with a permitted level not to exceed 10,000 tons per year, by the end of 2002. Nitrogen oxide emissions were also reduced. As part of the agreement, tax reductions were provided to the plant owners to help finance the cost of controls ensuring the continued economic viability of the facility, which was the major employer in the area.

Human perception and values

The NPS has performed numerous perception studies to research the value of perceived visual air quality. The studies show that various physical factors influence an individual's perception, including atmospheric clarity, variation of cloud cover and illumination, and landscape features, but a scenic element most sensitive to changes in air pollution is key to determining perceived visual air quality. These scenic elements specific to the different parks (e.g., mountains, plains, and bluffs) may be perceived differently and thereby be valued differently by individuals.

Gaseous pollutant special studies

NPS also participates in research activities and special regional air pollution studies aimed at understanding the formation and long-range transport of gaseous pollutants and the development of regional pollution control programs. It is important to include national parks in the domain of these monitoring studies so that atmospheric models developed or evaluated as part of these studies can provide information on how air quality levels in parks will change as a result of any proposed emissions control scenarios. For example, scientific investigations by the Southern Oxidant Study (SOS) in 1992, 1994, 1995, and 1999 to understand the contribution of urban and point source plumes to ozone formation over a large region included specially equipped air quality monitoring stations at Mammoth Cave and Great Smoky Mountains National Parks. The North Atlantic Research Experiment (NARE), which studied the export of air pollutants from the continental U.S. to the Atlantic Ocean, included a ground station at Acadia National Park. In 1996, Shenandoah National Park and Cape Cod National Seashore participated in a regional study investigating ozone transport in the Northeast. Research findings from these studies have appeared in numerous scientific journals.

To understand the chemistry and transport of ozone into national parks it is important to measure ozone, ozone precursors, plus additional parameters. Over the last five years, NPS has operated enhanced monitoring activities in three national parks, Shenandoah, Great Smoky Mountains, and Mammoth Cave, as part of regional ozone studies. NPS has also cooperated with university researchers and other agencies (e.g., Tennessee Valley Authority) to investigate the causes of high ozone levels in these parks.

Some of the research findings from the Shenandoah, Big Meadows site include the identification of various areas that influence both high and low ozone levels at the park based on air mass back trajectory analysis. This analysis shows that air masses that are transported over areas west of Shenandoah National Park, including the Ohio River Valley, prior to arriving at the park are usually associated with high ozone levels measured at the park. On the other hand, clean air is most often associated with trajectories from the south and east having origins in the Atlantic Ocean. Other findings from Shenandoah indicate that the park's atmosphere in the summer months is rich in volatile organic compounds, 15 percent of which are emitted naturally from vegetation. As a result, the park's atmosphere is very sensitive to the addition of small amounts of nitrogen oxide emissions, which can result in the formation of high ozone levels in the park. This implies that the control of nitrogen oxides emissions may be a more effective strategy to control high levels of ozone in the park and may be a more effective strategy to control high levels of ozone in the park than controlling VOCs.

Chapter Four

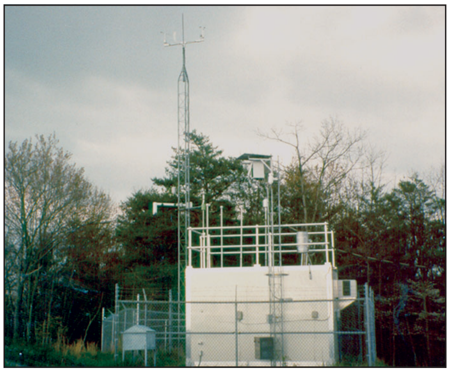
Great Smoky Mountains National Park -- Threatened by Air Pollution

Many national parks are being adversely affected by air pollution. One park facing the greatest threats from impacts of air pollution is Great Smoky Mountains National Park. As one of the Park System's "crown jewels," the preservation of the park's natural resources, including the elimination of existing air pollution impacts, is paramount to the park's resource management efforts. Great Smoky Mountains National Park encompasses over 520,000 acres in eastern Tennessee and western North Carolina, and is world-renowned for its prominent mountain ridges and deep-cleft valleys, its scenic beauty, and most notably, the incredible diversity of its plant and animal resources. It has more tree species than in all of northern Europe, and more species of vascular plants than any other North American national park. In fact, half of the old growth forest in the eastern U.S. lies within the park's boundaries. It also contains the headwaters for 45 watersheds containing over 2,100 miles of streams. Great Smoky Mountains has been designated as an International Biosphere Reserve and a World Heritage Site because of its worldwide significance.

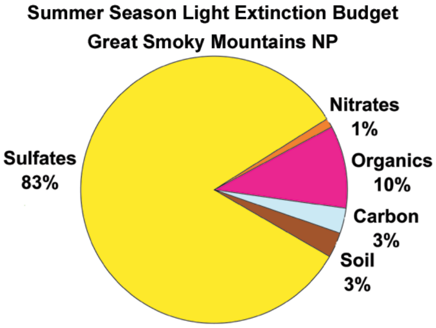
Air pollutants emitted from all kinds of sources (e.g., power plants, cars, trucks, and factories) located nearby and far away are degrading one of the park's chief natural resources—its air quality. Air pollution threatens the existence of many of the park's resources or significantly affects their condition, including its scenery, vegetation, streams, wildlife, and soils. Moreover, poor air quality diminishes visitor enjoyment of the park's renowned natural features and potentially affects public health. Burning of fossil fuels — coal, oil, and gas — produces oxides of nitrogen and sulfur, that convert to secondary pollutants (e.g., nitrate, sulfate, and ozone), that travel on air currents from all over the eastern U.S. As a result, Great Smoky Mountains National Park experiences some of the highest levels of these pollutants compared to any other national park in the East. The levels of some of these air pollutants have increased significantly over the past decade. Unless actions are taken soon to reduce air pollution emissions on a regional basis, the health and existence of the park's resources will continue to be threatened.

Views of Great Smoky Mountains on a clear and hazy day. Haze conditions result primarily from the light scattering associated with fine sulfate particles in the air. These particles are formed as chemical by-products of sulfur dioxide emissions from sources such as coal-fired power plants.

Great Smoky Mountains National Park was established on June 15, 1934; the park was designated an International Biosphere Reserve in 1976, and a World Heritage Site in 1983. View at Cades Cove, a popular park destination.



Air quality monitoring station at Look Rock, in Great Smoky Mountains National Park. Great Smokies has one of the most comprehensive air quality monitoring and research facilities within the NPS. Researchers often use the park to explore the many aspects of air pollution and its effects.



Various types of fine particles are responsible for the human-caused haze at Great Smoky Mountains National Park. Fine sulfate particles contribute over 80% to this haze during the summer, the season with the poorest visibility. Significant reductions in sulfur dioxide emissions from sources located in the Midwest and the southeastern U.S. are necessary to improve visibility conditions at the park.

Source: IMPROVE Program

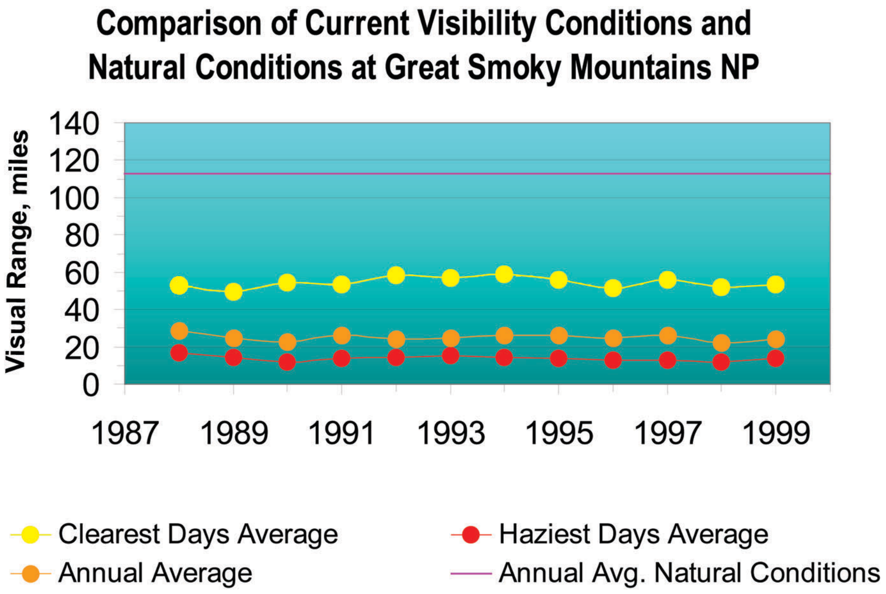
Resources under stress

Visibility impairment from regional haze

Good visibility in scenic areas like Great Smoky Mountains National Park has significant aesthetic and economic benefits. As evidenced by over 10 million visits in 1999, Great Smoky Mountains National Park has become the nation's most popular national park due in part to its accessibility and being within easy driving distance of two-thirds of the American population. It is estimated that these visits generate nearly a billion dollars annually for the local economy.

Views from scenic overlooks at the park have been seriously degraded over the last 50 years due to human-caused air pollution. Since 1950, based on regional airport records, average visual range in the southern Appalachians has decreased 80 percent in summer and 40 percent in winter. Summer used to have the clearest visibility, now it has the worst. This decline in visibility not only affects how far one can see from a scenic overlook, it also reduces how well one can see. Haze causes colors to appear bleached-out and obscures landscape features. Visible pollution typically appears as a uniform, whitish haze, different than the natural mist-like clouds for which the Great Smoky Mountains were named. In a survey, 74 percent of summer visitors to Great Smoky Mountains National Park said that clean, clear air was "extremely important" to them during their stay, and 84 percent said clear scenic views were "extremely important".

Increasingly, visitors no longer see distant mountain ridges because of this haze. Scenic views are impaired 90 percent of the time by human-caused air pollution. As shown in the figure below, current annual average visibility at Great Smoky Mountains National Park is 25 miles—much less than the estimate of natural visibility conditions, (113 miles). Current summer average visibility is 15 miles—it should be 77 miles in the absence of human-caused air pollution. During severe haze episodes, visibility has been reduced to less than 2 miles. Summer sulfate concentrations between 1988 and 1999 have increased 17 percent. Declining visibility is well correlated with increasing ambient sulfate concentrations. Fine particle sulfates, are the principal causes of the human-caused hazes at the park, as well as throughout the eastern U.S., as illustrated in the figure at left, which also identifies the other chemical constituents of fine particles that contribute to summer visibility impairment. It is primarily the burning of high-sulfur coal in eastern power plants and industrial facilities that produces sulfur dioxide emissions that are transformed in the atmosphere into fine airborne sulfate particles.



Visibility conditions, in miles, at Great Smoky Mountains National Park, have not shown improvement from 1988 through 1999. The annual average of 25 miles is very much less than the estimated natural conditions of 113 miles. Even the average of the clear days is far below natural conditions.

Atmospheric deposition impacts to terrestrial and aquatic ecosystems As shown in the figure below, Great Smoky Mountains National Park receives some of the highest rates of nitrogen and sulfur deposition of any monitored location in North America. These pollutants fall to the ground not only as acid rain and snow, but also as acidic dry particles and cloudwater. The acidity (pH) of annual precipitation measured at Great Smoky Mountains National Park, as part of the National Atmospheric Deposition Program (NADP) is 4.5, 5-10 times more acidic than natural rainfall whose pH ranges between 5.0 and 5.6. Cloudwater acidity averages 3.5 pH and has been measured as low as 2.0 pH. These acidic clouds bathe the high elevation forests during much of the growing season. Ninety percent of clouds sampled during a three-year period at the park were found to be acidic. Almost 33 percent of nitrogen and 50 percent of sulfur deposition to the park's high-elevation ecosystems results from clouds. As illustrated in the figure at the top of the next page, concentrations of sulfate, nitrate, ammonium, and hydrogen ions in clouds have increased since 1995.

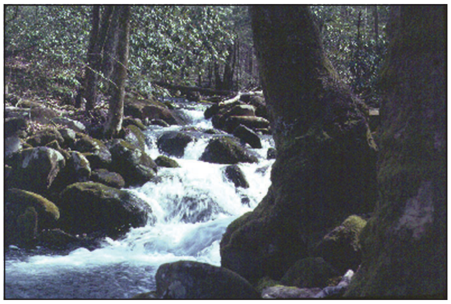
Great Smoky Mountains National Park contains 74 percent of the spruce-fir forests in the southern Appalachians, the largest remnant red spruce-Fraser fir ecosystem in the world. The park's spruce-fir forests are undergoing greater stress, which is thought to be the result of atmospheric deposition inputs to forest soil-water chemistry.

