National Park Service
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Air Quality Monitoring in the Northern Colorado Plateau Network

2008 Annual Report

Natural Resource Technical Report NPS/NCPN/NRTR—2009/251

ON THE COVER

Various modules of the IMPROVE fine-particle sampler at Canyonlands National Park. Data from the filters in the modules are used to estimate visibility conditions. NPS/A. Wondrak Biel

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Prepared by

Dustin W. Perkins
Richard Houk
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

Editing and Design

Alice Wondrak Biel
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

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Abstract

The National Park Service Organic Act and the Clean Air Act protect air resources in national parks, and in 2005, the National Park Service's Northern Colorado Plateau Network (NCPN) selected ozone, wet and dry deposition, and visibility as vital signs for long-term natural resources monitoring. Information relative to these three vital signs supports evaluation of compliance with legislative requirements of the Clean Air Act's Regional Haze Guidelines and facilitates interpretation of plot-based vegetation and water-quality measurements. In 2009, the National Park Service's Air Resources Division published a nationwide report on air quality in national park units. This report expands on that information to provide a more comprehensive look at air quality in NCPN parks. Some type of air quality monitoring occurs within the boundaries of six network park units: Bryce Canyon National Park (BRCA), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), Colorado National Monument (COLM), Dinosaur National Monument (DINO), and Zion National Park (ZION). An additional six park units have air quality monitoring stations close enough to the park to be reasonably considered representative of the park's air quality: Arches National Park (ARCH), Black Canyon of the Gunnison National Park (BLCA), Cedar Breaks National Monument (CEBR), Curecanti National Recreation Area (CURE), Natural Bridges National Monument (NABR), and Timpanogos Cave National Monument (TICA). Of these 12 parks, nine were determined to be meeting the 2008 Government Performance and Results Act (GPRA) goals for air quality. One (CANY) was found not to be fully meeting 2008 GPRA goals, and two (COLM and DINO) had too little information to determine whether GPRA goals were being met. Canyonlands National Park failed to meet 2008 GPRA goals for air quality due to increasing trends in ammonium; however, CANY did meet GPRA goals for visibility, ozone, and sulfur. Visibility was estimated to be in moderate condition at ARCH, BLCA, BRCA, CANY, CARE, CEBR, CURE, and NABR, and of significant concern at ZION. Across the NCPN, visibility has generally improved on the clearest days over the past 10 years. Sulfur deposition was estimated to be in good condition at BRCA and CANY. Nitrogen deposition was estimated to be in good condition at CANY and moderate condition at BRCA. Ozone levels were estimated to be in moderate condition at CANY and DINO, of significant concern at TICA and ZION, and could not be determined at COLM.

Acronyms

AQRV	air quality-related value
ARCH	Arches National Park
BLCA	Black Canyon of the Gunnison National Park
BRCA	Bryce Canyon National Park
CANY	Canyonlands National Park
CARE	Capitol Reef National Park
CASTNet	Clean Air Status and Trends Network
CEBR	Cedar Breaks National Monument
COLM	Colorado National Monument
CURE	Curecanti National Recreation Area
DINO	Dinosaur National Monument
DV	deciviews
EPA	Environmental Protection Agency
GPRA	Government Performance and Results Act
IMPROVE	Interagency Monitoring of Protected Visual Environments
N	nitrogen
NAAQS	National Ambient Air Quality Standards
NABR	Natural Bridges National Monument
NADP	National Atmospheric Deposition Program
NCPN	Northern Colorado Plateau Network
NH_3	ammonia
NH_4	ammonium
NO_2	nitrogen dioxide
NO_3	nitrate
NOx	nitrogen oxides
NP	national park
NPS	National Park Service
NTN	National Trends Network
NPS-ARD	National Park Service Air Resources Division
OMC	organic mass by carbon
$PM_{2.5}$	mass of particulates up to 2.5 μm in diameter (fine particles)
PM_{10}	mass of particulates up to 10 μm in diameter (coarse particles)
POMS	portable ozone monitoring system
ppb	parts per billion
S	sulfur
SO_2	sulfur dioxide
SO_4	sulfate
TICA	Timpanogos Cave National Monument
VOCs	volatile organic compounds
ZION	Zion National Park

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1 Introduction

1.1 Background

The National Park Service (NPS) is charged with maintaining national park units and their resources unimpaired for the enjoyment of future generations. Park resources affected by air quality include scenery and vistas, vegetation, water, and wildlife. Both the NPS Organic Act and the Clean Air Act protect air resources in national parks. Six Northern Colorado Plateau Network (NCPN) park units are designated as Class I areas: Arches National Park (ARCH), Black Canyon of the Gunnison National Park (BLCA), Bryce Canyon National Park (BRCA), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), and Zion National Park (ZION) (see Section 1.3). These parks receive the highest protection under the Clean Air Act.

