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-

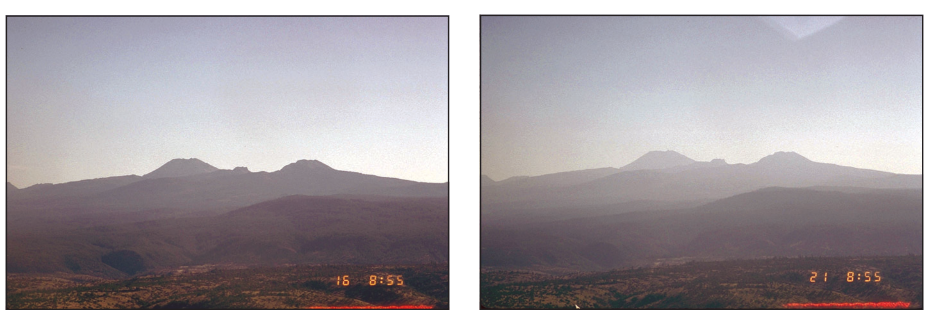
Parks with Best Annual Average Visibility, in miles

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

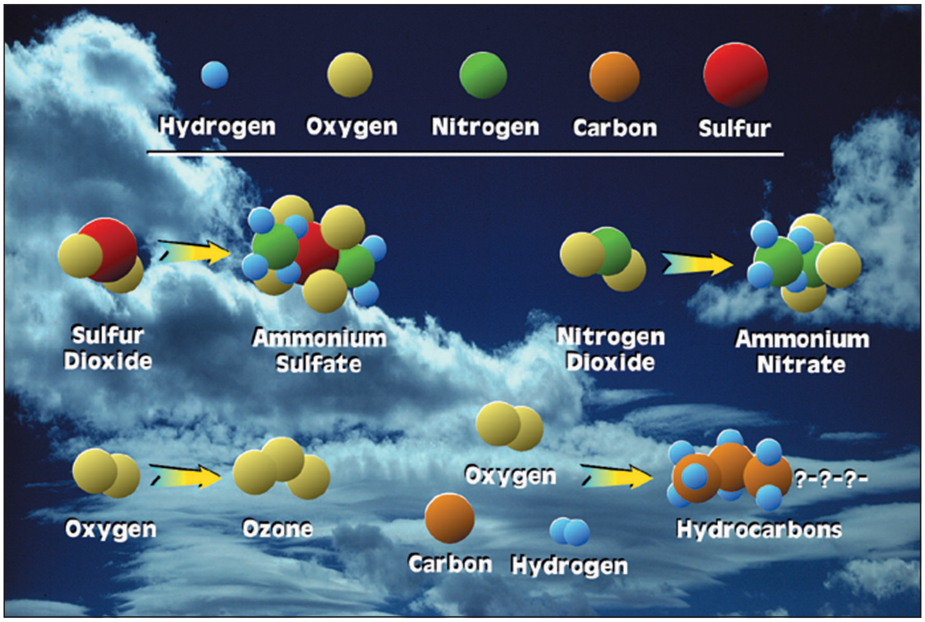
Mammoth Cave NP	*17*
Great Smoky Mtns. NP	*24*
Shenandoah NP	*24*
Sequoia NP	*42*
Acadia NP	*45*

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.

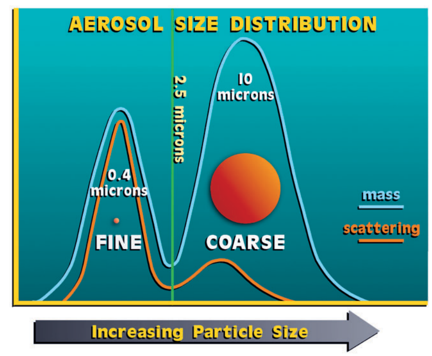
Source: IMPROVE Monitoring Network Permanent Photographic Archive



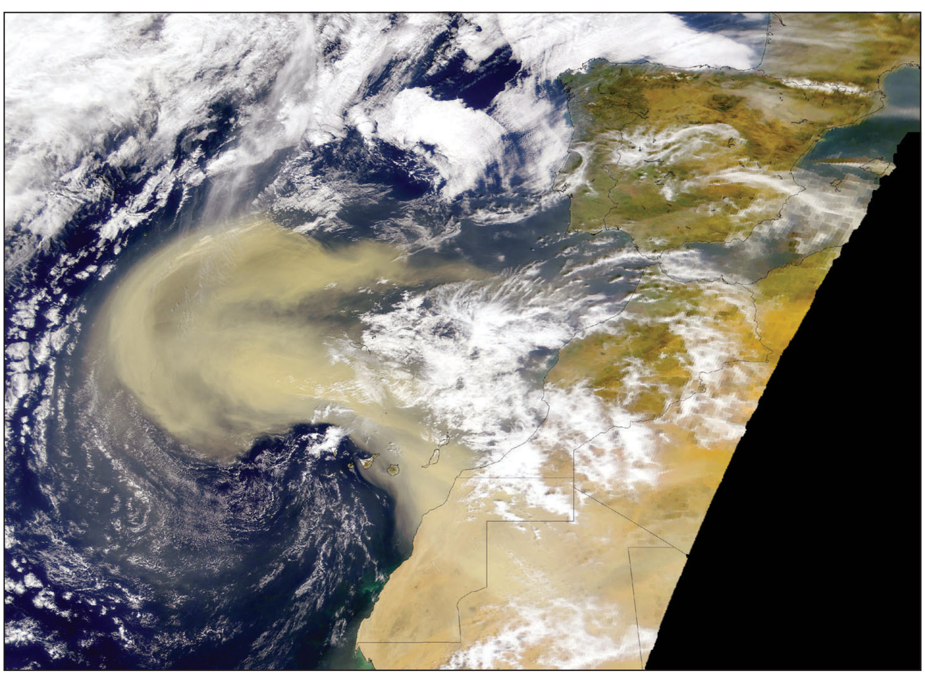
Five atoms, hydrogen, oxygen, nitrogen, carbon, and sulfur, play a significant role in determining air quality. Through complex sets of chemical reactions, gases are formed that, in some cases, react to form visibility reducing particles. Sulfur dioxide reacts to form ammonium sulfate, nitrogen oxide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