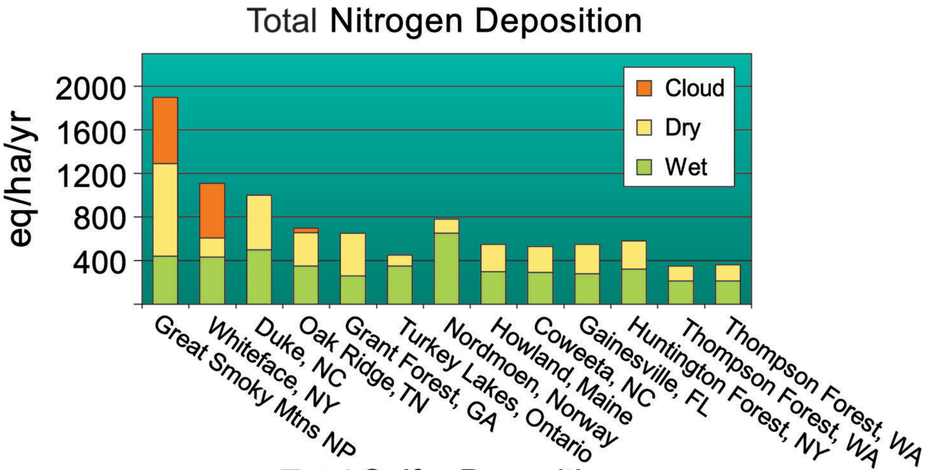
Research shows that both chronic (long-term) and episodic (short-term) acidification are adversely affecting sensitive streams and soils. Most high elevation park streams and soils are highly sensitive to acidification with little ability to neutralize acids resulting from nitrogen and sulfur pollution. Certain high elevation soils are receiving so much atmospheric nitrogen that they are suffering from advanced stages of nitrogen saturation. This condition limits the availability of forest nutrients (mainly calcium) to plants

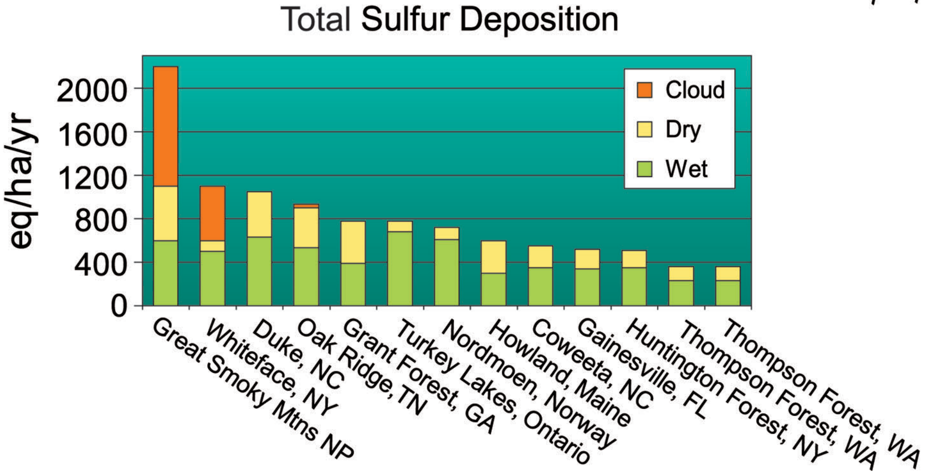
Acidic Deposition Impacts on Streams at Great Smoky Mountains

Nine of ninety streams sampled over an eight-year period at Great Smoky Mountains had median pH less than or equal to 5.6, the lower limit of brook trout population viability. Stream water acidity increased significantly over this period.

Nitrate and sulfate levels, and acidity in streams increase with increasing elevation. Higher elevation streams also have less ability to neutralize acidic deposition, and thus, are more at risk.



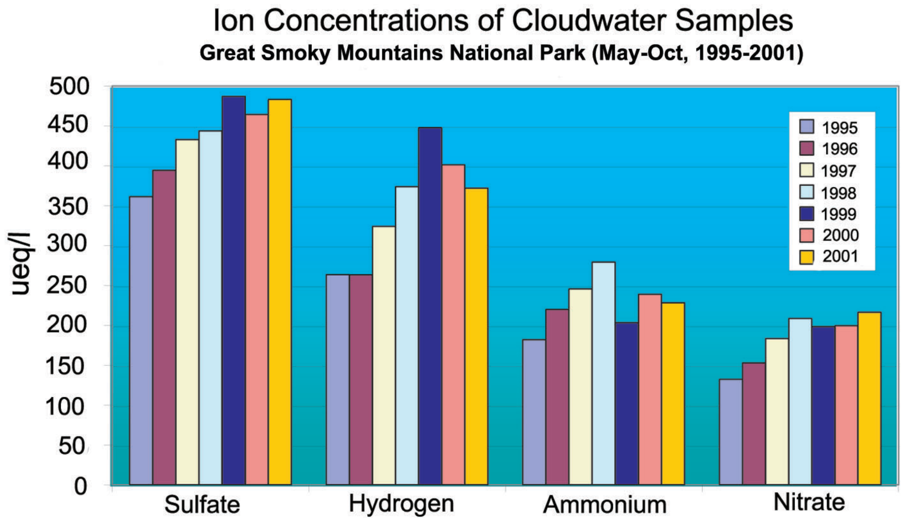




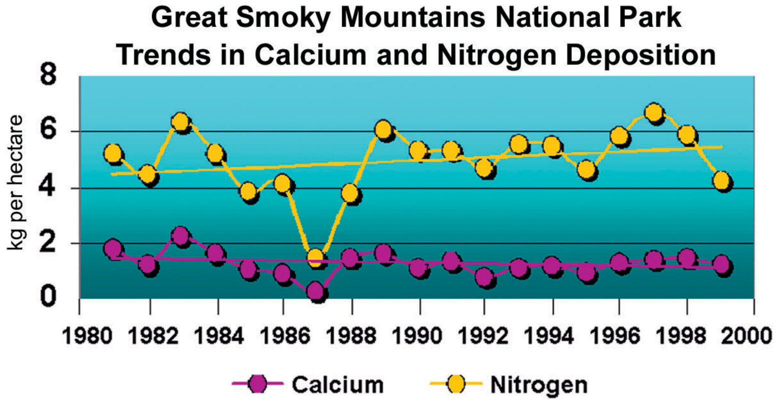
Total nitrogen and sulfur deposition at Great Smoky Mountains National Park compared to other locations worldwide. The park experiences some of the highest atmospheric deposition levels on the North American continent. One hundred equivalents per hectare is about 1.2 pounds per acre of nitrogen and 2.8 pounds per acre of sulfur.

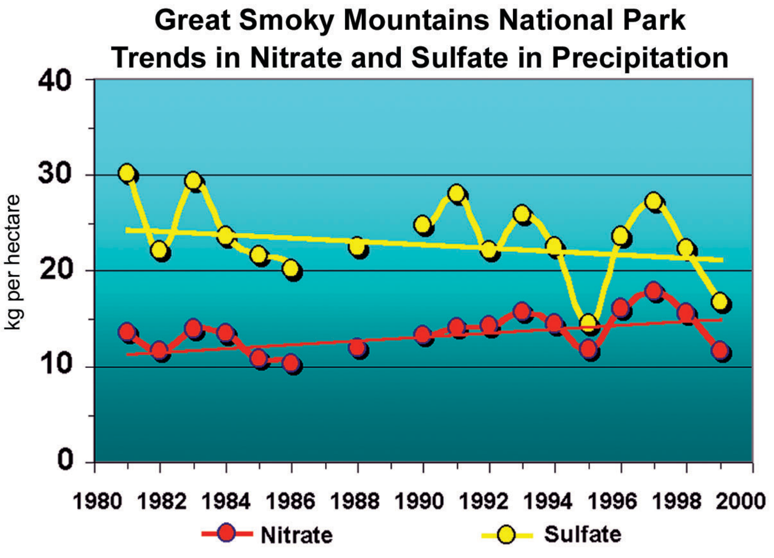
Source: Integrated Forest Study

Cloud samples taken annually from May through September at Great Smoky Mountains National Park show rising levels of several chemical constituents. The park partners with Tennessee Valley Authority and EPA to investigate the effects of acidic deposition on the park's ecosystems.



and causes the release of toxic aluminum that can harm vegetation and stream life. Sensitive mountain streams and forest soils are being acidified to the point that the health of the park's high elevation ecosystems are in jeopardy. Results of atmospheric deposition monitoring at the park show that annual wet nitrogen deposition between 1981 and 1999 increased 22 percent, while calcium deposition over the same period decreased by 24 percent, as shown in the figure below. Less calcium deposited in the park may also contribute to less nutrients for aquatic and terrestrial systems. Given the documented effects on park ecosystems and the continuing rise in many constituents of atmospheric deposition, large reductions in nitrogen and sulfur emissions are necessary to protect sensitive streams and soils in the park.





Several trends in wet deposition levels have park managers concerned. Total nitrogen deposition and nitrate in precipitation increased from 1981-1999. Decreased calcium deposition could result in fewer nutrients being available for aquatic and terrestrial ecosystems. Although sulfate levels in precipitation declined significantly, further reduction in sulfate is needed to restore ecosystems adversely impacted by atmospheric deposition to their natural condition.

Ozone pollution and its impacts

Ground-level ozone, produced by the reaction of nitrogen oxides and volatile organic compounds (VOCs) in the presence of sunlight, is one of the most widespread pollutants affecting vegetation and public health in the eastern U.S. Power plants, cars, trucks, and factories are the main emitters of nitrogen oxides, whereas VOCs are emitted by vehicles and by industry. VOCs (primarily isoprene) are also emitted by vegetation, including trees that are common to the eastern U.S. These natural emissions exceed human-caused emissions during the summer. However, with the addition of emissions associated with human activities, ozone levels can rise substantially above background levels of 20 to 40 parts per billion.

From a resource protection perspective, high ozone levels at Great Smoky Mountains National Park have been a concern since the 1970s when foliar injury symptoms consistent with ozone injury were first documented. In the late 1980s, Great Smoky Mountains NP researchers teamed with EPA and other researchers to confirm these earlier reports and identify those vegetative species susceptible to ozone injury and to quantify the relationship between ozone levels and effects, such as foliar injury and biomass loss. Based on these controlled experiments conducted at the park (see figure at right), 25 of 39 native species tested showed injury similar to that observed in the park indicating that vegetation throughout the park was being damaged by ambient levels of ozone. In a separate study conducted in the early 1990s, researchers found ozone foliar injury on black cherry, yellow poplar, and sassafras trees in the vicinity of three of the park's ozone monitoring stations. Ozone injury increased with increasing elevation and ozone exposure, indicating that vegetation on mountain tops and ridges were likely more susceptible to ozone injury. From these investigations, 30 species of plants have shown leaf damage after being exposed to controlled ozone levels identical to those that occur in the park, and an additional 60 species have been identified that exhibit ozone-like symptoms. Sensitive species like black cherry and yellow poplar show both visible injury and significant growth reductions due to ambient ozone. Failure to show visible injury is not indicative of a plant not being injured, as reduced photosyn-

Researchers use fumigation chambers such as these to expose different plant species to varying amounts of ozone pollution in order to document the type of injury or damage that occurs from different levels of exposure. This type of experiment was used to determine which types of plants were being affected by ozone pollution at Great Smoky Mountains National Park. Nearly 100 different species of plants have shown ozone-like injury symptoms.

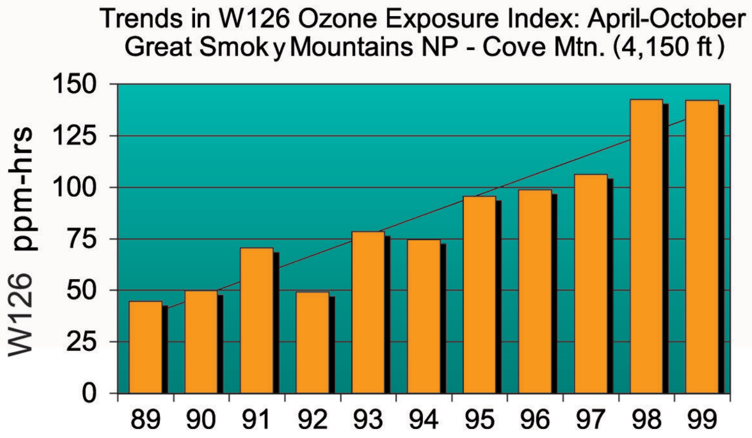
How Ozone Injures Plants

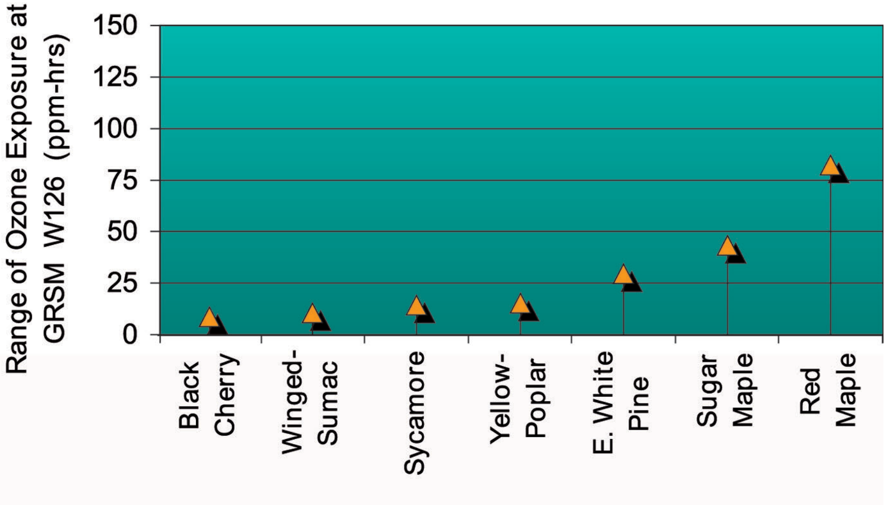
Ozone enters plant leaves through small openings called stomates during normal photosynthesis. Once inside the leaf, ozone changes the integrity of cells. Cells collapse and die and visible symptoms can occur on upper leaf surfaces. Depending on the type and variety of the plant, the concentration and duration of ozone, and other environmental factors, ozone can cause an array of symptoms in plants. The injury usually manifests itself as small necrotic areas or stippling, change in pigmentation, chlorosis from chlorophyll breakdown, and premature aging and senescence. These types of visible injury can lead to changes in physiology and growth.

Examples of healthy (left) and injured (right) foliage from ozone exposure are illustrated by the two species pictured: black cherry (top) and tall milkweed (bottom).

thesis or growth reductions could be occurring in the absence of any visible injury.