The NCPN has identified three aspects of air quality as high-priority vital signs for long-term natural resources monitoring: atmospheric deposition, ozone, and visibility. Over the past three decades, the NPS has developed several internal and cooperative programs for monitoring these measures of air quality. The NCPN relies on the results of that cooperative monitoring for its reporting (NPS-ARD 2002). NCPN air quality reports include data from parks with any type of monitoring—currently BRCA, CANY, CARE, Colorado National Monument (COLM), Dinosaur National Monument (DINO), and ZION. Table 1-1 lists air quality monitoring currently occurring in the NCPN.

In addition, the National Park Service Air Resources Division (NPS-ARD) has determined that deposition and ozone monitors within 16.1 km (10 miles) of a park boundary, as well as particulate (visibility) monitors within 100 km (60

Table 1-1. Summary of ambient air quality monitoring in and nearby to NCPN parks.

Park code	Wet deposition	Dry deposition	Ozone	Visibility
Parks with monitoring stations within their boundaries				
BRCA	UT99 (NADP/NTN)	-	-	Bryce Canyon NP (BRCA1-IMPROVE)
CANY	UT09 (NADP/NTN)	CANY 407 (CASTNet)	CANY-IS (CASTNet)	Canyonlands NP (CANY1-IMPROVE)
CARE	-	-	-	Capitol Reef NP (CAPI1-IMPROVE)
COLM	-	-	COLM-MY (POMS)*	-
DINO	-	-	DINO-WE (POMS)*	-
ZION	-	-	ZION-DP (NPS-GPMP)	Zion NP (ZICA1-IMPROVE)
Parks with monitoring stations close enough to be reasonably considered representative of the park				
ARCH	-	-	-	Canyonlands NP (CANY1-IMPROVE)
BLCA	-	-	-	Weminuche Wilderness (WEMI1-IMPROVE)
CEBR	-	-	-	Bryce Canyon NP (BRCA1-IMPROVE)
CURE	-	-	-	Weminuche Wilderness (WEMI1-IMPROVE)
NABR	-	-	-	Canyonlands NP (CANY1-IMPROVE)
TICA	-	-	EPA Site # 490495008442011	-

*POMS sites are designated for short-term monitoring Source: http://www.nature.nps.gov/air/monitoring/MonHist/park.cfm miles), may be reasonably considered representative of a park's air quality (NPS-ARD in press). Under these guidelines, the NCPN also reports on status for ARCH, BLCA, Cedar Breaks National Monument (CEBR), Curecanti National Recreation Area (CURE), Natural Bridges National Monument (NABR), and Timpanogos Cave National Monument (TICA) (Table 1.1).

1.1.1 Atmospheric deposition

Wet deposition occurs when air-pollutant emissions, such as sulfur dioxide (SO_2), nitrogen oxides (NOx), and ammonia (NH_3) from power plants, automobiles, agriculture, and other sources are transported and transformed in the atmosphere and deposited to ecosystems as gases and particles (including sulfate [SO_4], nitrate [NO_3], and ammonium [NH_4] compounds) via rain or snow. Dry deposition of particles and gases occurs through complex processes, such as settling, impaction, and adsorption.

Atmospheric deposition can have a variety of effects on ecosystems, including acidification, fertilization or eutrophication, and accumulation of toxins. In freshwater lakes, streams, and watersheds, acid deposition from nitrogen (N) and sulfur (S) compounds can cause changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic-invertebrate communities.

Throughout the southwest, there is concern that soils and vegetation may be affected by increasing loads of nitrogen from atmospheric deposition. Deposition can cause changes in soil that affect soil microorganisms, plants, and trees. Because certain plants are better able to utilize nitrogen than others, N deposition can result in shifts in plant-species composition. In some parts of the country, N deposition has altered soil nutrient cycling, and native plants that have evolved under nitrogen-poor conditions have been replaced by invasive species better able to utilize nitrogen (NPS-ARD 2006a). Excess N deposition can cause unwanted fertilization effects, leading to changes in plant-community structure and diversity. Nitrogen additions also can result in higher plant biomass and, consequently, higher fire frequency and severity.