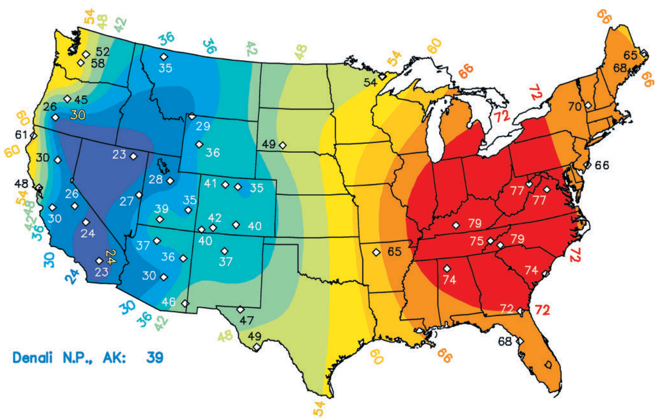
The size of particles affects visibility due to light scattering. The blue line shows the relative amount of mass typically found in a given particle size range. The orange line shows the relative amount of particle scattering associated with that mass. Note that even though mass is associated with coarse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



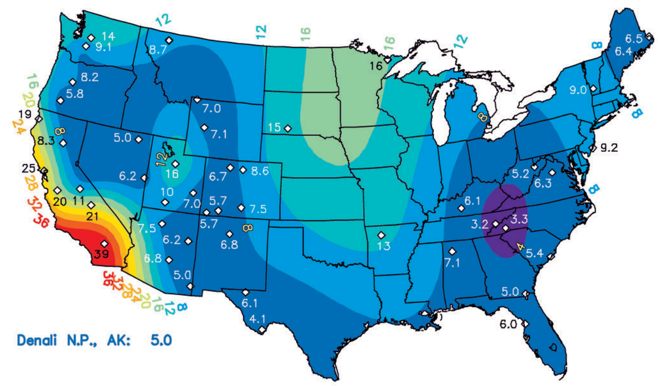
A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand, which reached over 1,000 miles into the Atlantic. These storms and the rising warm air can lift dust 15,000 feet or so above 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

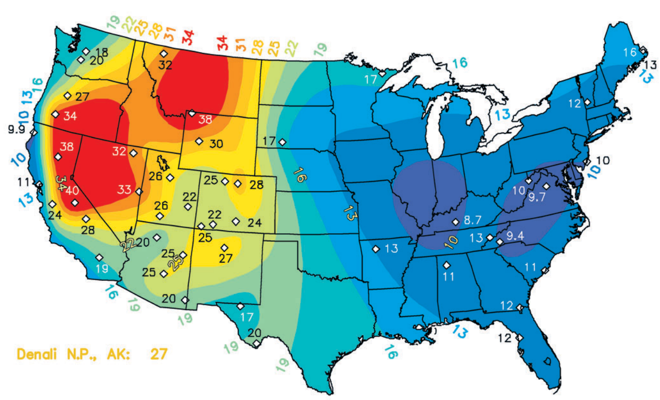
Sulfates



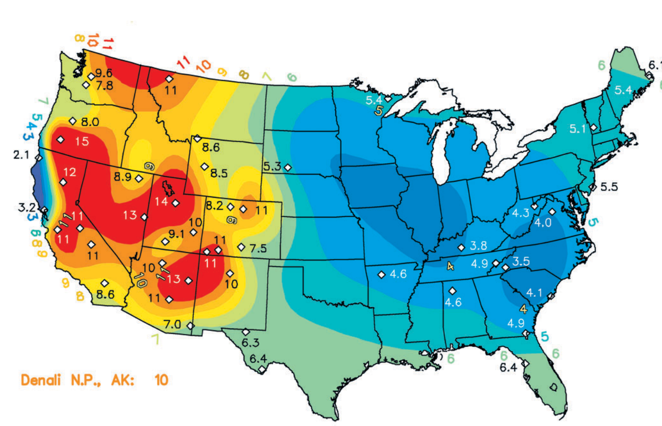
Nitrates



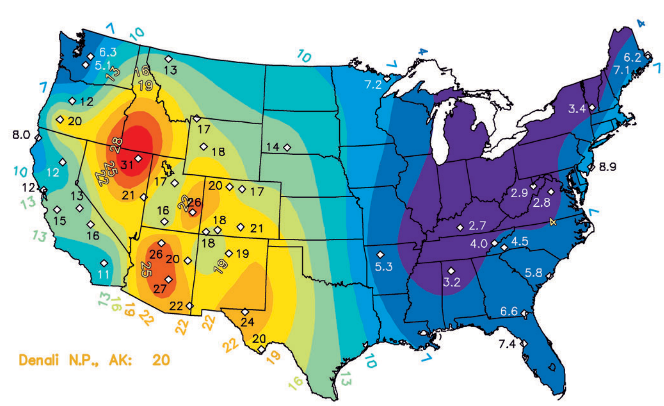
Organics



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).