Ozone exposure indices that are calculated by summing ozone concentrations over a specified period of time (for example, a month or an entire summer) are often used to relate ozone levels to ozone injury to vegetation. Some researchers use an exposure index known as W126 that is similar to the SUM06 discussed in Chapter Two. As illustrated in the graphs below, different species of trees native to the park show a large variability in the level of ozone exposure (W126) that causes a 10 percent growth reduction. Black cherry, for example, is extremely sensitive to ozone and can be damaged at rather low levels of exposure. Sugar and red maples, on the other hand, require much higher exposures to inhibit growth. The figure below also illustrates how ozone exposure levels at the park, as recorded at the Cove Mountain site, have risen rather dramatically since 1989 implying that injury to vegetation has also increased during this same time period. In fact, researchers have found a 12 percent reduction in radial growth over 5 years, and 8 percent over 10 years, in black cherry in the park. For yellow poplars, the reduction has been much greater, 43 percent over 5 years and 30 percent over 10 years.

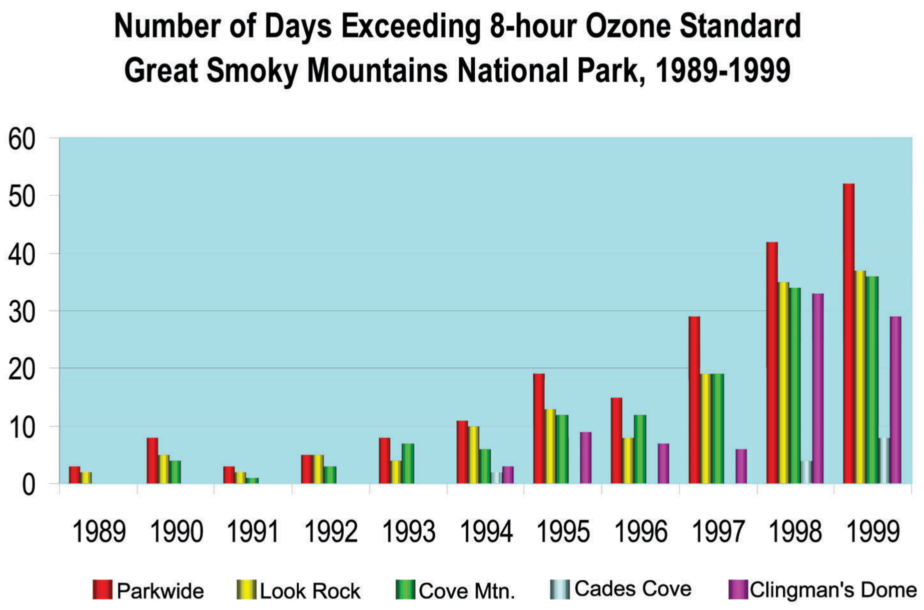




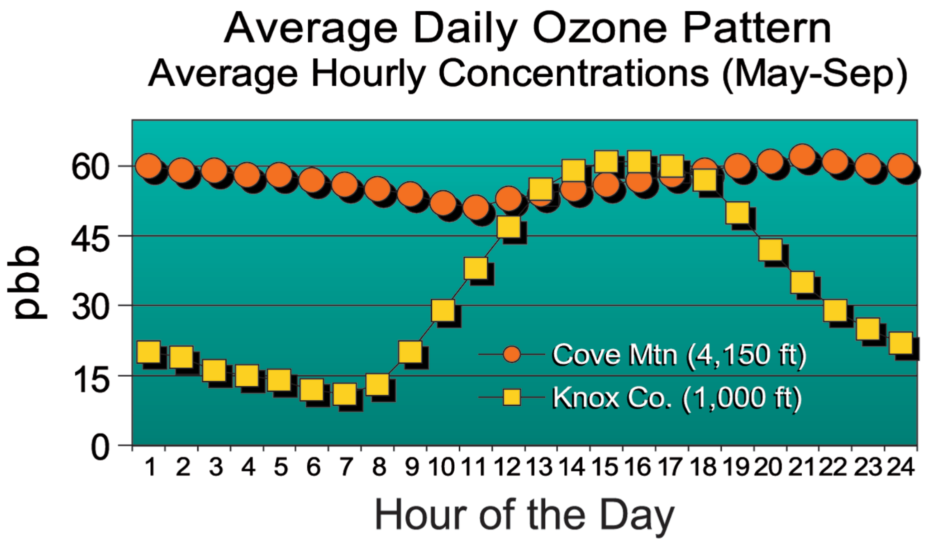
Ozone exposures at Great Smoky Mountains National Park, which typically exceed the injury level for numerous plant species, increased steadily between 1989 and 1999 (top graph). The bottom graph shows the ozone exposure levels associated with a 10 percent growth reduction in seedlings for various native plant species, based on fumigation chamber studies conducted at the park. Various plant species showed growth reductions at very low levels of exposure.

Ozone monitoring conducted at five locations in the park has shown that ozone exposures are among the highest in the eastern U.S. Levels have exceeded EPA's 1-hour and 8-hour ambient air quality standards set to protect public health. The figure below illustrates the sharp rise in the number of times the maximum 8-hour ozone concentration has exceeded the EPA 8-hour standard in the park. Three locations, Clingman's Dome, Cove Mountain, and Look Rock, recorded over 30 days above the 8-hour health standard in 1998 and 1999. Most ozone pollution measured at the park is transported from large urban areas in the southeastern U.S., such as Knoxville, TN, and Atlanta, GA.

Ozone is a powerful respiratory irritant for humans. Research shows that ozone can cause coughing, sinus inflammation, chest pains, scratchy throats, permanent damage to lung tissue, and reduced immune system functions. Children, the elderly, those with pre-existing respiratory and pulmonary problems, and healthy adults engaged in strenuous outdoor activities are most vulnerable. The park recorded 52 unhealthy ozone days in 1999, the second highest total for any location in the eastern U.S., second only to Atlanta, GA. The park now issues ozone advisories to visitors, staff, and the media on the high ozone days, recommending that people take precautions and reduce their exposures by hiking or working at lower elevations and taking frequent breaks.



The number of days with ozone levels above the national ambient air quality standard have risen sharply since 1989 posing threats to vegetation, as well as park visitors and employees. The "Parkwide" column represents the total number of separate days that at least one monitoring location exceeded the standard. In 1999, the park recorded 52 "unhealthy" days that exceeded the standard. High ozone levels are typically recorded during the summer. Regional pollution control strategies are necessary to improve air quality.



Average daily ozone patterns at Great Smoky Mountains National Park and Knoxville, Tennessee. Higher elevation sites at the park are constantly exposed to high ozone levels throughout the day. In contrast, when areas show a characteristic diurnal pattern in ozone levels with peaks occurring in mid-afternoon. The depletion of ozone in urban areas at night results from the destruction of ozone by nitrogen oxides emitted by automobiles.

Air Quality Monitoring at Great Smoky Mountains National Park

Precipitation Chemistry Monitoring[1]
Elkmont (elev. 2,100 ft) ongoing since 1980
Noland Divide (elev. 5,700 ft) ongoing since 1985

Dry Deposition Monitoring[2]
Look Rock (elev. 2,700 ft) ongoing since 1998
Clingman's Dome (elev. 6,670 ft) ongoing since 1996

Cloudwater Chemistry Monitoring[2]
Clingman's Dome - ongoing since 1994

Visibility and Fine Particle Monitoring[3]
Look Rock - ongoing since 1984
Cove Mountain (elev. 4,150 ft) since 2000

Ozone, other gaseous pollutants, Meteorology[4]
Look Rock - ongoing since 1984
Cove Mountain - ongoing since 1986
Clingman's Dome - ongoing since 1993
Cades Cove (elev. 1,850 ft) - ongoing since 1994
Purchase Knob (elev. 4,900 ft) - ongoing since 1995
Twin Creeks (elev. 2,000 ft) 1987-1995

Mercury Deposition Monitoring[1]
Elkmont 2002-
Clingman's Dome 2002-

EPA UVB Monitoring
Cades Cove - ongoing since 1998

[1] *As part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN)*
[2] *As part of EPA's Clean Air Status and Trends Network (CASTNet)*
[3] *As part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network*
[4] *As part of NPS air quality monitoring network*

Most monitoring activities at the park are coordinated through the NPS Air Resources Division

Using volunteers in the air quality monitoring and research program is one way of obtaining air pollution information.

Air quality monitoring and research activities
Great Smoky Mountains National Park prides itself in having a comprehensive air quality monitoring and research program that is a major component of the park's overall natural resource management program. This is a result of the vital importance of air quality to many of the resources for which the park is noted. The goals of the program are to:

- Determine the status and trends of pollutant concentrations in the ambient environment
- Determine the effects of air pollutants on park resources
- Determine the sources of pollutants affecting park resources

Since the early 1980s, an extensive network of air and water quality monitoring stations has been established in the park to assess the status and trends of several key pollutants or conditions. The air monitoring program includes gaseous pollutants (ozone, sulfur dioxide, carbon monoxide, and nitrogen oxides), visibility, fine particle, precipitation chemistry, and meteorological monitoring. Long-term monitoring and research data collected at Great Smoky Mountains National Park have allowed the park to document the status and trends of important air quality indicators and the effects that airborne pollutants are having on the park's terrestrial, aquatic, and scenic resources.

Cooperative research efforts with other government agencies have also allowed for a greater understanding of the probable causes of air pollution effects being observed, the transport pathways for pollutants reaching the park, and the atmospheric chemistry or mechanisms associated with poor air quality.

Southeastern Aerosol and Visibility Study (SEAVS) Particle data, such as that collected by the IMPROVE visibility network, have routinely been used to provide a measurement of visibility conditions. Historically, the haziest conditions have been underestimated by 30 percent to 50 percent in the eastern U.S. using these data. The contribution that fine particles have on visibility reduction is very dependent on the amount of water absorbed by some of the chemical constituents of these particles and their physical and chemical properties. Using the intensive measurements made at the park various mathematical models were applied to estimate light extinction. The study revealed that sulfate aerosols are more acidic than previously believed thereby causing greater reductions to visibility during some episodes. This resolved a major limitation in estimating light scattering from fine particle measurements. By properly accounting for aerosol acidity, better predictions can be made on how changes in emissions, such as those required by the Clean Air Act, will translate into changes in haziness at the park and throughout the eastern U.S.

Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet) In 1996, the EPA and the NPS agreed to use 14 national parks, including Great Smoky Mountains, as "outdoor laboratories" to examine trends in global and regional environmental stressors, such as air pollutants and UV-B radiation, and the response of natural systems and populations to these stressors. Findings from this research will guide NPS managers in making science-based decisions related to the protection and preservation of park natural resources. Activities from this effort will enable park scientists to scale atmospheric deposition measurements made at one location to entire landscapes using tools like a geographic information system (GIS). Two methods are being investigated to characterize the deposition-terrain response fields: sulfate fluxes in through-fall and lead in surface soils, which have been shown to be excellent tracers of primary deposition processes. This project represents a crucial step in atmospheric deposition research at the park and important for the management of ecosystems exposed to acid deposition.

Research on ozone damage to the growth and physiology of native trees and wildflowers Research on the effects of ozone pollution on vegetation has occurred at Great Smoky Mountains for nearly 20 years and has contributed to what is known nationally about its effects on native vegetation. New research is focusing on the impacts of ozone on selected tree and wildflower species found in the park. In addition, researchers hope to learn how historical ozone levels and climate variations have affected tree growth by examining tree rings. Measurements of visible ozone injury on native wildflowers and trees will be made to determine differences in species sensitivity and if injury varies by location. Information derived from this and previous investigations is useful in establishing air quality standards that adequately protect park vegetation.

Southern Appalachian Mountains Initiative (SAMI) SAMI, started in 1992, is a broad-based effort focusing on regional air quality and its effects on natural resources of the Southern Appalachian Mountains. SAMI conducted an integrated assessment modeling of the effects of air pollution (haze, ozone, and acid deposition) on streams, soils, forests, and visibility, with particular attention to the 10 Class I national parks and wilderness areas in the region. SAMI brought together representatives from state and federal agencies, industries, environmental groups, academia, and the interested public to identify and recommend emissions management strategies. It is hoped that these strategies when implemented will remedy existing impacts and prevent future impacts for the eight states surrounding the Southern Appalachian Mountains: Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

Public awareness: a key to success

This challenging regional air pollution problem at Great Smoky Mountains National Park was brought to the forefront at the beginning of the 1990s and has continued to grow. Lacking authority under the Clean Air Act to regulate new or existing pollution sources directly, Great Smoky Mountains National Park uses the information and tools that are available to influence and convince regulatory authorities, governmental and industry officials, and the public, that action must be taken to clean up the air. The park has reached out to all stakeholders to ensure that they are aware of the scientific information gathered and of the resource protection issues facing the park. The management and staff of Great Smoky Mountains National Park have confronted this challenge head-on and have become a forceful advocate for clean air throughout the entire region surrounding the park. This has been done by successfully leveraging limited NPS funds to acquire the necessary data documenting resource damage and the need for pollution reductions. Key to this effort is an aggressive, comprehensive educational effort to communicate the air quality issues in a way that is understandable to the public and governmental officials.

Partnerships

Increasing public awareness and understanding of pollution problems in Great Smoky Mountains National Park has been successful by building strong partnerships at the local, state, and federal levels. The park's air quality management program is actively involved with the people engaged in air quality management, including citizen's groups, individuals, industry, and various levels of government. These include city and county officials, state, regional, and national legislators and policymakers. In addition the park has partnered successfully with numerous scientists, universities, and other researchers to develop the science base needed to deal effectively with air pollution issues.