The NPS monitors the chemistry of precipitation in national park units as a partner in the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) (NADP 2002). Rainwater samples are collected weekly using standard methods and are sent to a central laboratory for analysis. Measured constituents include hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (including calcium, magnesium, potassium, and sodium). In the NCPN, BRCA has participated in this program since 1985, and CANY since 1997. Nitrogen dioxide (NO_2) and SO_2 are also contaminants for which "non-attainment" areas are designated when regulatory thresholds for human-health effects are exceeded, although impacts to ecological systems could occur below these thresholds. No NCPN park units are currently in non-attainment areas for NO_2 or SO_2 (EPA 2009).

Dry-deposition chemistry is monitored in CANY in conjunction with the Clean Air Status and Trends Network (CASTNet) (MACTEC 2003). Over a weeklong period, fine particles and gases suspended in the air are collected on filters that are sent to a central laboratory for analysis. Meteorological, vegetation, and land-use data from the sites are used to calculate deposition velocities, which are combined with the concentration measurements to estimate dry deposition in kilograms per hectare per year (kg/ha/yr) of ammonium, nitrate, nitric acid, sulfate, and sulfur dioxide.

1.1.2 Ozone

Ozone is a gaseous constituent of the atmosphere usually formed by reactions of NOx and volatile organic compounds (VOCs) in the presence of sunlight. Ground-level ozone is the major constituent in smog. Ozone in certain concentrations is toxic to humans, and some plant species are particularly sensitive to ozone damage (Porter 2003). The Environmental Protection Agency (EPA) has set a national standard for ozone to protect human health and the environment. Areas not meeting the standard are designated as non-attainment areas, and states are required to develop plans to bring such areas into attainment. No NCPN park units are currently in non-attainment areas for ozone (EPA 2009).

Ozone has been monitored using continuous samplers at CANY and ZION since 1992 and 2004, respectively. This method employs a gas analyzer that measures ultraviolet absorbance to produce hourly ozone concentration measurements. Continuous monitoring is done as part of the NPS Gaseous Pollutant Monitoring Program, in partnership with the EPA's CASTNet program (MACTEC 2003). At COLM and DINO, ozone data have been collected by portable ozone monitoring system (POMS) units, which are small, low-power ozone analyzers, since 2006 and 2005, respectively. Two POMS versions are available: one with and one without filter-pack sampling for dry deposition. POMS are generally used for survey and temporary monitoring projects. TICA has an ozone monitoring station located within 16.1 km of the park.

The NPS-ARD completed an ozone risk assessment for NCPN parks in 2004, based on the concept that foliar ozone injury to plants is the result of the interaction of the plant, ambient ozone, and the environment. The risk for foliar injury is high if three factors are present: plant species that are genetically predisposed to ozone injury; concentrations of ambient ozone that exceed a threshold required for injury; and environmental conditions that foster gas exchange and the uptake of ozone by the plant. The assessment concluded that the risk of foliar injury to plants is low in all NCPN parks (NPS 2004). Several parks have ozone levels that exceed thresholds for foliar injury to plants, but these ozone levels tend to occur during drought conditions, which reduce the potential for injury. However, recent information suggests that well-watered plants in riparian areas may be at increased risk (E. Porter, NPS-ARD, pers. comm.).

1.1.3 Particulate matter and visibility

Visibility-obscuring particulate matter consists of dust, soot, and other fine solid materials that become suspended in the air. Major sources of particulates are burning of fossil fuels, fires, wood smoke, and wind-blown soil. Regulatory standards for particulates and visibility include (1) designation of non-attainment areas and (2) visibility standards for Class I areas under the Clean Air Act. Timpanogos Cave National Monument, located in Utah County, Utah, is in a moderate non-attainment area for PM_{10} (mass of particulates up to 10 μm in diameter) (EPA 2009). (TICA is not one of the six NCPN units designated as Class I areas.)

Visibility monitoring currently occurs in BRCA (since 2000), CANY (since 2000), CARE (since 2000), and ZION (since 2003) as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program (Crocker 1996; IMPROVE 1998). Stations are located nearby to two additional Class I NCPN parks, ARCH and BLCA. The CANY station is located 35 km south of ARCH, and the Weminuche Wilderness site, in the San Juan National Forest, is located 96 km southwest of BLCA. Three non-Class I parks have sites nearby: NABR (CANY site), ZION (BRCA site), and CURE (Weminuche Wilderness site).