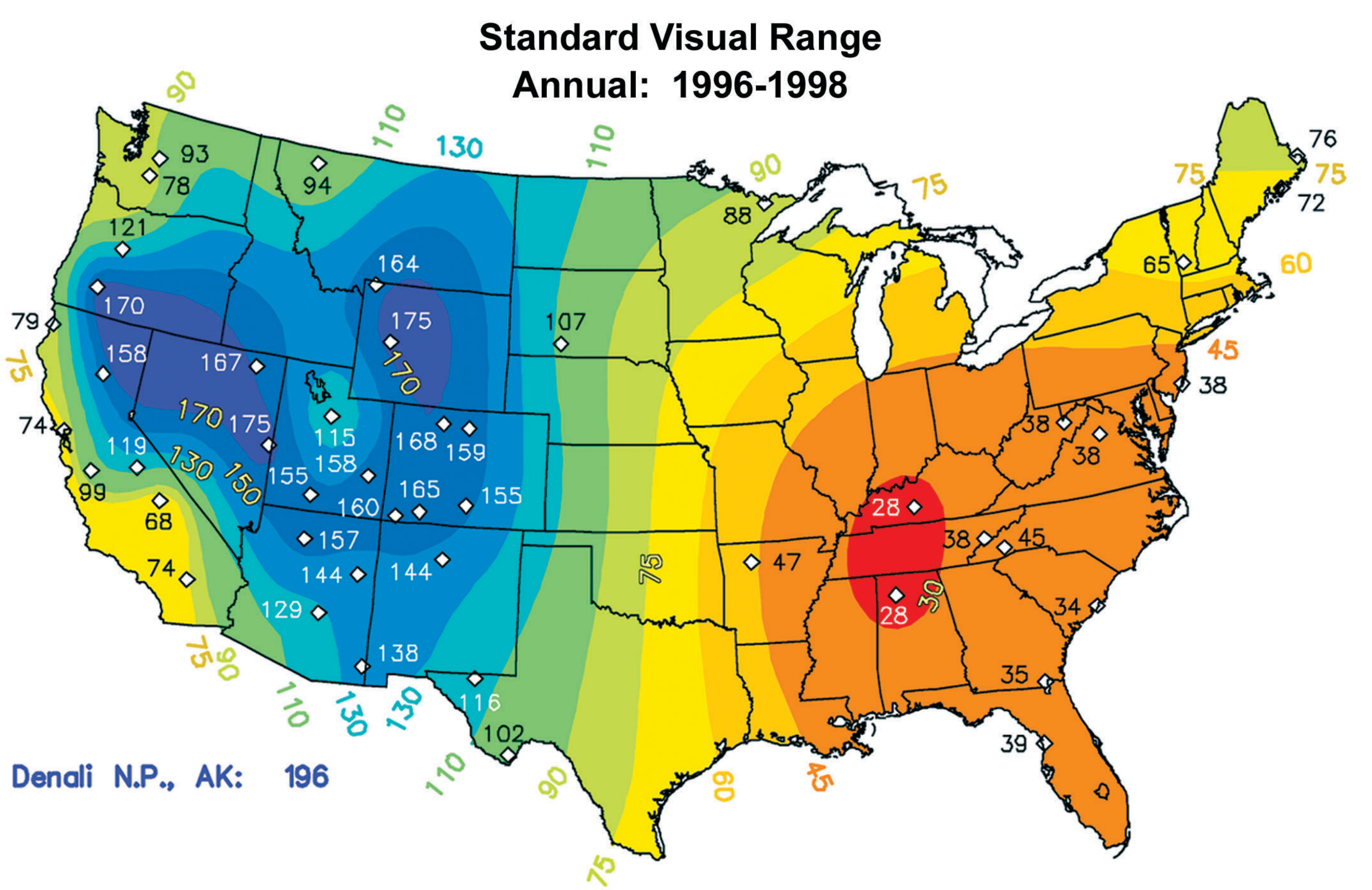
Prior to 1990, visibility degradation in the southeastern U.S. coincided with the increase in sulfur dioxide emissions associated with increased fossil fuel combustion primarily for electric generation, which accounts for 65 percent of total sulfur dioxide emissions in this country. Emissions from fuel 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.

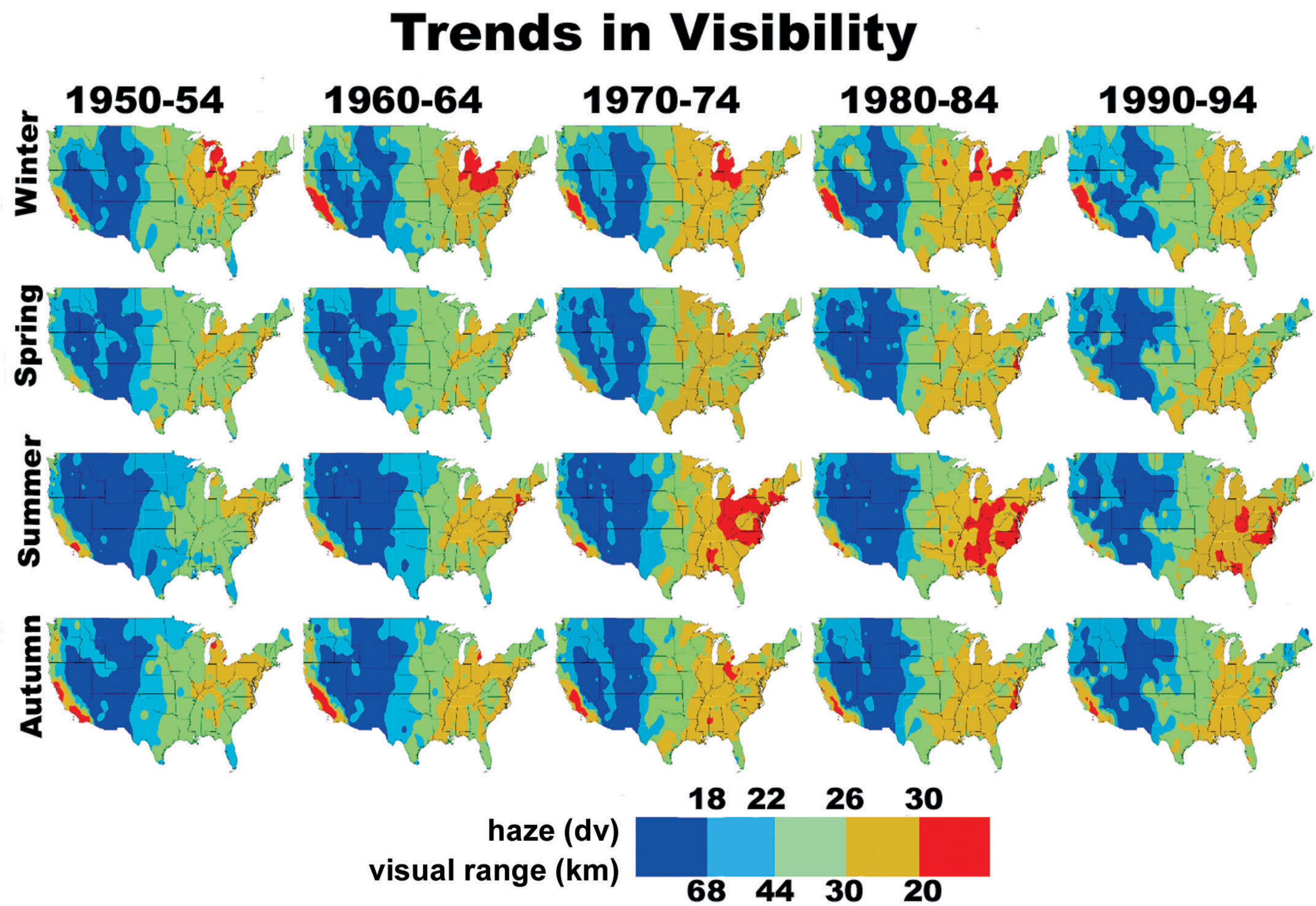
"...the loss of quality viewing is apparent through increased haze and many fewer days when Wheeler Peak in Great Basin National Park is visible."