Public awareness and education: "keep telling the story"

Park staff has made the case for improved air quality succinctly and consistently over the years. It has identified and suggested strategies to remedy the air quality problems facing the park. Great Smoky Mountains National Park's air quality program has increased credibility for the National Park Service's air resource management program that has produced broad-based public support for clean air not only for the Smokies but also for all our national parks.

Specific areas where Great Smoky Mountains National Park has been successful in enhancing public awareness of air quality issues facing the park include:

- Participating in one of the most extensive monitoring networks and research programs in the National Park Service with some of the highest quality data available

- Distribution of air quality background materials and publications

NPS Director Fran Mainella (far left) listens to Air Resource Management Specialist, Jim Renfro, as he discusses the effects that air pollution is having at Great Smoky Mountains National Park. The park uses information gathered by its air quality monitoring and research program to inform NPS management, state and federal officials, and the public as to why air quality is such an important park resource.

Production of interpretive materials, such as numerous wayside exhibits, a real-time Internet-accessible air quality display at Sugarland Visitor Center, and an interactive CD-ROM touch-screen exhibit at Oconaluftee Visitor Center are available.

- Maintenance of a Web site displaying real-time air quality conditions and describing air pollution problems at the park *(http://www2.nature.nps.gov/ard/parks/grsm/grsmcam/grsmcam.htm)*.

- Implementation of an ozone advisory program to inform visitors of unhealthy air quality, whenever it occurs at the park

- Highlighting air pollution issues at the park in the park's orientation film

- Sponsorship of a "Parks-as-Classrooms" program teaching thousands of children annually about air pollution issues at the park

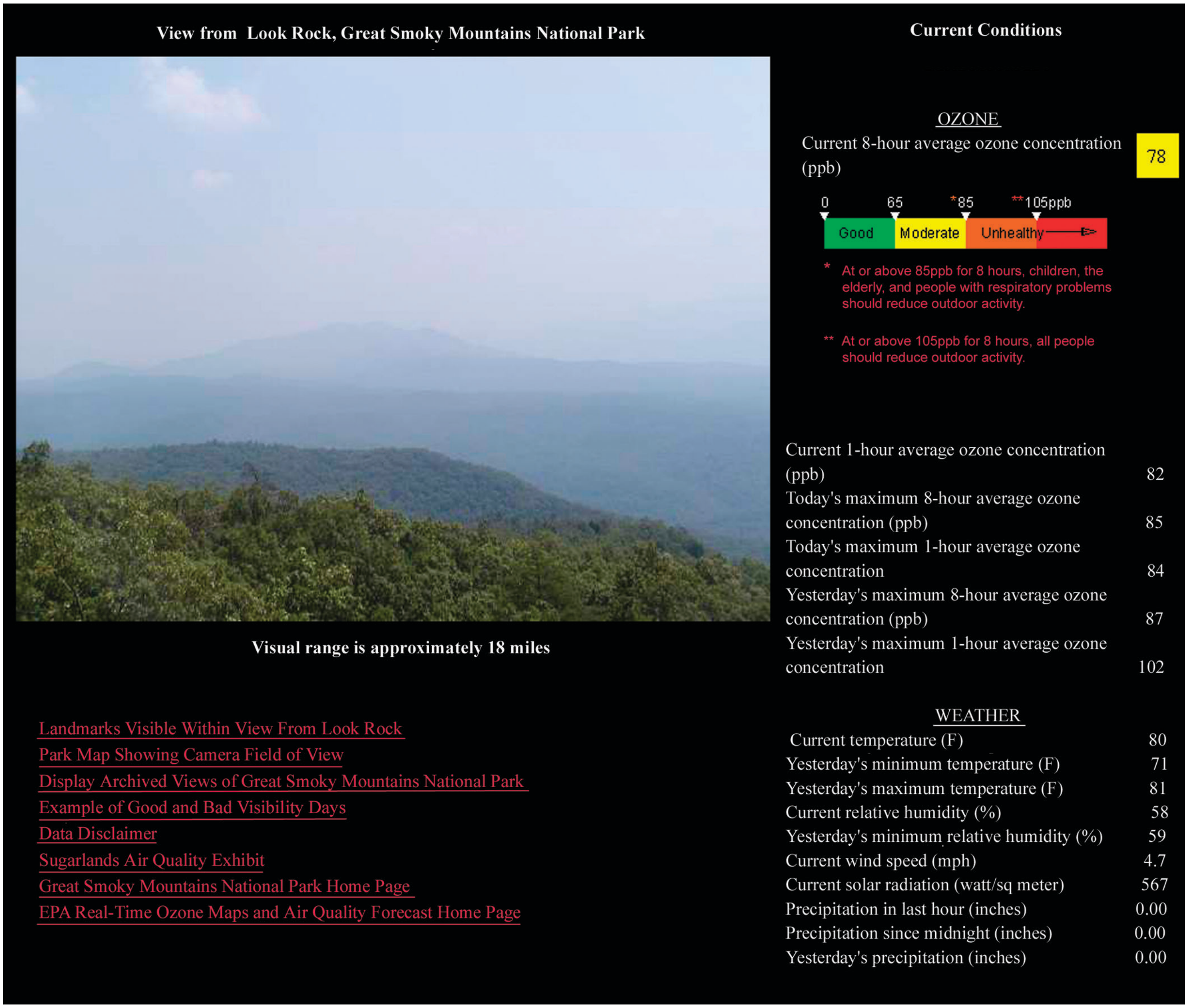
- Providing information to local and area Clean Air Campaigns

- Providing air quality monitoring "report cards" to a variety of stakeholders including governors, members of Congress, local leaders, media, scientists, staff, and environmental and industrial stakeholders

- Assisting states and industry in assessing the potential impacts of new air pollution sources on park resources to satisfy permit issuance requirements

All of these efforts are paying dividends in getting the public and decision-makers to understand why good air quality is vital not only to the park but also to the region as a whole. Only through public understanding of the air pollution issues facing the park and region, and making sound, science-based decisions will we be able to remedy existing and prevent future adverse impacts at Great Smoky Mountains National Park. Pristine views occur when the air is free of airborne pollutants.

Example Web page for Great Smoky Mountains National Park displaying near real-time image, ozone, and weather conditions.



View from Look Rock, Great Smoky Mountains National Park

Visual range is approximately 18 miles

Landmarks Visible Within View From Look Rock
Park Map Showing Camera Field of View
Display Archived Views of Great Smoky Mountains National Park
Example of Good and Bad Visibility Days
Data Disclaimer
Sugarlands Air Quality Exhibit
Great Smoky Mountains National Park Home Page
EPA Real-Time Ozone Maps and Air Quality Forecast Home Page

Current Conditions

OZONE

Current 8-hour average ozone concentration (ppb) 78

* At or above 85ppb for 8 hours, children, the elderly, and people with respiratory problems should reduce outdoor activity.

** At or above 105ppb for 8 hours, all people should reduce outdoor activity.

Current 1-hour average ozone concentration (ppb)	82
Today's maximum 8-hour average ozone concentration (ppb)	85
Today's maximum 1-hour average ozone concentration	84
Yesterday's maximum 8-hour average ozone concentration (ppb)	87
Yesterday's maximum 1-hour average ozone concentration	102

WEATHER

Current temperature (F)	80
Yesterday's minimum temperature (F)	71
Yesterday's maximum temperature (F)	81
Current relative humidity (%)	58
Yesterday's minimum relative humidity (%)	59
Current wind speed (mph)	4.7
Current solar radiation (watt/sq meter)	567
Precipitation in last hour (inches)	0.00
Precipitation since midnight (inches)	0.00
Yesterday's precipitation (inches)	0.00

Chapter Five

The Future of Air Quality in Our National Parks

Background

Since the late 1970s the National Park Service's air resources management program has grown steadily due to the importance that NPS and individual park managers placed on protecting this critical resource. Throughout this period, NPS placed a heavy emphasis on the collection of credible air quality information for its parks to support scientifically sound resource management decisions. This included information on air quality, its transport and fate in the atmosphere, and the effects on park resources and ecosystems. As part of its affirmative responsibility under the Clean Air Act, the NPS also assumed a larger role in the protection of parks and their resources from new sources of air pollution and a more visible role in national and regional initiatives to control air pollution. Protecting parks from new sources has been done through the review and comment of over 700 permit applications for new or modified sources of air pollution located near our national parks as required by EPA's Prevention of Significant Deterioration and New Source Review regulations. NPS has articulated its mission and need for good air quality in our national parks in many decision-making arenas, such as the Grand Canyon Visibility Transport Commission, the Southern Appalachian Mountains Initiative, and the Western Regional Air Partnership. It has fostered and maintained numerous partnerships with a diversity of private and public governmental and non-governmental organizations. Efforts to make park visitors and the general public more aware of air pollution issues faced by NPS have also been expanded using new Internet-based technologies. All of these efforts have been vital to the development of a successful and effective air resource management program.

NPS has not had, nor will it likely ever have, the regulatory authority commensurate with its responsibilities to control the air pollution emissions that cause ecosystem effects and visibility impairment so often observed in parks. Consequently, NPS will continue to rely mainly on non-regulatory approaches to achieve its air quality goals. New laws and regulations passed or that took effect during the 1990s, however, have been instrumental in some of the air quality improvements we are seeing in parks. The Acid Rain Provisions (Title IV) of the 1990 Amendments to the Clean Air Act and the Regional Haze Regulations have and will continue to have positive effects on park air quality related values. The new fine particle (PM2.5) and ozone standards will require states to revise their State Implementation Plans. This will translate into further reductions in air pollution emissions and likely benefit the air quality at some of our parks. New regulatory approaches will likely be necessary, however, to ensure that air pollution does not continue to pose a threat to any national park.

Future air quality challenges

In spite of the gains over the last 20 years, some air pollution trends in many of our parks continue to need our attention. Ozone levels in parks (see Chapter Two) rose steadily throughout the 1990s despite the overall improvement in ozone levels in urban areas. Over the past 20 years, national ambient ozone levels in urban areas decreased 21 percent based on 1-hour data, and 10 percent based on 8-hour data, according to EPA. Over the past 10 years, ozone 8-hour levels in 29 parks have increased by 4 percent, with some parks showing increases of nearly 20 percent. Nitrogen deposition levels in parks are generally on the rise causing a greater concern for nitrogen-saturated forests. Other effects from known and unknown environmental pollutants are likely going undetected because NPS lacks sufficient information about these pollutants or their effects.

Challenges

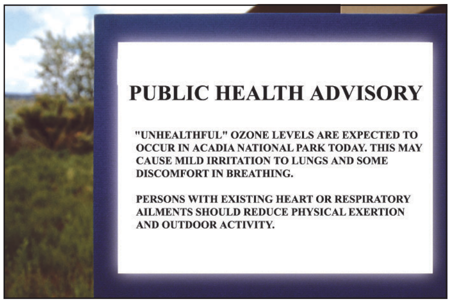
Some of the challenges the NPS will face arise from our experience over the past 20 years in trying to achieve better air quality for parks and their visitors. Some of these challenges reflect emerging issues such as those related to climate change and toxic airborne contaminants

Air quality interpretive displays, such as this one at Grand Canyon National Park, is only one way that the National Park Service informs the public about air pollution and how it affects national parks.

whose effects are largely unknown and yet to be investigated. Others reflect unanswered scientific questions on how air pollution is affecting park resources and ecosystems or arise as a result of some of the inadequacies of the current regulatory framework to mitigate air pollution effects in parks.

> *"... the quality of the air around Mount Rainier National Park serves to galvanize support among all the interested groups, governments, and the general public into actions that protect the entire region."*
>
> *Jon Jarvis, Superintendent*
> *Mount Rainier National Park, Washington*

Smoke control measures can reduce the air quality impact of prescribed burning.



PUBLIC HEALTH ADVISORY

"UNHEALTHFUL" OZONE LEVELS ARE EXPECTED TO OCCUR IN ACADIA NATIONAL PARK TODAY. THIS MAY CAUSE MILD IRRITATION TO LUNGS AND SOME DISCOMFORT IN BREATHING.

PERSONS WITH EXISTING HEART OR RESPIRATORY AILMENTS SHOULD REDUCE PHYSICAL EXERTION AND OUTDOOR ACTIVITY.

Some parks, such as Acadia National Park, often post health advisories for its visitors due to unhealthy levels of ozone (smog) measured in the park. High pollution days are usually associated with the long-range transport of polluted air masses that have passed over large urban areas along the eastern seaboard.

One clear message that has emerged over the past 20 years, however, is that good air quality in national parks cannot be taken for granted. It will require continued NPS involvement in the nation's air quality agenda, continued scholarship by researchers on air pollution effects, and enhanced public awareness and participation.

Visibility Achieving natural visibility conditions in parks over the next 60 years, envisioned by the Regional Haze Regulations, will be a major challenge. NPS must work in partnership with EPA, states, tribes, and regional planning organizations in developing strategies to achieve this goal. NPS will provide data on air quality conditions in parks, and assist states as they track progress toward the national visibility goal. Research to identify source categories contributing to visibility impairment and to differentiate smoke-related from industry-related carbon aerosols will need to be completed so that proper accountability measures can be developed to ensure that the national goal is realized.

Atmospheric deposition Under current levels of atmospheric deposition some parks are receiving inputs of air pollutants beyond the critical load levels necessary to maintain healthy ecosystems. Sufficient research and monitoring, however, that would help the NPS determine these ecosystem-dependent critical loads is lacking for most parks. Our challenge will be to initiate targeted research, monitoring, and modeling of dose-response relationships to identify these levels. Of particular concern is the increasing levels of nitrogen deposition in many of our parks, and the effects that this may be having on park ecosystems. Continued research on how best to estimate dry atmospheric deposition and accurately extrapolate measurements from a single monitoring location to entire ecosystems will also be necessary.