In the past, cameras were used at the BRCA and CANY IMPROVE monitoring sites as an additional visibility monitoring tool. The acquired photographs provide images representing the range of visibility conditions at each site. Photography began in 1984 at BRCA, and in 1987 at CANY. Representative images can be viewed at http://vista.cira.colostate.edu/improve/Data/IMPROVE/Data_IMPRPhot.htm. In 2009, BRCA's Yovimpa Point camera became active again, now funded by the park. Data from this station will be analyzed in future years.

1.2 Monitoring objectives

The NPS monitors air quality parameters in NCPN park units in cooperation with national air quality monitoring programs. Air quality data are summarized and analyzed for conditions and trends by both the NPS-ARD and those national programs. Therefore, it is not the NCPN's objective to replicate these analyses. Instead, the network aims to compile the data summaries performed by these groups and provide them in a concise report to be analyzed in conjunction with other NCPN vital signs. In addition, the NCPN seeks to understand how ozone, nitrogen deposition, sulfur deposition, and visibility-reducing pollutants vary with associated vital signs (e.g., integrated upland systems, integrated riparian systems, climate).

NCPN air quality monitoring objectives are to:

1. Determine the seasonal and annual status and trends in concentrations of N- and S-containing ions from wet deposition at BRCA and CANY;
2. Determine the seasonal and annual status and trends in dry-deposition chemistry at CANY;
3. Determine the seasonal and annual status and trends in ozone concentration at CANY, COLM, DINO, and ZION, and make status estimates for TICA, which has a station in the vicinity of the park; and

4. Determine the seasonal and annual status and trends in concentrations of visibility-reducing pollutants at BRCA, CANY, CARE, and ZION from stations in the park and make status estimates for ARCH, BLCA, CEBR, CURE, and NABR based on stations from the vicinity.

2 Methods

2.1 Atmospheric deposition

Atmospheric deposition is monitored in the NCPN by the NADP and CASTNet. Because of differences between wet and dry deposition, NADP and CASTNet monitoring and analysis methods are different.

The NADP collects and analyzes rainfall samples for cations and anions, reporting concentrations of those constituents in milligrams per liter of rainfall. Rainfall amount is factored in to estimate deposition rates in kilogram per hectare per year (kg/ha/yr). The NADP reports individual site data and produces isopleth maps of wet deposition concentrations and deposition.

The NADP maps of interpolated wet deposition values are useful for examining spatial differences in the loadings of pollutants to ecosystems. NADP concentration data (as opposed to deposition data) are typically used to track temporal trends in the components of deposition. Deposition data are less useful for tracking temporal trends because deposition is affected by annual variations in rainfall amounts.

CASTNet uses filters to collect atmospheric particles suspended in the air, analyzes the filters, and reports concentrations in micrograms per cubic meter of air. An inferential model is then applied to estimate deposition in kg/ha/yr. Because the inferential model is very site-specific (e.g., dependent on vegetation types), CASTNet does not recommend extrapolating the dry-deposition data between areas, and does not produce isopleth maps of deposition as NADP does.

CASTNet has recently started reporting both dry and wet (from NADP) deposition data, providing total deposition estimates for areas with CASTNet samplers.

2.2 Ozone

In addition to harming human health, research shows that certain plant species are more sensitive than humans to ozone, and that effects on plants occur well below the National Ambient Air Quality Standards (NAAQS). Scientists use various exposure indices to quantify ozone exposure to plants—indices considered biologically relevant because they take into account both peak ozone concentrations and cumulative exposure to ozone. These indices include the SUM06 (the running, 90-day maximum sum of the 0800–2000 hourly concentrations of ozone equal to or greater than 0.06 ppm) and the W126 (the weighted sum of the 24 one-hour ozone concentrations daily from April through October, with the N100, i.e., number of hours ≥100 ppb). In general, both indices—SUM06 and W126 with N100—need to be satisfied in order for there to be a moderate-to-high risk for ozone injury, and soil moisture needs to be sufficient enough that plant stomates are likely to be open, and ozone able to enter the leaves. Continuous ozone analyzers and POMS are used to monitor ozone in NCPN parks.

2.3 Visibility

IMPROVE monitoring protocols include three types of visibility monitoring: particle (or aerosol), scene, and optical. Particle samplers, located at all IMPROVE sampling sites, are used to calculate the mass and chemical composition of fine particle matter ($PM_{2.5}$) and the mass of coarse particulate matter (PM_{10}) in the atmosphere. Fine particles of two size classes are collected on filters and sent for laboratory analysis of chemistry and mass. Samples are collected for a 24-hour period every third day.