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.

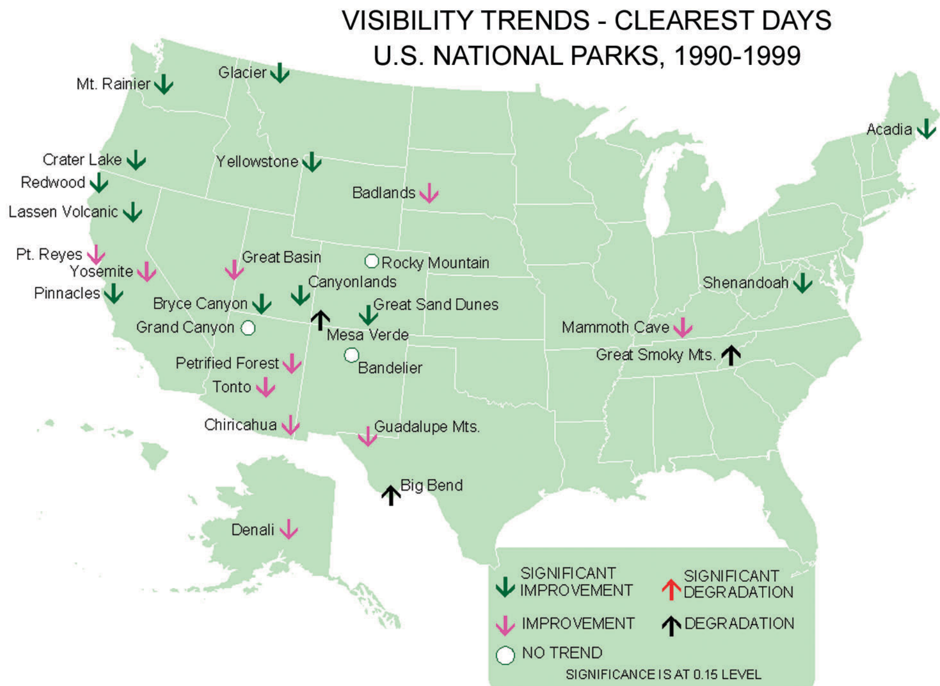
Source: IMPROVE



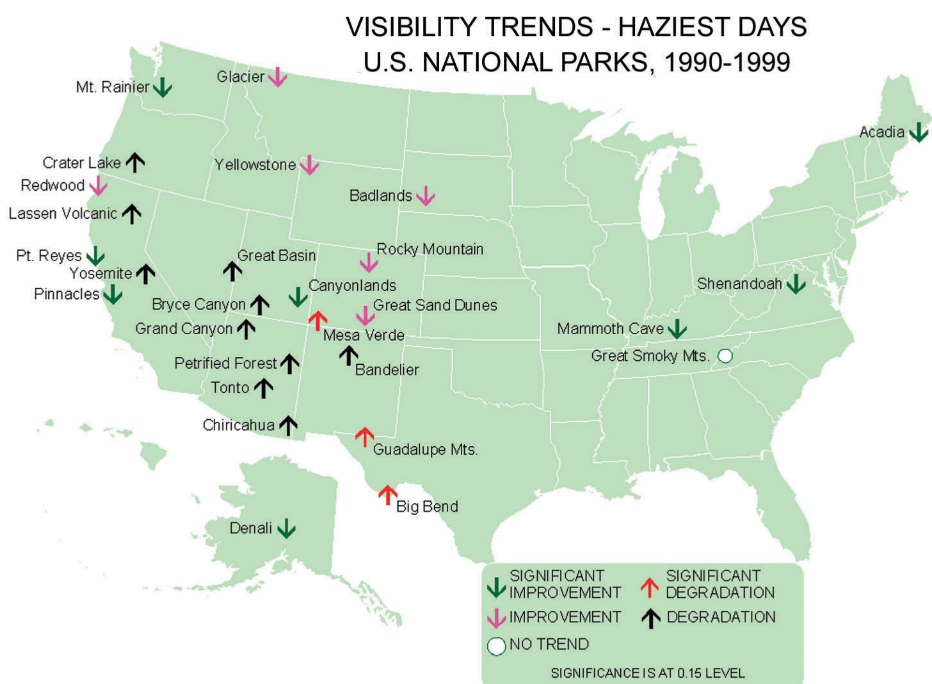
Trends in seasonal visibility across the United States from 1950 through 1994 based on the analysis of airport visibility records. Visibility declined steadily between 1950 and 1984, particularly in the eastern U.S. Some improvements occurred in most areas of the country between 1984 and 1994.

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.

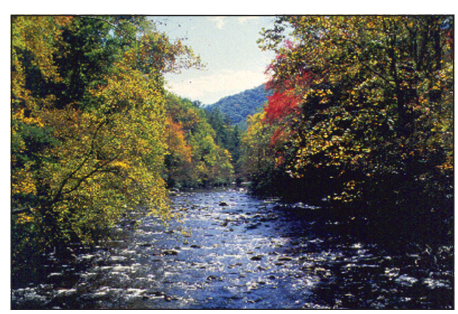
Highest concentrations of nitrate range from 1.35 to greater than 1.8 mg/l, and occur from the Midwest to the Northeast. Relatively high concentrations also extend into the Great Plains and appear in the Southwest. The lowest concentrations, less than 0.4 mg/l, are found in the Northwest and Alaska. 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.