Ozone and other criteria pollutants A continuing challenge will be to track ozone trends and concentrations in parks, to assess effects on visitor health and sensitive vegetation. To meet this challenge, the NPS must continue monitoring so that data are available to detect changes in ozone and other pollutants over the long-term. Research into the formation and transport of elevated levels of ozone in national parks must be continued as part of the North American strategy. Our ability to link ozone concentrations to changes in plant health in parks will need improvement, and NPS will work with other federal agencies to ensure that this research occurs in these national parks most threatened by ozone.

Smoke management Fire is a potential major source of air pollution; it also plays an important role in many forest ecosystems. The protection of human health and air resources including visibility must be given full consideration in fire management planning and operations. Throughout most of the twentieth century, the occurrence of fire in natural ecosystems of the United States has been greatly diminished by land management practices, such as fire suppression. Through the exclusion of fire and its effects on natural systems, many wildland areas are now in an unhealthy state due to unnaturally high fuel loadings, the presence of plant species that are not endemic to these areas, and increased susceptibility of plant species to insect infestations and disease. As demonstrated by the many recent major wildfire events in western parks and wilderness areas, wildland areas are now prone to catastrophic fires largely due to conditions brought about or enhanced by decades of fire exclusion. A major challenge will be protecting human health and air quality while restoring fire-dependent forest ecosystems to their natural, wilderness character. Increased use of fire as a management tool must not impede progress being made in restoring visibility to natural conditions and complying with legal and regulatory requirements related to human health, welfare, and safety.

Toxic air pollutants Little is known about the impacts of airborne toxic compounds on park ecosystems. Some evidence suggests that persistent organic pollutants (POPs), pesticides, and metals may be deposited via atmospheric transport into parks. The NPS hopes to gain sufficient knowledge over the next decade to assess the exposure, accumulation, and impacts of airborne contaminants in key park ecosystems. In addition, mercury exposure and accumulation up the food chain will continue to be an issue in eastern and northeastern parks. Some parks have fish consumption advisories for humans, due to high mercury levels, yet little is known about the effects of high mercury levels on fish and wildlife in parks.

Park emissions The NPS Environmental Leadership Initiative directs NPS to manage the parks in a manner "that demonstrates sound environmental stewardship by implementing sustainable practices in all aspects of NPS management..." To achieve these objectives, it is necessary to understand air pollution emissions that result from activities within parks and to reduce these emissions as much as possible. In recent years, the NPS has developed emissions inventories for several parks. This is aimed at quantifying emissions from park sources, identifying strategies for reducing emissions, and ensuring compliance with state and local air regulations. The NPS has found that prescribed burning is typically the largest contributor to park emissions, and these emissions will be minimized using best smoke management practices. Park and concessionaire operations and facilities, as well as visitor vehicles, present the greatest opportunity for reducing emissions. Park emissions inventories will continue to be instrumental in guiding parks in developing sound management practices geared at protecting air resources.

Legislation and regulations New laws or regulations will likely be necessary to ensure that park natural resources and ecosystems are fully protected from the adverse effects of air pollution. EPA has set revised standards for ozone and fine particulate matter, which NPS hopes will benefit park ecosystems. Other than the Regional Haze Regulations requiring visibility conditions in Class I areas to be restored to their natural conditions, there are no current regulatory requirements for similar restoration or protection of other park "air quality related values". Lacking new standards or regulations, park resources and ecosystems sensitive to air pollution will continue to be adversely affected.

The designation of some national parks and wilderness areas as Class I under the Clean Air Act has afforded these areas special protection from air pollution emissions associated with new industrial facilities. This special designation provides an important tool needed to preserve air quality in these areas.

Cap and trade programs Cap and trade programs, such as the one developed under the Acid Rain Provisions (Title IV), can result in substantial reductions in air pollution emissions while minimizing air pollution control costs. By their very nature, these programs operate on a regional or national scale. Consequently, air quality gains at specific locations, such as national parks, cannot be predicted nor guaranteed. A mechanism must be found that would allow states and federal land managers an opportunity to ensure that their air quality management objectives are satisfied without impeding free market cap and trade programs.

Science and research NPS has a small, yet effective, science and research program supporting its air resource management efforts. The results of past air quality science and research activities have played a large role in this nation's understanding of air pollution effects on park resources, investment in these science and research efforts will assure that decisions regarding air quality in parks are based on sufficient scientific information. More air pollution effects research must be conducted in national parks, and other agencies and academic institutions must be encouraged to use parks as outdoor laboratories. Research must be expanded beyond the natural and physical sciences to include scholarly research on economic and social science topics related to air pollution effects in national parks.

Education and outreach An informed public is vital for the societal changes needed to reduce air pollution to protect park resources. The NPS conducts education and outreach programs to help promote public appreciation and awareness of highly complex air quality issues facing the agency. A variety of media formats (Internet, publications, visitor service programs, etc.) must be used to com-

White River maintenance building at Mount Rainier National Park. Three hundred seventy-four photovoltaic panels provide 47 kW of power and reduce air pollution inside the park.

> *"The Pacific Northwest needs a comprehensive public transportation system. While we have little influence over the enormous investment required for a system for the Puget Sound, we can lead by example at the park."*
>
> Jon Jarvis, Superintendent
> Mount Rainier National Park, Washington

Clean mass transit bus systems like the one at Zion National Park is one of the innovative ways that the National Park Service is eliminating traffic congestion in parks. These systems have the added benefit of reducing air pollution caused by automobiles, diesel buses, and recreational vehicles.

municate with the public, Congress, state legislators, and non-governmental organizations. Interpretive exhibits, including interactive ones like that at Great Smoky Mountains National Park, must be used more to inform park visitors on air quality and what actions they can take to improve air quality conditions in parks. NPS will also need to manage, analyze, and synthesize information and provide this information to the public, especially school-aged children, in a timely and routine manner using various approaches and in different languages. As this country's demographics change, the NPS air quality message will have to resonate with more diverse audiences, which will be an increasingly challenging task.

Using the Internet

The NPS Internet AirWeb site provides for the exchange of air quality related information on air quality monitoring levels, regulations/policy issues, guidance to new source permit applicants, links to real-time images and air quality data in parks, educational materials, and publications. It also provides illustrations of the effects of air pollution on natural resources in NPS areas:

National Park Service AirWeb
http://www2.nature.nps.gov/ard/

In addition, the following parks have Web sites that show real-time visibility and air quality data:

Great Smoky Mountains National Park
http://www2.nature.nps.gov/ard/parks/grsm/grsmcam/grsmcam.htm

Acadia National Park
http://www.hazecam.net/acadia.htm

Grand Canyon National Park
http://www2.nature.nps.gov/ard/parks/grca/grcacam/grcacam.htm

Mammoth Cave National Park
http://www2.nature.nps.gov/ard/parks/maca/macacam/macacam.htm

Joshua Tree National Park
http://www2.nature.nps.gov/ard/parks/jotr/jotrcam/jotrcam.htm

Hawaii Volcanoes National Park
http://www2.nature.nps.gov/ard/parks/havo/so2alert/havoalert.htm

Big Bend National Park
http://www2.nature.nps.gov/ard/parks/bibe/bibecam/bibecam.htm

A strategy for the future

The framework that the NPS develops to meet future air quality challenges must be based on the successful elements of our air resource management program. It must also rely on three basic elements: communication, particularly with diverse audiences; collaboration and partnership with our numerous stakeholders; and environmental leadership, leading by example and holding ourselves to the highest standards.

Communicating our message

> *Our vision is a National Park System with air quality and other resources sensitive to air quality unimpaired by human-caused pollution...*
>
> from VISION STATEMENT
> NPS AIR RESOURCES DIVISION

Communicating the NPS message regarding the importance of good air quality for parks to as many diverse audiences as possible is essential. Without public understanding and support as to why air quality is such a vital component of park ecosystems, NPS will be limited in its ability to meet its air quality goals. Before we can convey our air quality message to the public and others successfully, however, NPS as an organization must know and understand the importance of its message. Approaches to reach both internal and external audiences must be developed simultaneously.

In the past we have communicated our message and scientific information by disseminating a variety of air quality materials to internal and external audiences. Materials have included brochures, pamphlets, manuals, summary reports, slides, videotapes, exhibits, posters, scientific journal articles, and Web sites. Air quality information has been and must continue to be presented at technical conferences and professional association meetings, at congressional hearings, and at stakeholder meetings.

Public awareness programs in parks help promote public appreciation for preserving air quality in national parks. More NPS air quality information will be hosted on the Internet, including real-time air quality data collected at parks (see *Using the Internet* at left); data will continue to be formatted and accessible on the NPS Web site along with technical reports and findings. More air quality educational programs and lesson plans for all age groups must be developed and placed on the NPS Web site.

Working with others to improve air quality

> *The Air Resources Division, in partnership with parks and others, works to preserve, protect, enhance, and understand air quality and other resources sensitive to air quality in the National Park System.*
>
> from MISSION STATEMENT
> NPS AIR RESOURCES DIVISION

The NPS will continue its cooperative efforts with other federal land management agencies (i.e., U.S. Forest Service, U.S. Fish and Wildlife Service, and Bureau of Land Management), Environmental Protection Agency, tribes, federal, state, and local governments, industry, and non-governmental organizations to ensure that air quality and related resources in parks are not adversely impacted by air pollution. Through this effort we hope to increase understanding of air quality conditions, trends, and effects as they relate to national parks. This information will provide a basis for future protection and enhancement of NPS resources. The collaborative efforts will include participating in multi-stakeholder partnerships, such as those listed in Table 5-1, reviewing and commenting on state and federal regulations and policies, and reviewing permit applications for proposed sources near the parks.

Table 5-1. NPS Air Resources Management Collaborative Efforts

Partnership	Participants	Purpose
Federal Land Managers' Air Quality Related Values Work Group (FLAG)	National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), U.S. Forest Service (USFS)	FLAG is an interagency workgroup whose objective is to achieve greater consistency in the procedures Federal Land Managers use in identifying air quality related values and evaluating air pollution effects on these resources.
Southern Appalachian Mountains Initiative (SAMI)	AL, GA, KY, NC, SC, TN, VA, WV, National Park Service, U.S. Forest Service, Environmental Protection Agency, industry, environmental groups, academia, interested public	SAMI's mission is to identify and recommend appropriate measures to remedy existing and prevent future adverse air pollution affects on air quality related values of the southern Appalachians.
Visibility Regional Planning Organizations (RPOs)	National Park Service, U.S. Fish and Wildlife Service, state and local air quality agencies, industry, Indian tribes	The five RPOs (Western Regional Air Partnership, Midwest Regional Planning Organization, Central States Regional Air Partnership, Mid-Atlantic/Northeast Visibility Union, and Visibility Improvement State and Tribal Association of the Southeast States) are comprised of multi-state agencies that coordinate each state's development of plans to address regional haze.
Regional Air Quality Partnerships (RAQPs)	Federal Land Managers, states, Environmental Protection Agency	RAQPs are voluntary, ecosystem-oriented cooperative groups that have formed to deal with regional air pollution and its impacts on air quality related values.

Environmental leadership The NPS will continue strong support for its Environmental Leadership Program, which focuses on reducing the footprint NPS operations leave on the environment, and on ensuring exemplary environmental performance in NPS facilities. The plan for demonstrating environmental leadership focuses on air and water resource protection. Maintaining and restoring the air quality and water resources in national parks are essential to protecting all the resources of the National Park System, as well as the quality of the visitor experience. NPS has begun to improve its environmental stewardship by examining all maintenance, concessions, and other operations to improve sustainability and reduce environmental impact. An area where NPS can demonstrate this leadership is in the area of renewable energy. As of 2001, the NPS had over 700 photovoltaic applications in use ranging from single modules powering monitoring stations to the large 115 kW installation at Glen Canyon National Recreation Area. Building integrated, rooftop mounts and ground arrays will continue to be viable applications as renewable energy applications are implemented. Many remote field stations are converting from diesel generation to hybrid systems in the 30-35 kW range.

In-park emissions The NPS is proposing to address area, mobile, and stationary air pollution sources within parks. The NPS can minimize air pollution emissions in parks through the use of best management practices related to park transportation planning, operations and maintenance, vehicle emissions, smoke management, and energy conservation. Pollution prevention could take the form of energy conservation, using alternative energy sources, and substituting polluting practices with less polluting practices. This could be accomplished by applying cost-effective pollution prevention practices rather than by installing expensive pollution control equipment. Park operation and maintenance is an area where the NPS is currently experiencing successes in pollution prevention. For ex-

> *"Obstructed views strike the heart of the reason we human beings love Acadia."*
>
> *Jim Vekaki, Chief of Maintenance*
> *Acadia National Park, Maine*

Renewable Energy in the Parks

Proud NPS employees at Joshua Tree National Park pose by the 14 kW photovoltaic/propane system installed at the park's Cottonwood complex. The system will provide 76 percent of the area's electrical requirements while eliminating 16,000 gallons of diesel annually.

The solar-powered entrance station at Lake Mead National Recreation Area is another example as how the National Park Service will rely more on renewable sources of energy in the future.

For additional information on the National Park Service's use of renewable energy systems visit http://www.nps.gov/renew.

ample, many parks have converted their paints to low-solvent formulations; thus reducing emissions of smog-forming volatile organic compounds (VOCs). Many parks are now using organic citrus-based or enzyme-based "degreasing" solvents that contain no VOCs. Road maintenance activities can also result in VOC emissions, some parks now use only VOC-free latex emulsion asphalt.