2.4 Statistical analyses

To calculate servicewide percentages necessary for comparison with air-quality goals, the NPS-ARD (2009) performed a trend analysis for ammonium, nitrates, sulfates, visibility and ozone over a 10-year period. The FY2008 analysis used data collected from 1998 to 2007, and required that each monitoring site have at least six years of data in this 10-year period. The trend time period is a sliding, 10-year window that will change to 1999–2008 for next year's analysis. A sliding, 10-year window was chosen (rather than a variable-length trend from a single, fixed, baseline year) because individual parks began monitoring in different years; thus, there is no single, fixed, baseline year that can be applied to all parks.

Trends were computed using the Thiel test, a non-parametric technique that does not require any assumptions about data distribution. Trended statistics were computed for (1) the three-year average of annual fourth-highest eight-hour ozone concentration, as defined by EPA; (2) annual volume-weighted concentrations of N and S in wet deposition as reported by NADP, multiplied by a normalized precipitation amount to give a total deposition in kg/ha; and (3) annual deciviews (DV) for the 20% clearest and 20% haziest days, as defined by Tracking Progress Guidance Document for EPA's regional haze rule.

The NADP Technical Committee defines completeness based on four criteria:

- Criterion 1: the percentage of the summary period for which there are valid samples.
- Criterion 2: the percentage of the summary period for which precipitation amounts are available, either from the rain gage or the sample volume.
- Criterion 3: the percentage of the total measured precipitation associated with valid samples.
- Criterion 4: the collection efficiency as defined by the sum of the sample bucket depths (in centimeters) in the summary period divided by the sum of the rain gage amounts (in centimeters) for all valid samples, where both values are available.

To qualify as complete, the values for criteria 1, 3, and 4 must be >= 75%. The values for criterion 2 must be >= 90% (http://nadp.sws.uiuc.edu). For the trend analyses, only values that met criteria 1 and 3 were used; others were set to missing. No smoothing was applied.

2.5 Condition assessments

The NPS-ARD has developed condition assessments for the major air quality parameters (NPS-ARD in press). A stable trend may not be sufficient if the overall park air quality is in a degraded state. The following three sections are derived from the division's 2008 Annual Performance & Progress Report (NPS-ARD in press).

2.5.1 Atmospheric deposition condition

Park scores for current condition of atmospheric deposition were based on wet deposition, because dry deposition data were not available for most areas. Wet deposition was calculated by multiplying N or S concentrations in precipitation by a normalized precipitation amount. Deposition data were obtained from the NADP. Several factors were considered when rating deposition condition, including natural background deposition estimates and the effects of deposition on ecosystems. Estimates of natural background deposition for total deposition are approximately 0.25 kilograms per hectare per year (kg/ha/yr) in the West, for either N or S. For wet deposition only, this is roughly equivalent to 0.13 kg/ha/yr in the West. Certain sensitive ecosystems respond to levels of deposition on the order of 3 kg/ha/yr total deposition, or about 1.5 kg/ha/yr wet deposition.

There is currently no evidence to indicate that less than 1 kg/ha/yr of wet deposition causes ecosystem harm. Therefore, parks with wet deposition of less than 1 kg/ha/yr were considered to be in good condition for deposition. Parks with 1–3 kg/ha/yr were considered to be in moderate condition, and parks with more than 3 kg/ha/yr were considered to have a significant concern for deposition (Table 2-1).

Table 2-1. Deposition condition as determined by kg/ha/yr.

Deposition condition	Wet deposition (kg/ha/yr)
Good	<1
Moderate	1–3
Significant Concern	>3

Scores for parks with ecosystems potentially sensitive to N or S were adjusted up one category (e.g., a park with N deposition of 1–3 kg/ha/yr that contained N-sensitive ecosystems would be assigned the deposition condition "red").

2.5.2 Ozone condition

The NAAQS for ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum eight-hour average ozone concentration. In March 2008, the standard value was lowered to 75 ppb to be more protective of human health (Ray 2008). To attain this standard, the three-year average of the fourth-highest daily maximum eight-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 75 parts per billion (ppb).

To derive an estimate of the current ozone condition at parks, the five-year average of the annual fourth-highest eight-hour ozone concentration was determined for each park from the interpolated values described above. Good condition for ozone was assigned to parks with average five-year ozone concentrations of less than 61 ppb (concentrations less than 80% of the standard).

Moderate condition for ozone was assigned to parks with average five-year fourth-highest eight-hour ozone concentrations of 61–75 ppb (concentrations greater than 80% of the standard). If the resulting five-year average was greater than or equal to 76 ppb, then a condition of "significant concern" was assigned to that park. (Table 2-2).

Table 2-2. Ozone condition as determined by ppb.