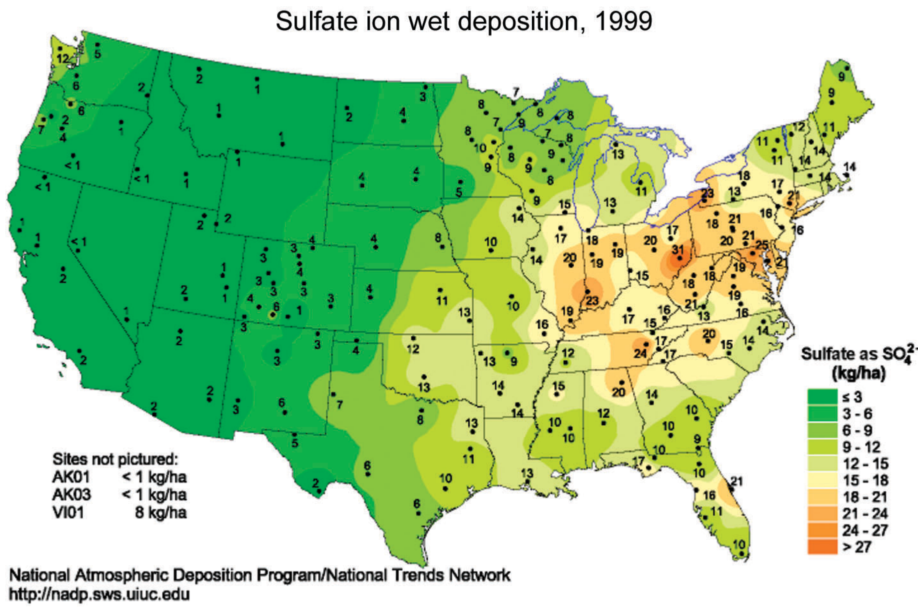
are in northern Utah and northern California. Lower concentrations occur in the Northwest, Southeast, and Alaska.

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.

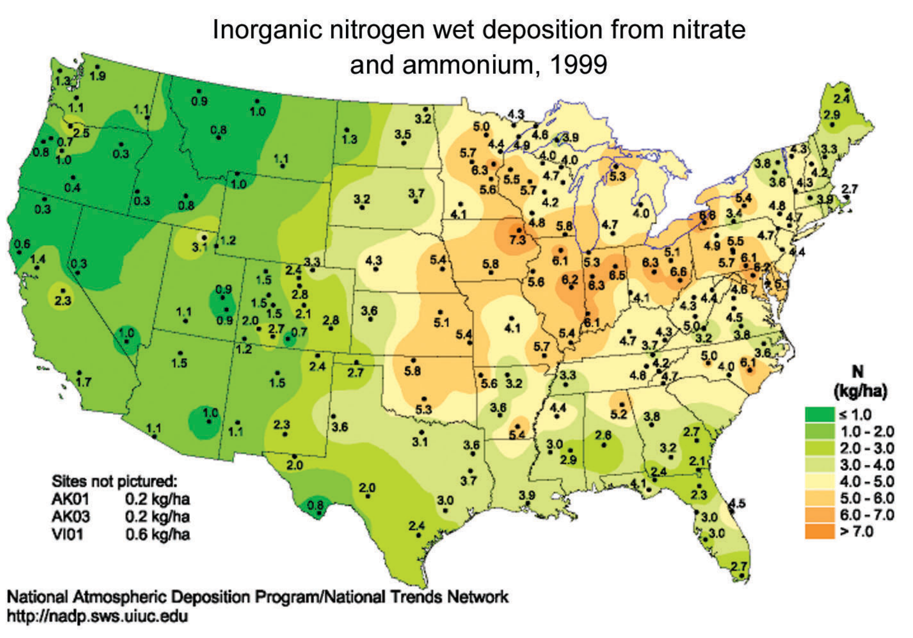
Acid Clouds and Fog

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.



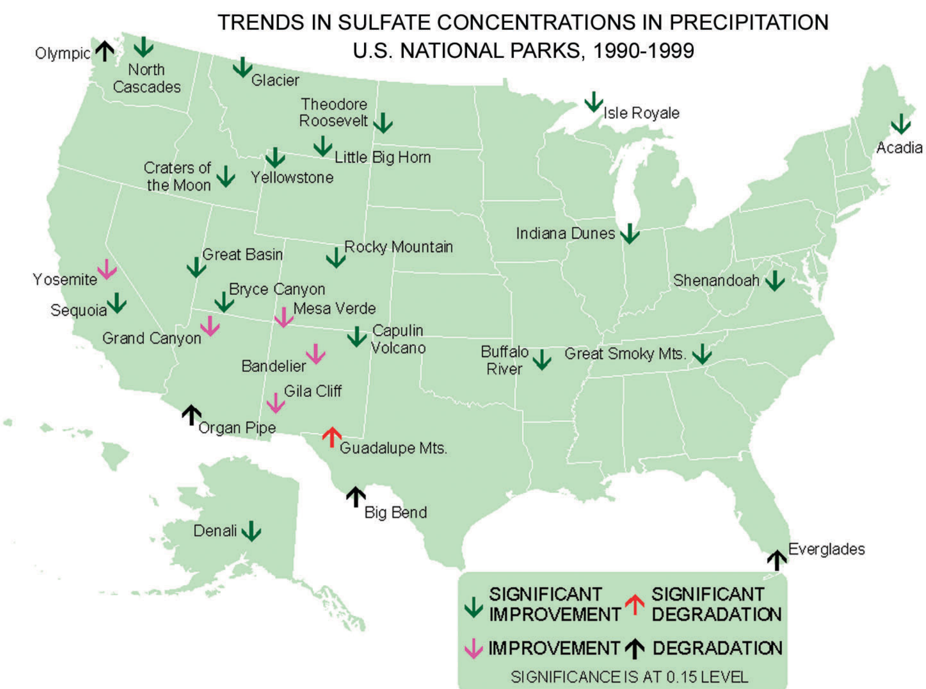
Wet sulfate deposition in 1999 shows the highest levels are in the Ohio River Valley, with most of the western U.S. showing levels less than or equal to 3 kg/ha/yr. In spite of recent reductions in deposition levels across the eastern U.S., sulfur deposition to some park ecosystems exceeds levels that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