Mobile emissions Based on national park emission surveys, exhaust from vehicles is a major emission source within parks. On- and off-road vehicles are major sources of nitrogen oxides, particulate, carbon monoxide, and volatile organic compounds. The NPS is beginning to develop alternative means of transportation in some of the larger parks and, where feasible, converting fleet vehicles to compressed natural gas or electric power. To limit road dust, the NPS may minimize the application of surface traction treatments to those areas necessary for public safety. Those materials (usually sand) could be removed to prevent their dispersion.

Fire management air issues The Environmental Protection Agency has developed National Ambient Air Quality Standards for those particulates with a diameter less than 2.5 microns in diameter (PM2.5). These standards are designed to protect sensitive portions of the public from adverse health affects. The standards are of interest to the wildland fire community because approximately 70 percent of the particulates emitted from biomass burning are in this size range. Also, the Regional Haze Regulations require states to develop programs and regulations to improve visibility in Class I air quality areas. To develop regulatory programs to implement the Regional Haze Regulations, states will need to consider controls on a variety of air pollution sources including wildland fire. As a result of these and other regulations and policies, the NPS must address fire management/air issues in a coordinated manner with state, local, and other federal agencies. Through this effort the NPS will help develop guidance and internal policies that will ensure fire management air issues are properly addressed.

Energy conservation Because so many park buildings are old, they tend to be poorly insulated and energy inefficient. The NPS is evaluating the feasibility of improving insulation and otherwise reducing energy demand by installing more efficient appliances and lighting. Where feasible, new construction will include energy efficient heating and cooling and use sustainable building materials and practices by taking advantage of passive solar energy and natural shading. Where fossil fuels are still required for heating, the NPS will discourage the continued use of old-fashioned woodstoves or high sulfur fuel oil, and encourage conversion to natural gas; LPG; modern, clean-burning woodstoves; or lower sulfur fuel oil.

Responding to the challenge

How we as a nation respond to air quality challenges faced by the National Park Service will ultimately determine whether or not we leave our parks unimpaired for future generations. Fossil fuel consumption by industry and automobiles account for most of the air pollution affecting our parks. Reducing our consumption of fossil fuels by changing our lifestyles and relying more on renewable energy sources and sustainable practices will not only make this country less dependent on foreign oil but will also improve the quality of the air we breathe -- and that nourishes park ecosystems. More than 100 years ago Americans invented the concept of national parks as a way of preserving its natural and cultural heritage. Americans must demonstrate to the rest of the world that we indeed are willing to preserve and protect our heritage from the adverse effects of air pollution.

Appendix A
Data Tables

Haziness Index in U.S. National Parks for the Clearest Days, 1990 - 1999: Average of Best 20 percent days, in deciviews (dv)

Haziness Index in U.S. National Parks for the Haziest Days, 1990 -1999: Average of Worst 20 percent days, in deciviews (dv)

Precipitation-Weighted Mean Sulfate Ion Concentration in U.S. National Parks, 1990 - 1999: Annual Average in μeq/liter

Sulfate Ion Wet Deposition in U.S. National Parks, 1990 - 1999: Annual Average in kilograms/hectare

Precipitation-Weighted Mean Nitrate Ion Concentration in U.S. National Parks, 1990 - 1999: Annual Average in μeq/liter

Inorganic Nitrogen Wet Deposition From Nitrate and Ammonium in U.S. National Parks, 1990 -1999: Annual Average in kilograms/hectare

Ozone Levels in U.S. National Parks, 1990 - 1999: Average of the Daily 1-hour Maximum, May-September, in ppb

Ozone Levels in U.S. National Parks, 1990 - 1999: Annual 4th Highest 8-hour Average, in ppb

Haziness Index in U.S. National Parks for the Clearest Days
1990 – 1999: Average of Best 20 percent days, in deciviews (dv)

Park	Year 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, dv/yr
Acadia, ME	10.6	10.7	10.2	10.6	9.8	9.6	9.1	9.7	9.3	8.7	9.8	⊙	⬇	-0.20
Badlands, ND	7.6	7.4	7.2	7.4	7.9	6.6	7.9	7.1	7.4	6.6	7.3	○	⇩	-0.07
Bandelier, NM	–	–	–	7	6.7	5.9	6.0	6.3	6.8	6.7	6.5	○	⇧	+0.00
Big Bend, TX	8.4	8.2	7.5	7.7	8.5	7.8	–	6.9	9.3	8.8	8.1	⊙	⇧	+0.06
Bryce Canyon, UT	4.9	5.0	5.7	4.8	4.5	4.3	4.1	4.6	4.5	4.7	4.7	🟢	⬇	-0.07
Canyonlands, UT	5.9	6.2	6.3	6	6.5	5.7	4.9	6.0	5.8	5.8	5.9	◉	⬇	-0.04
Chiricahua, AZ	–	6.8	6.6	6.4	6.6	6.8	6.4	6.7	6.6	6.4	6.6	○	⇩	-0.02
Crater Lake, OR	–	–	5.1	5.1	–	3.7	4.3	4.3	4.1	4.1	4.4	🟢	⬇	-0.14
Denali, AK	–	3.5	3.4	3.7	3.4	3.2	3.7	4.1	3.1	3.2	3.5	🟢	⇩	-0.03
Glacier, MT	8.0	9.8	8.9	9.0	8.5	7.9	8	7.9	8.3	7.5	8.4	⊙	⬇	-0.20
Grand Canyon, AZ	–	–	–	5.7	5.3	3.9	4.0	4.4	4.8	5.2	5.1	🟢	–	+0.00
Great Basin, NV	5.1	5.5	–	5.1	4.9	5.0	5.1	5.0	5.0	5.3	4.8	🟢	⇩	-0.02
Great Sand Dunes, CO	6.6	6.7	6.3	6.1	5.4	4.8	4.9	5.3	6.6	5.5	5.8	◉	⬇	-0.17
Great Smoky Mts., TN/NC	15.3	13.8	13.6	14.4	13.8	13.5	15.3	15.1	14.4	15.2	14.4	🔴	⇧	+0.09
Guadalupe Mts., TX	–	–	7.3	8.0	7.5	8.3	7.8	7.2	7.5	7.6	7.7	○	⇩	-0.01
Lassen Volcanic, CA	4.5	4.3	4.7	5.1	4.4	3.9	4.0	4.4	4.3	4.1	4.4	🟢	⬇	-0.06
Mammoth Cave, KY	–	–	16.3	17.3	–	15.5	16	16.8	16.2	16.1	16.3	🔴	⇩	-0.03
Mesa Verde, CO	5.5	6.1	5.6	5.7	6.3	4.9	5.0	–	5.9	5.7	5.6	◉	⇧	+0.01
Mt. Rainier, WA	–	7.0	7.2	7.5	6.3	5.0	5.4	5.5	5.0	5.3	6.0	◉	⬇	-0.28
Petrified Forest, AZ	–	8.0	7.6	6.2	6.2	6.2	6.1	6.9	6.8	6.7	6.7	○	⇩	-0.10
Pinnacles, CA	9.4	9.3	9.1	8.7	9.4	8.3	8.0	8.9	–	8.7	8.9	⊙	⬇	-0.12
Point Reyes, CA	9.1	8.8	8.6	9.5	8.1	7.9	8.1	–	8.7	8.9	8.6	⊙	⇩	-0.08
Redwood, CA	6.7	6.8	6.9	6.7	6.3	6.6	5.3	6.1	5.5	6.2	6.3	◉	⬇	-0.10
Rocky Mountain, CO	4.3	4.1	3.9	4.5	5.0	4.3	3.9	4.2	4.8	3.9	4.3	🟢	–	+0.00
Shenandoah, VA	14.1	13.4	12.6	14.2	12.3	12.8	14.2	13.5	11.8	11.9	13.1	🔴	⬇	-0.15
Tonto, AZ	–	8.2	–	7.7	7.2	7.7	7.7	7.6	7.0	8.1	7.7	○	⇩	-0.04
Yellowstone, WY	–	–	5.9	5.2	4.7	4.8	5	–	–	3.8	4.9	🟢	⬇	-0.23
Yosemite, CA	5.4	5.6	4.8	4.8	4.5	5.3	4.6	5.5	4.7	5.0	5.0	🟢	⇩	-0.02
Average	7.7	7.5	7.6	7.5	6.9	6.8	6.8	7.2	7.1	7.0	7.2			

Symbols:

"–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	◉	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Haziness Index in U.S. National Parks for the Haziest Days
1990 – 1999: Average of Worst 20 percent days, in deciviews (dv)

Park Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, dv/yr
Acadia, ME	24.9	24.8	26.2	26.2	27.4	23.5	24.0	23.1	23.9	24.2	24.8	🔴	⬇	-0.15
Badlands, ND	17.9	18.1	18.4	17.3	18.2	17.2	17.3	17.0	19.0	17.1	17.8	○	⇩	-0.09
Bandelier, NM	–	–	–	13.1	12.5	13.0	12.7	13.1	14.4	12.8	13.1	⊙	⇧	+0.05
Big Bend, TX	16.2	17.1	16.3	16.8	17.4	17.5	–	17.3	20.9	19.3	17.6	○	⬆	+0.35
Bryce Canyon, UT	11.4	11.5	11.2	12.1	11.5	11.1	12.9	12.4	11.5	11.7	11.7	🟢	⇧	+0.04
Canyonlands, UT	12.9	14.1	13.2	12.5	11.9	11.2	12.8	11.9	12.2	11.8	12.5	🟢	⬇	-0.17
Chiricahua, AZ	–	13.1	13.2	13.7	14.0	14.1	13.4	12.9	15.1	13.0	13.6	⊙	⇧	+0.06
Crater Lake, OR	–	–	13.3	13.8	–	12.8	15.6	12.1	13.4	13.5	13.5	⊙	⇧	+0.02
Denali, AK	–	12.3	9.2	11.2	10.4	9.4	9.5	12.1	8.2	9.3	10.2	🟢	⬇	-0.35
Glacier, MT	19.5	19.6	19.1	19.0	19.6	18.1	17.9	17.4	20.4	19.4	19.0	◉	⇩	-0.17
Grand Canyon, AZ	13.5	11.7	–	11.9	11.8	11.8	12.1	11.3	12.6	12.1	12.1	🟢	⇧	+0.01
Great Basin, NV	–	–	–	12.0	11.4	10.8	12.9	11.0	11.6	11.9	11.7	🟢	⇧	+0.05
Great Sand Dunes, CO	13.9	12.7	11.4	12.1	15.3	11.8	12.5	11.9	13.2	12.5	12.7	🟢	⇩	-0.02
Great Smoky Mts., TN/NC	32.8	29.6	30.7	30.9	31.6	30.6	31.2	30.9	31.8	30.5	31.1	🔴	–	+0.00
Guadalupe Mts., TX	–	–	14.7	15.4	16.2	16.2	15.2	16.6	17.8	18.1	16.3	○	⬆	+0.46
Lassen Volcanic, CA	13.3	13.0	13.5	13.3	13.6	12.8	13.4	12.1	15.4	20.7	14.1	⊙	⇧	+0.10
Mammoth Cave, KY	–	–	30.7	31.5	–	30.3	30.5	29.9	30.5	29.6	30.4	🔴	⬇	-0.16
Mesa Verde, CO	12.6	11.5	11.2	12.0	11.8	11.9	12.7	–	12.2	13.9	12.2	🟢	⬆	+0.12
Mt. Rainier, WA	–	21.0	20.7	20.0	20.2	18.7	18.9	18.6	20.3	19.7	19.8	◉	⬇	-0.26
Petrified Forest, AZ	–	13.6	13.0	12.6	12.3	13.0	12.6	12.7	13.7	13.4	13.0	⊙	⇧	+0.02
Pinnacles, CA	19.5	19.1	19.0	18.3	17.7	18.5	17.9	17.7	–	19.3	18.6	◉	⬇	-0.20
Point Reyes, CA	20.8	21.1	21.1	20.9	20.4	20.2	20.1	–	19.6	21.8	20.7	◉	⬇	-0.15
Redwood, CA	19.7	18.9	19.7	18.0	17.3	18.5	18.0	18.9	16.7	20.1	18.6	◉	⇩	-0.15
Rocky Mountain, CO	13.9	13.1	13.1	12.9	13.4	13.3	13.3	12.4	13.4	12.4	13.1	⊙	⇩	-0.09
Shenandoah, VA	30.9	32.4	31.3	32.6	31.9	30.4	29.3	29.9	30.3	28.4	30.7	🔴	⬇	-0.30
Tonto, AZ	–	14.2	–	15.3	13.8	15.2	14.8	14.2	14.9	15.4	14.7	○	⇧	+0.08
Yellowstone, WY	–	–	13.2	11.9	14.8	11.7	14.9	–	–	11.8	13.1	⊙	⇩	-0.02
Yosemite, CA	16.3	16.1	17.3	15.1	16.8	17.5	19.6	15.7	15.7	22.0	17.2	○	⇧	+0.23
Average	18.2	17.2	17.5	16.9	16.7	16.5	16.9	16.5	17.3	17.3	16.9			

Symbols: "–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	◉	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	⊙	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Precipitation-Weighted Mean Sulfate Ion Concentration in U.S. National Parks
1990 – 1999: Annual Average in µeq/liter