Ozone condition	Ozone concentration
Good	≤60 ppb
Moderate	61–75 ppb
Significant Concern	≥76 ppb

In addition to the standard, vegetation sensitivity was considered when assigning park condition. Data show that some plant species are more sensitive to ozone than humans, and the ozone standard is not protective of some vegetation. In accordance with the 2004 risk assessment, which rated parks as low, moderate, or high risk for ozone injury to vegetation, parks that were evaluated at high risk were moved into the next condition category (e.g., a park with an average ozone concentration of 72 ppb, but judged to be at high risk for vegetation injury, would move from the category "yellow" for ozone to "red") for this report. No NCPN parks were rated as high-risk.

2.5.3 Visibility condition

Individual park scores for visibility were based on the deviation of the current Group 50 visibility conditions from estimated Group 50 natural visibility conditions, where Group 50 is defined as the mean of the visibility observations falling within the range from the 40^{th} through the 60^{th} percentiles. Current visibility was estimated from the interpolation of the five-year averages of the Group 50 visibility.

Visibility in this calculation is expressed in terms of a Haze Index in deciviews. As the Haze Index increases, visibility worsens. The visibility condition is expressed as:

Visibility Condition = current Group 50 visibility – estimated Group 50 visibility under natural conditions.

Good condition was assigned to parks with a visibility condition estimate of less than two DV above estimated natural conditions. Parks with visibility condition estimates ranging from two to eight DV above natural conditions were considered to be in moderate condition, and parks with visibility condition estimates greater than eight DV above natural conditions were considered to have a significant concern (Table 2-3). The DV ranges of these categories, while somewhat subjective, were chosen to reflect, as nearly as possible, the variation in visibility conditions across the monitoring network.

Table 2-3. Visibility condition as determined by number of DV above estimated natural conditions.

Visibility condition	DV above estimated natural conditions
Good	<2
Moderate	2–8
Significant Concern	>8

2.6 Government Performance and Results Act goals

Data from visibility monitoring, gaseous air pollutant monitoring (primarily ozone), and precipitation monitoring are used to assess air-quality trends. Six total measures are used in calculating the goal percentages: two are used to measure progress toward the visibility goal, one is used for the ozone goal, and three measures are used for the atmospheric-deposition goal. Not all parks monitor all six indicators. A park is considered to have improving or stable air quality if none of the measures used for that goal show a statistically significant degrading trend (NPS-ARD in press).

Assessing performance for this goal is based on a 10-year trend of three performance indicators: atmospheric deposition, ozone, and visibility. Six measures are used to assess performance under the three indicators. Trends in sulfate, nitrate, and ammonium ions in precipitation (rain and snow) are used as indicators of atmospheric deposition, because they can be directly linked to ecological effects (e.g., acidification of surface waters, nutrient enrichment that disrupts natural systems). The NPS calculates ozone trends using the EPA's metric for the NAAQS (i.e., the three-year average of the annual fourth-highest daily maximum eight-hour ozone concentration). For visibility, the NPS examines the annual reconstructed atmospheric extinction in deciviews for both clear and hazy days.

3 Results

3.1 Regional trends

The NPS-ARD's FY2008 Government Performance and Results Act (GPRA) report (NPS-ARD in press) addressed air quality trends in parks nationwide with long-term monitoring from 1998 to 2007. For visibility, this report found increasing trends (improving air quality) for clear days in all NCPN parks where measurements were taken (ARCH, BLCA, BRCA, CANY, CARE, CEBR, CURE, NABR, and ZION). Similar trends were found at parks close to the NCPN, including Great Basin, Great Sand Dunes, and Mesa Verde national parks. Trends for parks further south on the Colorado Plateau (Glen Canyon National Recreation Area, Grand Canyon National Park, and Walnut Canyon National Monument) remained stable, rather than increasing (or decreasing). Trends in visibility for the haziest days were stable for all NCPN parks and surrounding parks.

Of all measurements taken in 10 NCPN parks, only one degrading trend in air quality was detected, as air quality at CANY showed increasing amounts of ammonium. Nearby Mesa Verde National Park (NP), in the Southern Colorado Plateau Network, also had increasing levels of ammonium. BRCA and Great Basin NP showed similar patterns for ammonium but did not have statistically significant increasing trends. There were no statistically significant trends for nitrates and sulfates at BRCA or CANY, which are the only two NCPN locations where these parameters are monitored. TICA was found to have decreasing levels of ozone (improving air quality), in contrast to increasing trends found at Mesa Verde NP and stable levels of ozone at CANY and Great Basin NP.