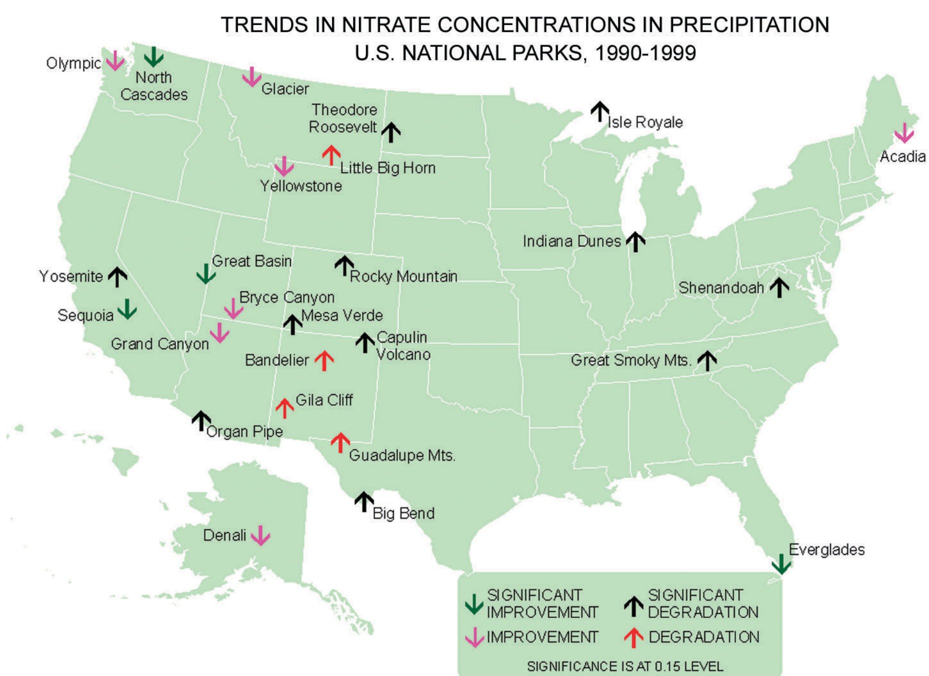
Nitrogen deposition in 1999 shows the highest levels are in the Midwest. In spite of lower nitrogen deposition levels in the West, some high elevation ecosystems in the Rocky Mountains are being affected.

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.



litrate 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.

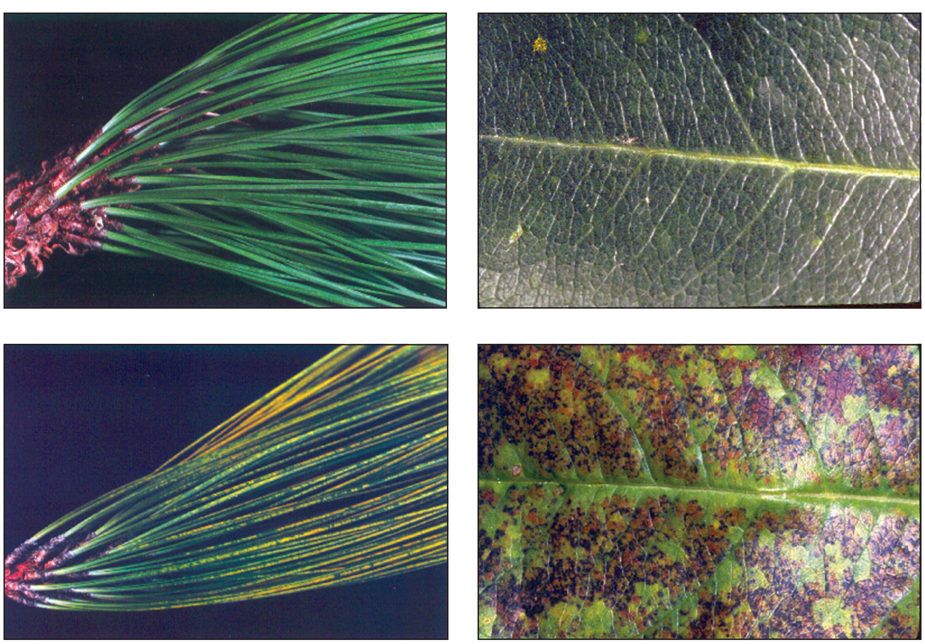
Ozone and its ecological effects Ozone is one of the most phytotoxic air pollutants, and causes considerable damage to vegetation throughout the world. Data show that plants are more sensitive to ozone than humans. Most ozone effects research has concentrated on crops and large economic losses have been 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

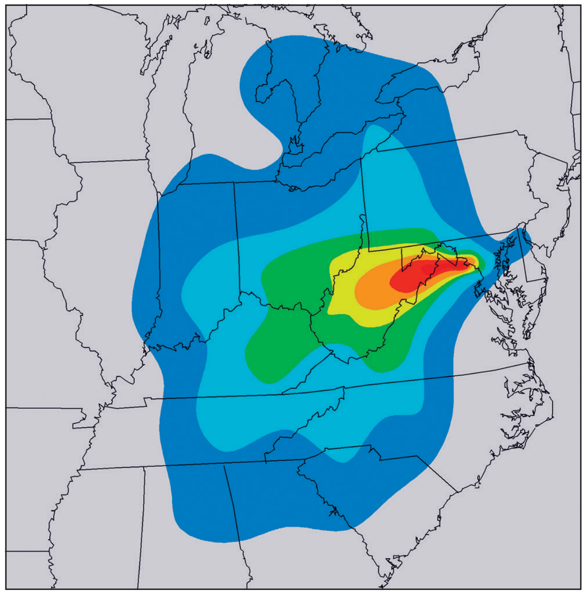
- *Ozone interferes with the ability of plants to produce and store food, so that growth, reproduction, and overall plant health are compro mised.*
- *Ozone makes plants more suscep tible to disease, pests, and environ mental stresses.*
- *Ozone reduces agricultural yields for many economically important 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 precur sor, contributes to fish kills and algae blooms in sensitive water-ways, 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.



