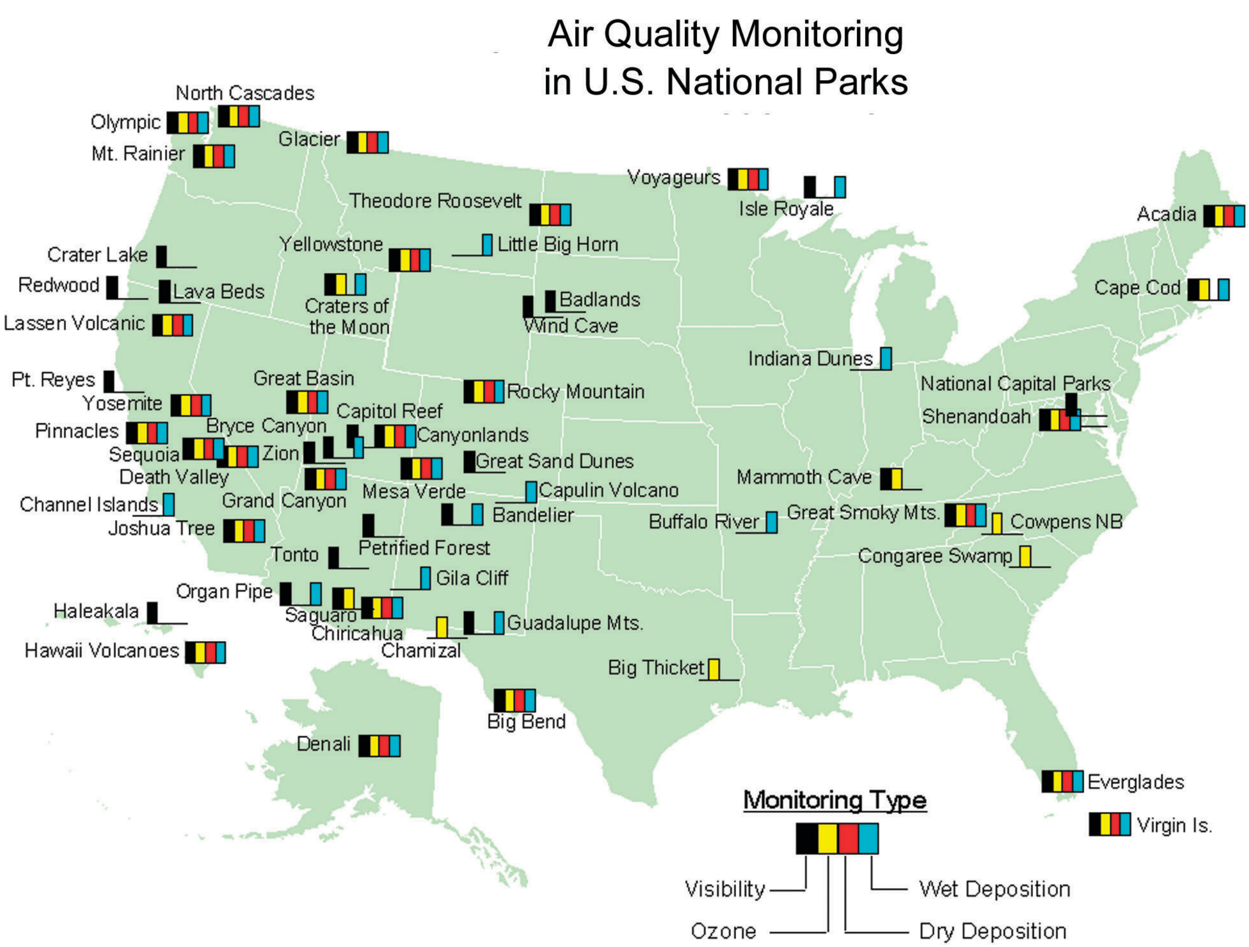
Chapter Three

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.

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.

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)

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.

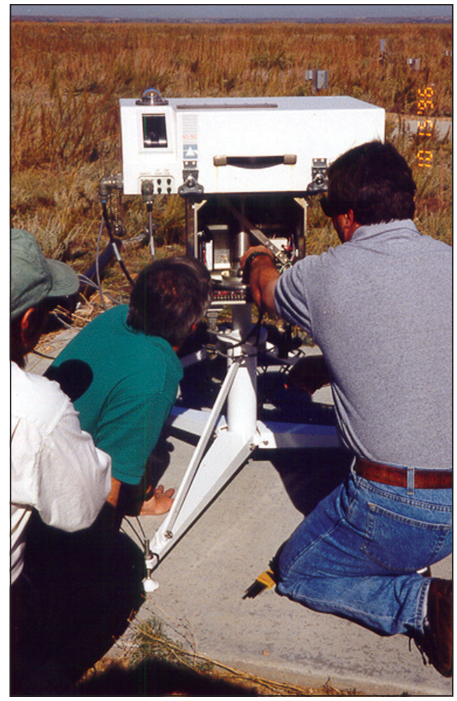
Gaseous pollutant and meteorological monitoring
The gaseous pollutant monitoring program historically concentrated on determining the levels of two gaseous air pollutants, ozone and sulfur dioxide, which are most toxic to native vegetative species found in NPS units at levels at or below the National 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	UV Photometric	Continuous	1-hour average
	28[1]	Passive Sampling (Ogawa samplers)	Daily to weekly	Daily/weekly average
Sulfur Dioxide	5	Pulsed Fluorescent	Continuous	Hourly average
	27	Filter Pack	Weekly	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.

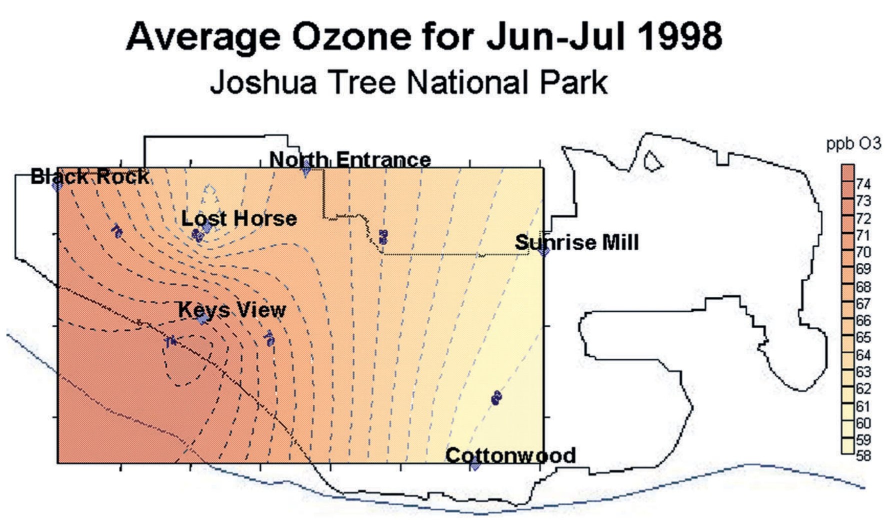
Volunteer places a passive ozone sampler at Great Smoky Mountains National Park.

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 SO_2 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.