Park	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, µeq/l/yr
Acadia, ME		30.9	24.1	30.9	23.7	23.0	23.1	20.3	29.4	25.1	19.4	25.0	🔴	⬇	-0.72
Bandelier, NM		16.6	13.9	15.4	14.5	13.7	13.4	12.1	16.5	–	14.7	14.5	○	⇩	-0.28
Big Bend, TX		–	16.4	16.6	14.3	27.9	29.6	22.7	22.4	23.4	20.2	21.5	⊙	⇧	+0.76
Bryce Canyon, UT		14.3	–	–	–	14.0	11.9	–	15.2	10.8	9.2	12.5	⦿	⬇	-0.56
Buffalo River, AR		–	–	25.9	23.1	20.8	23.5	23.2	24.3	21.9	19.5	22.8	⊙	⬇	-0.56
Cape Cod, MA		33.8	–	32.0	31.2	–	31.4	–	–	–	27.1	31.1	🔴	–	–
Capulin Volcano, NM		14.8	14.1	16.9	15.1	15.0	13.4	17.8	–	10.1	13.5	14.5	○	⬇	-0.26
Craters of the Moon, ID		12.9	11.4	10.7	9.6	8.2	8.6	4.9	6.5	7.2	6.8	8.7	⦿	⬇	-0.71
Denali, AK		3.5	4.1	3.8	3.9	3.8	2.5	2.4	3.5	2.3	2.2	3.2	🟢	⬇	-0.14
Everglades, FL		15.2	14.0	–	–	15.8	14.5	15.4	–	16.8	13.4	15.0	○	⇧	+0.04
Gila Cliff Dwellings, NM		21.3	15.6	19.0	20.5	18.4	16.8	18.1	22.8	17.7	19.3	18.9	⊙	⇩	-0.13
Glacier, MT		7.2	7.1	8.1	7.8	7.6	5.4	4.9	7.0	6.1	5.3	6.6	🟢	⬇	-0.22
Grand Canyon, AZ		14.6	–	10.2	10.2	12.4	8.8	11.0	–	9.0	11.5	10.9	⦿	⇩	-0.22
Great Basin, NV		14.8	11.8	16.5	–	12.4	11.0	10.1	14.3	10.1	–	12.6	⦿	⬇	-0.51
Great Smoky Mts., TN/NC		32.0	36.1	30.1	33.9	24.3	20.9	25.0	30.2	28.6	24.0	28.5	🔴	⬇	-0.99
Guadalupe Mts., TX		–	13.7	24.1	22.7	26.8	20.1	36.6	23.4	27.9	25.1	24.5	🔴	⬆	+1.14
Indiana Dunes, IN		51.3	59.6	66.8	57.0	48.3	56.2	47.3	47.1	50.1	49.2	53.3	🔴	⬇	-0.98
Isle Royale (Chassell), MI		26.8	25.6	29.9	22.4	21.4	21.0	18.4	16.5	18.9	19.2	22.0	⊙	⬇	-1.27
Little Big Horn, MT		16.4	12.7	14.6	13.9	13.8	11.1	12.6	13.3	12.8	10.6	13.2	○	⬇	-0.44
Mesa Verde, CO		27.3	21.1	18.7	16.0	21.2	18.1	20.6	16.7	18.6	20.9	19.9	⊙	⇩	-0.28
North Cascades, WA		6.1	6.8	6.3	6.5	–	4.4	5.2	5.0	4.2	4.9	5.5	🟢	⬇	-0.24
Olympic, WA		–	4.5	5.0	5.2	5.0	4.7	–	5.3	4.3	5.7	4.9	🟢	⇧	+0.07
Organ Pipe Cactus, AZ		16.8	16.9	10.8	7.6	11.9	16.6	28.5	16.8	–	14.5	15.6	○	⇧	+0.09
Rocky Mountain, CO		13.7	14.6	14.8	11.5	16.1	12.8	13.1	10.5	13.5	11.6	13.2	○	⬇	-0.25
Sequoia, CA		10.2	5.7	8.0	5.2	5.2	3.9	2.4	2.9	4.9	–	5.4	🟢	⬇	-0.66
Shenandoah, VA		31.2	34.5	23.0	30.9	29.2	–	28.4	29.3	–	27.7	29.3	🔴	⬇	-0.39
Theo. Roosevelt, ND		24.0	16.8	18.4	17.3	20.0	16.7	15.8	–	–	14.7	18.0	⊙	⬇	-0.54
Yellowstone, WY		12.0	11.0	8.1	8.6	9.7	5.8	4.8	6.9	6.7	7.2	8.1	⦿	⬇	-0.57
Yosemite, CA		–	5.2	3.5	–	4.5	2.7	2.3	2.8	4.6	3.6	3.6	🟢	⇩	-0.16
	Average	19.5	16.7	18.1	17.3	16.7	15.3	16.3	16.2	14.8	15.6	16.7			

Symbols:

"–" indicates insufficient or no data

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	⦿	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Sulfate Ion Wet Deposition in U.S. National Parks
1990 – 1999: Annual Average in kilograms/hectare

Park Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, Kg/ha/yr
Acadia, ME	22.7	16.5	18.1	16.9	15.9	16.5	15.0	16.2	17.7	12.5	16.8	🔴	⬇	-0.51
Bandelier, NM	3.2	3.7	2.6	3.3	2.9	2.1	2.0	4.0	–	2.8	3.0	○	⇩	-0.09
Big Bend, TX	–	3.9	3.0	2.3	3.2	3.1	3.0	3.2	2.7	2.1	3.0	○	⬇	-0.14
Bryce Canyon, UT	2.4	–	–	–	2.2	2.2	–	3.3	2.7	1.5	2.4	◉	⇩	-0.04
Buffalo River, AR	–	–	12.7	13.0	12.1	11.3	13.1	10.1	10.8	8.9	11.5	⭕	⬇	-0.56
Cape Cod, MA	16.3	–	16.4	19.6	–	16.4	–	–	–	13.5	16.4	🔴	–	–
Capulin Volcano, NM	3.3	3.9	3.8	4.1	3.4	3.8	4.3	–	2.3	3.5	3.6	○	⇩	-0.03
Craters of the Moon, ID	1.8	1.7	1.0	2.0	0.9	1.9	0.8	1.0	1.6	0.7	1.3	🟢	⬇	-0.08
Denali, AK	1.1	0.8	0.7	0.7	0.6	0.4	0.4	0.6	0.4	0.4	0.6	🟢	⬇	-0.06
Everglades, FL	9.1	10.8	–	–	13.0	12.1	9.2	–	13.3	9.9	11.1	⭕	⇧	+0.09
Gila Cliff Dwellings, NM	3.8	3.3	4.3	4.6	3.4	2.5	3.2	4.7	2.4	2.7	3.5	○	⬇	-0.12
Glacier, MT	3.9	2.4	2.8	3.1	2.5	2.7	2.7	2.4	2.3	1.7	2.6	○	⬇	-0.15
Grand Canyon, AZ	3.0	–	2.2	2.1	1.8	2.1	1.7	–	1.9	1.9	2.1	◉	⬇	-0.06
Great Basin, NV	2.7	1.9	1.8	–	2.1	2.0	1.8	2.6	1.9	–	2.1	◉	⇩	-0.01
Great Smoky Mts., TN/NC	24.7	28.0	22.2	25.9	22.4	14.5	23.6	27.2	22.4	16.7	22.8	🔴	⬇	-0.72
Guadalupe Mts., TX	–	4.2	5.7	4.0	4.0	4.0	8.5	4.6	4.8	4.7	4.9	⭕	⇧	+0.06
Indiana Dunes, IN	34.4	28.1	25.1	33.7	19.5	22.7	25.6	20.4	23.6	17.6	25.1	🔴	⬇	-1.31
Isle Royale (Chassell), MI	10.5	11.0	10.1	7.8	6.9	8.9	7.8	5.4	6.5	8.0	8.3	⭕	⬇	-0.52
Little Big Horn, MT	2.2	2.1	2.4	2.3	1.9	1.8	1.8	2.0	2.1	1.5	2.0	◉	⬇	-0.07
Mesa Verde, CO	5.6	5.0	4.5	4.0	4.7	3.7	4.5	4.1	3.8	2.9	4.3	⭕	⬇	-0.22
North Cascades, WA	8.4	6.3	5.1	4.8	–	5.0	5.6	6.4	3.9	5.5	5.7	⭕	⇩	-0.20
Olympic, WA	–	7.2	7.1	6.1	8.2	6.9	–	10.9	8.1	11.5	8.3	⭕	⬆	+0.42
Organ Pipe Cactus, AZ	2.6	1.7	2.2	1.1	1.7	1.6	2.0	1.8	–	1.5	1.8	🟢	⇩	-0.08
Rocky Mountain, CO	3.1	2.7	2.6	2.3	2.7	3.3	2.3	2.5	2.8	3.0	2.7	○	⇧	+0.01
Sequoia, CA	2.6	1.9	2.8	2.8	2.1	2.9	1.8	1.2	3.6	–	2.4	◉	⇧	+0.02
Shenandoah, VA	23.6	17.8	18.7	22.4	19.3	–	23.4	17.8	–	18.8	20.2	🔴	⇩	-0.07
Theo. Roosevelt, ND	3.5	2.9	2.8	3.8	4.2	3.9	2.8	–	–	2.1	3.3	○	⇩	-0.09
Yellowstone, WY	2.1	2.4	1.8	1.6	1.7	1.1	1.0	1.6	1.1	1.3	1.6	🟢	⬇	-0.12
Yosemite, CA	–	2.5	1.5	–	1.8	2.5	2.1	0.9	3.8	1.7	2.1	◉	⇩	-0.01
Average	8.2	7.4	6.8	7.5	6.6	6.2	6.9	6.9	6.5	5.7	6.7			

Symbols: "–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⭕	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	◉	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Precipitation-Weighted Mean Nitrate Ion Concentration in U.S. National Parks
1990 – 1999: Annual Average in μeq/liter

Park Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, μeq/l/yr
Acadia, ME	15.3	11.1	16.4	12.3	10.2	11.5	11.3	15.9	12.7	10.8	12.7	◉	⇩	-0.19
Bandelier, NM	12.5	12.2	12.3	12.2	13.8	16.7	11.6	17.0	–	17.4	14.0	○	⬆	+0.60
Big Bend, TX	–	10.3	10.2	10.7	17.7	15.5	13.5	13.3	16.8	13.1	13.5	○	⇧	+0.47
Bryce Canyon, UT	15.4	–	–	–	14.1	10.7	–	15.4	11.4	15.0	13.7	○	⇩	-0.04
Buffalo River, AR	–	–	14.2	14.1	12.4	14.4	14.8	15.4	13.8	13.2	14.0	○	–	0.00
Cape Cod, MA	15.2	–	17.2	13.6	–	19.5	–	–	–	13.4	15.8	⊙	–	–
Capulin Volcano, NM	13.5	12.7	15.8	14.9	16.4	14.0	17.5	–	12.1	15.1	14.7	⊙	⇧	+0.23
Craters of the Moon, ID	9.8	11.6	12.5	9.8	14.3	10.7	6.8	11.1	11.5	10.7	10.9	◉	–	0.00
Denali, AK	1.8	4.2	2.3	2.4	2.8	1.4	1.4	3.3	1.3	2.0	2.3	🟢	⇩	-0.07
Everglades, FL	9.6	8.4	–	–	9.3	8.2	8.5	–	8.4	8.0	8.6	◉	⬇	-0.15
Gila Cliff Dwellings, NM	12.9	9.3	9.9	11.2	12.2	11.8	14.2	13.5	12.6	17.1	12.5	◉	⬆	+0.64
Glacier, MT	5.8	6.3	6.8	6.3	7.4	5.1	5.7	7.7	5.9	5.7	6.3	🟢	⇩	-0.01
Grand Canyon, AZ	16.9	–	11.9	10.7	15.9	10.4	15.0	–	10.2	18.5	13.7	○	⇩	-0.11
Great Basin, NV	20.0	15.2	19.9	–	16.9	12.2	14.7	17.6	15.1	–	16.4	⊙	⬇	-0.46
Great Smoky Mts., TN/NC	13.3	14.1	14.9	15.8	12.1	13.2	13.2	15.3	15.4	13.0	14.0	○	⇧	+0.03
Guadalupe Mts., TX	–	8.7	15.1	13.6	18.0	14.2	11.8	14.4	15.5	18.2	14.4	⊙	⬆	+0.54
Indiana Dunes, IN	21.6	29.4	31.2	26.3	28.2	33.3	26.7	29.7	27.6	28.3	28.2	🔴	⇧	+0.26
Isle Royale (Chassell), MI	16.7	17.0	18.2	16.5	19.2	18.5	17.6	17.4	17.2	17.8	17.6	🔴	⇧	+0.08
Little Big Horn, MT	13.1	11.4	10.8	10.9	11.8	10.2	13.6	14.9	14.8	12.7	12.4	◉	⬆	+0.25
Mesa Verde, CO	19.4	14.3	14.1	11.9	17.8	14.1	19.5	15.4	14.7	21.9	16.3	⊙	⇧	+0.23
North Cascades, WA	4.9	5.0	5.2	5.7	–	3.8	4.9	4.8	4.3	4.6	4.8	🟢	⬇	-0.06
Olympic, WA	–	1.6	1.6	1.8	1.5	1.8	–	1.8	1.3	1.2	1.6	🟢	⇩	-0.04
Organ Pipe Cactus, AZ	15.8	11.6	9.4	4.5	8.2	12.8	23.1	14.4	–	19.0	13.2	○	⇧	+0.97
Rocky Mountain, CO	15.8	16.3	17.1	14.2	20.9	16.5	17.2	15.1	18.7	16.7	16.8	🔴	⇧	+0.15
Sequoia, CA	22.0	8.4	13.0	7.6	11.2	6.3	3.4	6.7	8.2	–	9.6	◉	⬇	-0.96
Shenandoah, VA	12.9	15.0	10.0	13.2	14.1	–	15.9	14.7	–	12.7	13.6	○	⇧	+0.19
Theo. Roosevelt, ND	14.2	14.7	13.3	12.1	16.1	15.0	15.7	–	–	14.6	14.4	⊙	⇧	+0.17
Yellowstone, WY	11.6	9.7	8.5	8.1	10.3	7.7	6.7	9.5	8.1	9.7	9.0	◉	⇩	-0.23
Yosemite, CA	–	6.8	6.1	–	7.8	4.0	2.8	5.7	9.6	7.5	6.3	🟢	⇧	+0.14
Average	13.7	11.4	12.5	11.1	13.1	11.9	12.6	13.5	12.4	13.2	12.5			