Ozone: Good or Bad?

Ozone occurs in two layers of the at mosphere. 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 ingre dient 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

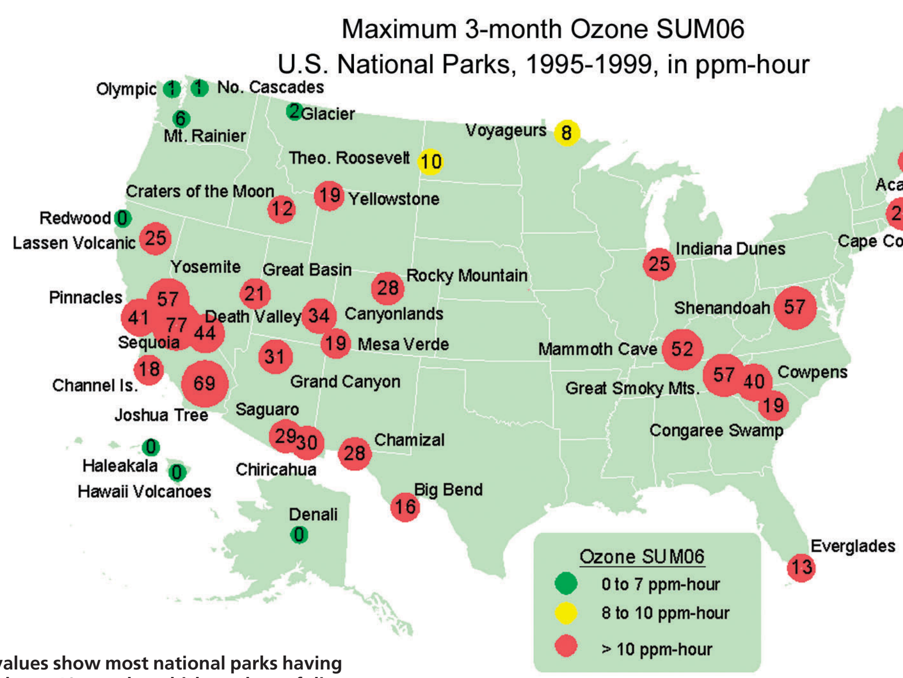
Nationwide fossil fuel combustion and motor vehicles[1] emit 40 percent and 55 percent of annual nitrogen oxides emissions, respectively.

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 vegeta tion (biogenic emissions) exceed human-caused emissions on an an nual basis.

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

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



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.

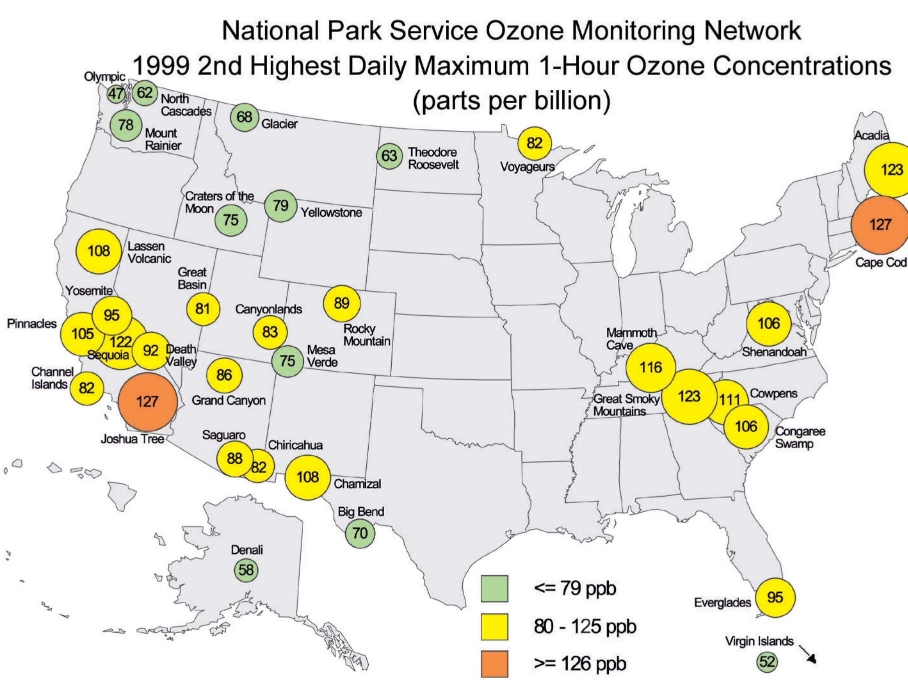
The map below shows the 2nd highest 1-hour average ozone concentrations measured in national parks for 1999. Several parks, primarily in the southeast, Northeast Coast, and California, exceeded or approached this standard. Since 1992, nine parks have measured at least one 1-hour ozone value above the 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 pneumo nia*