Spatial patterns of sulfur (from sulfate) and nitrogen (from nitrate and ammonium) from precipitation in 2007 appear in Figures 3-1 (concentration) and 3-2 (deposition) (figures begin on page 17). Sulfur and sulfate concentrations remain low throughout the NCPN and the western United States, reflecting regional differences in SO_2 emissions (primarily from coal-burning power plants). Nitrate concentrations were also generally lower in the West. However, northern Utah had a large increase in areas with high ammonium concentrations from 2006 to 2007, including the areas of Golden Spike National Historic Site and TICA, and, to a lesser extent, Fossil Butte National Monument, in Wyoming. Nitrate forms from emissions of nitrogen oxides from vehicles, power plants, and other combustion sources. Ammonium contributes to total N deposition, and ammonium concentrations were increasing at a faster rate than nitrate concentrations alone. Ninety-eight percent of reporting parks in the West showed stable or improving trends for nitrate in precipitation (NPS-ARD in press).

The NCPN is characterized by some of the better visibility in the country for the clearest days and is reasonably good relative to the rest of the country for hazy days (Figure 3-3).

3.2 Black Canyon of the Gunnison National Park and Curecanti National Recreation Area

3.2.1 Class I park overview

Black Canyon of the Gunnison NP was designated a Class I air quality area in 1977, receiving the highest protection under the Clean Air Act. Both local and distant air pollutant sources affect air quality in BLCA. Power plants in Mesa and Montrose counties, Colorado, are the largest nearby point sources of SO_2 and NOx. Other large power plants in the Four Corners area, as well as urban areas throughout the southwest, contribute to pollution in the park (NPS-ARD 2006a). Visibility is a sensitive air quality-related value (AQRV), and in many parks on the Colorado Plateau, visibility is often impaired by light-scattering pollutants (haze). Other AQRVs may also be sensitive and at risk from air pollution.

Surface waters in BLCA are generally well-buffered because of adequate amounts of cations, such as calcium and magnesium and, therefore, not likely to be acidified by atmospheric deposition. Most soils are also likely to be well-buffered from acidification. However, there may be areas in the park where rock is resistant to weathering, where cation concentrations are low, and soils and water (e.g., in potholes) may be sensitive to inputs of acidic deposition (NPS-ARD 2006a).

[†]Although the data for both parks come from the same site, trend analyses are slightly different due to the use of interpolated data.

3.2.2 Visibility

In 2007, based on interpolated data from the Weminuche Wilderness site in the San Juan National Forest, the average light extinction for the 20% clearest days was 3.79 Mm^{-1} and, for the 20% haziest days, 20.05 Mm^{-1} for BLCA and CURE. Light-extinction trends for the 20% clearest days decreased significantly (increasing air quality) based on three-year running averages from 1998 to 2007 (BLCA: slope = –0.13, p = 0.01; CURE: slope = –.013, p = 0.001), but no trend has been shown for the 20% haziest days (BLCA: slope = –0.10, p = 0.24; CURE (slope = –0.10, p = 0.24) (Figure 3-4).[†]

Visibility impairment results largely from small particles in the atmosphere. Figure 3-5 shows the contributions made by different classes of particles toward haze. On the 20% best days (the bottom 20% of the distribution by deciview, or haze index), ammonium sulfate made the largest contribution toward visibility impairment. On the 20% worst days (the top 20% of the distribution by deciview), organic particles made the largest contribution toward haze, likely a result of fire, which is often the source of organic particles in the West.

Some seasonal patterns in haze composition were evident at BLCA/CURE in 2007 (Figure 3-6), with highest haze occurring in the summer months. Visibility was estimated to be 3.40 deciviews at BLCA and 3.35 at CURE, based on interpolated averages from from 2003 to 2007, and estimated to be in moderate condition (see Table 2-3). The park is often impaired by light-scattering pollutants (haze) (NPS-ARD 2006a). Because BLCA and CURE have had improving visibility on clear days, and visibility on the haziest days has shown no degrading trends, these two parks are currently meeting their 2008 GPRA goal for visibility.

3.3 Bryce Canyon National Park and Cedar Breaks National Monument

Because the NPS-ARD has determined that particulate (visibility) monitors within 100 km (60 miles) may be reasonably considered representative of a park's air quality, the IMPROVE visibility monitor in BRCA is also suitable for CEBR. **Deposition data, however, cannot be extrapolated to CEBR.**

3.3.1 Class I park overview

Bryce Canyon National Park was designated a Class I air quality area in 1977, receiving the highest protection under the Clean Air Act. Both local and distant air pollutant sources affect air quality in Bryce Canyon NP. Nearby large point sources include power plants, refineries, and lime kilns in Coconino County, Arizona, and Clark County, Nevada. Pollutants also travel greater distances to the park from both mobile and point sources throughout the southwest (NPS-ARD 2006b).