Symbols: "–" indicates insufficient or no data

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	◉	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Inorganic Nitrogen Wet Deposition From Nitrate and Ammonium in U.S. National Parks
1990 – 1999: Annual Average in kilograms/hectare

Park	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, Kg/ha/yr
Acadia, ME		4.9	3.1	4.2	3.6	3.3	3.7	3.7	3.8	3.6	2.9	3.7	⊙	⇩	-0.08
Bandelier, NM		1.3	1.5	1.1	1.3	1.4	1.3	1.1	2.0	–	1.5	1.4	○	⇧	+0.03
Big Bend, TX		–	1.4	1.1	1.0	1.2	1.2	1.2	1.1	1.3	0.8	1.1	○	⇩	-0.04
Bryce Canyon, UT		1.3	–	–	–	1.0	0.9	–	1.6	1.2	1.1	1.2	○	⇩	-0.01
Buffalo River, AR		–	–	3.6	4.0	3.8	4.2	4.7	3.2	3.9	3.2	3.8	🔴	⇩	-0.04
Cape Cod, MA		3.1	–	3.5	3.5	–	4.4	–	–	–	2.7	3.4	⊙	–	–
Capulin Volcano, NM		1.9	2.0	2.3	2.2	2.1	2.3	2.5	–	1.5	2.4	2.1	○	⬆	+0.05
Craters of the Moon, ID		0.9	1.2	0.8	1.2	0.9	1.4	0.7	1.0	1.5	0.8	1.0	◎	–	0.00
Denali, AK		0.3	0.6	0.2	0.2	0.2	0.1	0.1	0.3	0.1	0.2	0.2	🟢	⬇	-0.02
Everglades, FL		3.0	2.6	–	–	4.0	3.4	2.4	–	4.1	2.8	3.2	⊙	⇧	+0.03
Gila Cliff Dwellings, NM		1.2	0.9	1.2	1.2	1.0	0.9	1.3	1.3	0.8	1.1	1.1	◎	⇩	-0.01
Glacier, MT		1.7	0.9	1.2	1.3	1.2	1.4	1.4	1.2	1.0	0.9	1.2	○	⇩	-0.04
Grand Canyon, AZ		1.7	–	1.2	1.0	1.1	1.3	1.0	–	1.0	1.5	1.2	○	⇩	-0.02
Great Basin, NV		1.9	1.2	1.2	–	1.5	1.2	1.4	1.7	1.4	–	1.4	○	–	0.00
Great Smoky Mts., TN/NC		5.4	5.4	4.7	5.6	5.5	4.6	5.8	6.7	5.9	4.3	5.4	🔴	⇧	+0.07
Guadalupe Mts., TX		–	1.4	2.0	1.5	1.7	1.8	1.6	1.6	1.6	2.0	1.7	○	⇧	+0.01
Indiana Dunes, IN		8.0	7.4	6.3	8.3	6.2	7.4	8.4	6.5	7.1	5.3	7.1	🔴	⬇	-0.14
Isle Royale (Chassell), MI		4.1	3.9	3.4	3.1	3.4	4.4	4.0	3.0	3.3	3.9	3.7	⊙	⇩	-0.02
Little Big Horn, MT		1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.2	1.3	1.1	1.1	◎	⬆	+0.02
Mesa Verde, CO		1.7	1.4	1.6	1.3	1.7	1.4	2.1	1.6	1.3	1.3	1.5	○	⬇	-0.02
North Cascades, WA		3.2	1.8	1.6	1.8	–	1.8	2.4	2.4	1.4	1.9	2.0	○	⇩	-0.01
Olympic, WA		–	1.0	1.0	1.1	1.2	1.3	–	1.5	1.0	1.3	1.2	○	⬆	+0.05
Organ Pipe Cactus, AZ		1.6	0.6	1.1	0.4	0.6	0.7	0.8	0.7	1.2	1.1	0.9	🟢	⇧	+0.02
Rocky Mountain, CO		2.0	1.6	1.7	1.6	1.8	2.2	1.7	1.8	2.1	2.4	1.9	○	⬆	+0.07
Sequoia, CA		3.7	1.8	3.7	2.9	2.9	3.1	1.7	1.6	4.3	–	2.8	⊙	⇩	-0.06
Shenandoah, VA		5.3	4.1	4.3	5.1	5.0	–	6.6	4.6	–	4.6	4.9	🔴	⇧	-0.02
Theo. Roosevelt, ND		1.5	1.5	1.3	1.6	2.2	2.5	1.9	–	–	1.3	1.7	○	⇧	+0.05
Yellowstone, WY		1.1	1.1	1.1	0.9	1.0	0.8	0.8	1.1	0.7	1.0	1.0	🟢	⬇	-0.02
Yosemite, CA		–	1.6	1.5	–	1.7	2.3	1.4	1.0	5.0	2.3	2.1	⊙	⇧	0.08
	Average	2.6	2.0	2.1	2.3	2.2	2.2	2.4	2.2	2.4	2.1	2.2			

Symbols: “–” indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement[**]	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	◎	Significant Degradation[**]	⬆
Much Better than NPS Average	🟢	No Trend	–

[**] Statistically significant at a=0.15

Ozone Levels in U.S. National Parks
1990 – 1999: Average of the Daily 1-hour Maximum, May–September, in ppb

Park	Year 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, ppb/yr
Acadia, ME	50	52	47	46	49	49	40	45	57	53	49	⊙	⇩	-0.1
Big Bend, TX	–	–	47	47	56	–	46	46	52	45	49	⊙	⬇	-0.3
Canyonlands, UT	–	–	–	55	58	56	63	56	61	62	59	◉	⬆	+0.7
Cape Cod, MA	55	64	56	54	57	56	57	64	58	55	57	○	⇧	+0.3
Chamizal, TX	–	–	54	44	–	60	55	58	–	58	55	○	⇧	+0.9
Chiricahua, AZ	55	55	54	56	59	–	57	54	57	55	56	○	⇧	+0.2
Channel Islands, CA	–	–	55	–	–	–	49	44	47	45	48	⊙	–	–
Congaree Swamp, SC	64	–	42	51	42	54	53	49	63	61	53	○	⇧	+1.7
Cowpens, SC	59	60	62	68	62	63	64	70	73	68	65	◉	⬆	+1.2
Craters of the Moon, ID	–	–	–	48	57	51	56	51	56	57	54	○	⬆	+1.3
Denali, AK	32	32	32	32	32	31	33	33	34	34	32	🟢	⬆	+0.2
Death Valley, CA	–	–	–	–	67	–	62	61	66	67	65	◉	–	–
Everglades, FL	32	29	–	30	–	31	29	28	35	35	31	🟢	⇧	+0.3
Glacier, MT	44	43	42	36	45	38	45	33	45	42	41	⊙	⇩	-0.2
Grand Canyon, AZ	51	52	51	53	56	59	60	57	60	58	56	○	⬆	+1.1
Great Basin, NV	–	–	–	–	56	54	59	56	58	59	57	○	⬆	+1.0
Great Smoky Mts., TN/NC	67	61	59	69	66	–	71	72	77	78	69	🔴	⬆	+1.9
Joshua Tree, CA	74	83	85	–	94	84	89	85	76	82	84	🔴	⇧	+0.04
Lassen Volcanic, CA	54	53	53	51	62	55	59	52	57	63	56	○	⬆	+0.6
Mammoth Cave, KY	60	56	53	55	60	64	64	60	70	–	60	◉	⬆	+1.4
Mesa Verde, CO	–	–	–	–	54	54	56	53	58	58	56	○	⬆	+1.0
Mount Rainier, WA	–	–	–	37	45	41	41	28	28	40	37	🟢	⇩	-1.1
Olympic, WA	29	29	30	28	29	32	32	27	29	28	29	🟢	⇩	-0.1
Pinnacles, CA	64	66	65	64	63	65	70	63	63	63	65	◉	⬇	-0.2
Rocky Mountain, CO	47	56	57	59	62	59	62	58	63	58	58	◉	⬆	+1.0
Saguaro, AZ	62	62	63	65	69	65	60	65	65	60	64	◉	⇩	-0.02
Sequoia, CA	79	76	83	85	86	73	84	75	74	79	79	🔴	⇩	-0.3
Shenandoah, VA	62	68	60	64	62	67	64	63	74	71	66	◉	⬆	+0.9
Theo. Roosevelt, ND	46	48	45	42	47	47	49	50	–	47	47	⊙	⇧	+0.3
Voyageurs, MN	34	34	39	36	39	43	44	45	44	40	40	⊙	⬆	+1.2
Yellowstone, WY	38	47	47	46	53	51	52	49	52	56	49	⊙	⬆	+1.1
Yosemite, CA	–	–	–	–	74	69	73	61	70	71	70	🔴	⇩	-0.6
Average	53	54	53	51	57	54	56	53	57	56	55			

Symbols: "–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	◉	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	⊙	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

**Statistically significant at a=0.15

Ozone Levels in U.S. National Parks
1990 – 1999: Annual 4th Highest 8-hour Average, in ppb

Park Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Avg	Status	Trend	Slope, ppb/yr
Acadia, ME	89	95	80	80	74	92	73	77	88	92	84	⊙	⇩	-0.7
Big Bend, TX	–	57	61	63	69	65	73	63	70	64	65	⊙	⬆	+1.2
Canyonlands, UT	–	–	60	63	68	63	74	67	71	73	67	⊙	⬆	+1.8
Cape Cod, MA	97	111	96	88	88	105	96	100	84	101	97	🔴	⇩	-0.5
Chamizal, TX	–	–	72	59	75	84	78	71	88	71	75	○	⇧	+1.5
Chiricahua, AZ	69	71	65	68	71	69	72	65	67	72	69	○	⇧	+0.1
Channel Islands, CA	56	80	81	–	–	–	75	63	66	69	70	○	⇩	-1.0
Congaree Swamp, SC	88	59	66	62	64	76	74	65	81	80	72	○	⬆	+1.7
Cowpens, SC	74	77	85	82	82	84	80	90	96	94	84	⊙	⬆	+2.0
Craters of the Moon, ID	–	–	42	55	63	57	64	60	65	68	59	🟢	⬆	
Denali, AK	48	49	50	48	49	53	53	51	54	54	51	🟢	⬆	+0.7
Death Valley, CA	–	–	–	–	84	67	78	77	82	79	78	⊙	⇧	+0.3
Everglades, FL	60	58	61	64	64	58	63	66	72	67	63	⊙	⬆	+1.0
Glacier, MT	50	51	51	44	55	43	57	40	53	50	49	🟢	–	+0.0
Grand Canyon, AZ	65	72	68	64	69	69	73	72	72	76	70	○	⬆	+1.0
Great Basin, NV	–	–	–	51	69	67	74	74	70	72	68	○	⬆	+1.7
Great Smoky Mts., TN/NC	92	79	88	88	93	99	88	98	110	106	94	🔴	⬆	+2.6
Joshua Tree, CA	95	107	106	92	112	103	109	117	110	101	105	🔴	⇧	+0.8
Lassen Volcanic, CA	78	66	66	64	78	74	73	67	78	84	73	○	⬆	+1.2
Mammoth Cave, KY	83	78	73	72	75	88	82	85	97	98	83	⊙	⬆	+2.5
Mesa Verde, CO	–	–	–	58	62	63	72	62	68	69	65	⊙	⬆	+1.5
Mount Rainier, WA	–	–	–	55	67	65	65	40	51	64	58	🟢	⇩	-0.6
Olympic, WA	46	41	46	42	41	44	46	45	41	43	44	🟢	–	+0.0
Pinnacles, CA	83	84	84	82	78	83	94	76	88	82	83	⊙	⇩	-0.1
Rocky Mountain, CO	57	76	71	71	76	76	72	70	80	74	72	○	⇧	+0.5
Saguaro, AZ	75	73	74	82	80	83	76	79	76	69	77	⊙	–	+0.0
Sequoia, CA	96	97	102	106	106	95	105	97	94	97	100	🔴	⇩	-0.2
Shenandoah, VA	86	83	77	83	83	87	81	89	107	93	87	🔴	⬆	+1.5
Theo. Roosevelt, ND	62	60	57	55	57	58	59	71	56	58	59	🟢	⇩	-0.2
Voyageurs, MN	52	50	63	58	60	70	67	71	67	74	63	⊙	⬆	+2.4
Yellowstone, WY	54	57	63	53	61	60	61	61	66	70	61	⊙	⬆	+1.3
Yosemite, CA	78	98	91	–	94	91	90	81	94	85	89	🔴	⇩	-1.7
Average	72	73	71	67	73	74	75	72	77	77	73			

Symbols:

Numbers in RED exceed national ambient air quality standard
"–" indicates insufficient or no data, or no trend

Park Air Quality Status		Trend	
Much Worse than NPS Average	🔴	Significant Improvement**	⬇
Worse than NPS Average	⊙	Improvement	⇩
NPS Average	○	Degradation	⇧
Better than NPS Average	⊙	Significant Degradation**	⬆
Much Better than NPS Average	🟢	No Trend	–

** Statistically significant at a=0.15

National Park Service
U.S. Department of the Interior

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