Source: U.S. EPA



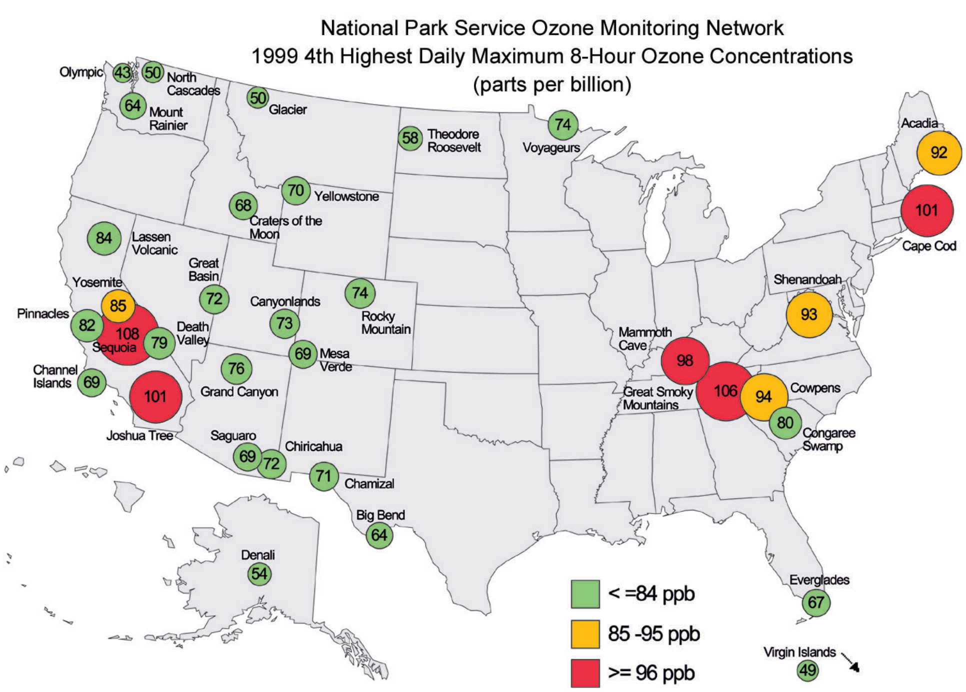
Spatial distribution of second maximum 1-hour ozone concentration, in parts per billion, in U.S. national parks for 1999. Circles are proportional to concentration, with circles in orange identifying the two parks exceeding EPA's 1-hour standard. Parks in the eastern U.S. and in California generally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

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.

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.

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.



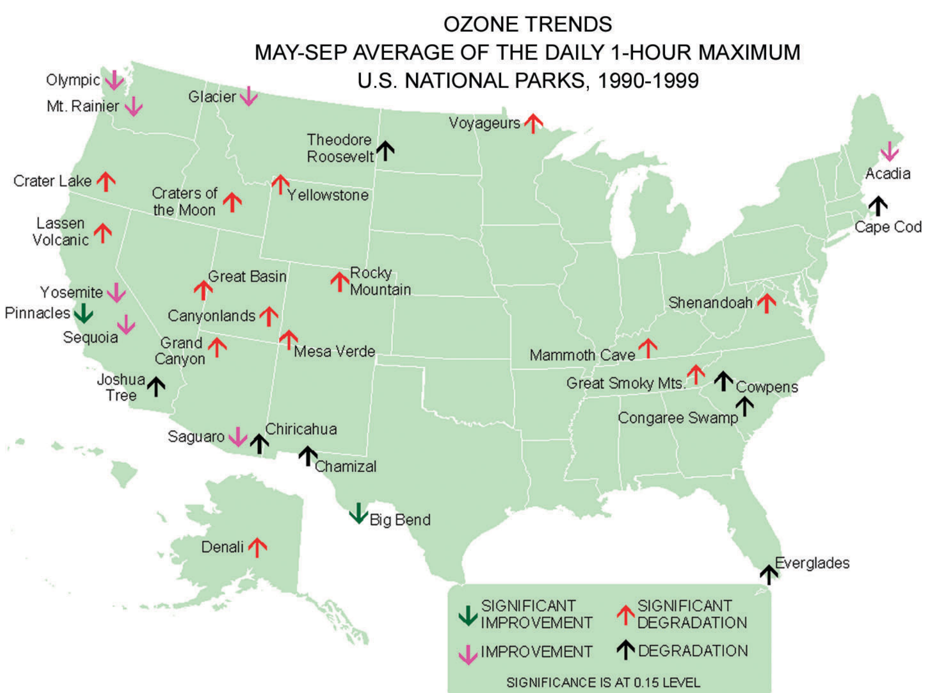
Spatial distribution of maximum 8-hour ozone averages in U.S. national parks for 1999. Circles are proportional to concentration, with circles in red and orange identifying the nine parks exceeding EPA's 8-hour standard. High ozone levels in parks present a threat to native vegetation, as well as to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

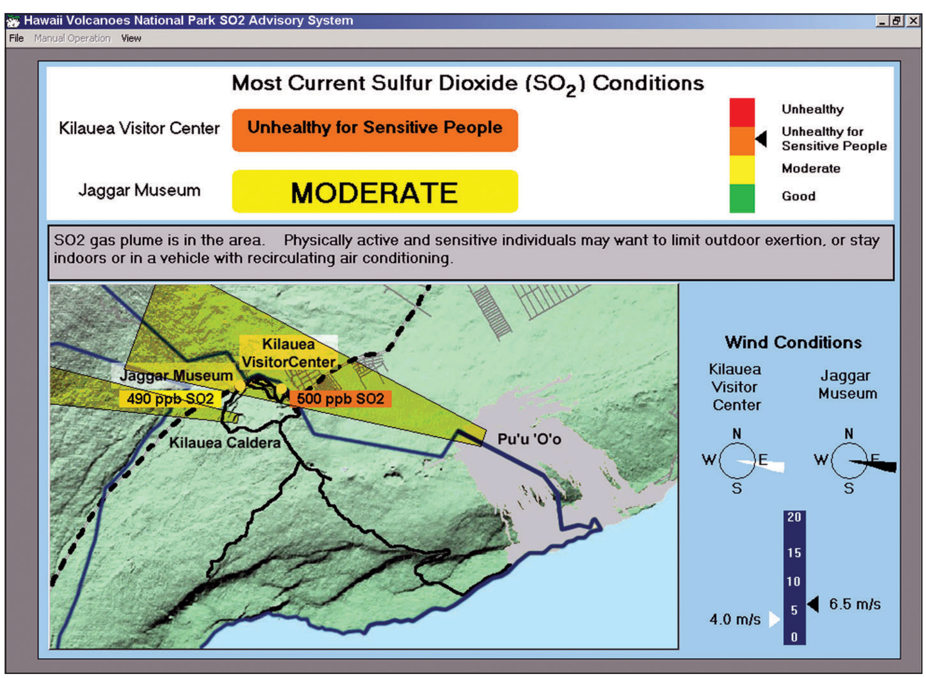
Volcanoes are a source of SO_2 emissions which pose a threat to human health, animal health, and plant life.

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.



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.