Surface waters in BRCA are expected to be generally well-buffered because of adequate amounts of cations, such as calcium and magnesium and, therefore, not likely to be acidified by atmospheric deposition. However, there may be areas in the park where rock is resistant to weathering, where cation concentrations are low, and soils and water (e.g., in potholes) may be sensitive to inputs of acidic deposition. Soils and vegetation in the park may also be sensitive to nutrient enrichment from nitrogen deposition (NPS-ARD 2006b).

3.3.2 Atmospheric deposition

Concentrations of nitrate in BRCA have been variable over the past 20 years, as well as over the past 10 years (1998–2007) (slope = –0.21, p = 0.036) (Figure 3-7). Sulfates have remained stable over the past 10 years (slope = –0.42, p = 0.054); however, the trend for declining sulfate levels is very close to significant (Figure 3-8). Ammonium appears to have increased over the past 20 years, but for the past 10 years, the increase has not been significant (slope = 0.62, p = 0.14) (Figure 3-9). In 2007, nitrate, sulfate, and ammonium concentrations were 2.39, 1.03, and 0.68 kg/ha/year, respectively. Five-year averages from 2003 to 2007 were 2.76, 1.42, and 0.66 kg/ha for nitrate, sulfate, and ammonium, respectively. Total N was 1.55 kg/ha and total S was 0.50 kg/ha in 2007. Five-year averages from 2003 to 2007 were 1.32 kg/ha for N and 0.55 kg/ha for S.

Estimates for nitrogen and sulfur at BRCA were higher than natural background deposition levels (0.13 kg/ha for wet deposition) for the overall West. Based on the five-year averages, BRCA has sulfur levels in good condition, while nitrogen levels are in moderate condition (see Table 2-1).

From 1998 to 2007, BRCA had no significant trends for sulfate, nitrate, and ammonium concentrations, but ammonium concentrations were close to reaching significance for increasing (degrading) levels. There has been an increase in ammonium in central and northern Utah over the past 10 years, and there are significant concerns about the levels of nitrates and sulfates at BRCA. However, the park is currently meeting its 2008 GPRA goal for deposition due to stable trends.

3.3.3 Visibility

In 2007, the average light extinction for the 20% clearest days was 3.88 Mm^{-1} and, for the 20% haziest days, 28.98 Mm^{-1} for BRCA and CEBR. Light-extinction trends for 20% clearest days decreased (increasing air quality) significantly based on three-year running averages from 2003 to 2007 (slope = –0.13, p = 0.01), but showed no trend for the 20% haziest days (slope = 0.13, p = 0.19) (Figure 3-10).

Visibility impairment results largely from small particles in the atmosphere. Figure 3-11 shows the contributions made by different classes of particles toward haze. On days with best visibility (the bottom 20% of the distribution by deciview, or haze index), most haze was caused by sulfates, followed by organic mass by carbon (OMC) and nitrates. On the worst days (the top 20% of the distribution by deciview), OMC contributed most to haze, but sulfates and nitrates were still significant contributors. Most OMC comes from forest fires, which usually occur in the summer. As such, some seasonal patterns in haze composition were evident at BRCA in 2007 (Figure 3-12), with highest haze occurring in the summer months. Visibility was estimated to be 3.83 DV at BRCA and 3.95 for CEBR.

At present, visibility has been identified as the most sensitive AQRV in BRCA; other AQRVs may also be sensitive, but have not been sufficiently studied. Although visibility in the park is still superior to that in many parts of the country, it is estimated to be in moderate condition at BRCA and CEBR (see Table 2-3), as both parks are often impaired by light-scattering pollutants (haze) (NPS-ARD 2006b). Visibility on the clearest days has improved, and visibility on the haziest days has had no degrading trends. Therefore, BRCA and CEBR are currently meeting their GPRA goal for visibility in 2008.

3.4 Canyonlands National Park, Arches National Park, and Natural Bridges National Monument

Because the NPS-ARD has determined that particulate (visibility) monitors within 100 km (60 miles) may be reasonably considered representative of a park's air quality, visibility estimates recorded by the IMPROVE visibility monitor in CANY, located 35 km south of ARCH and 92 km north of NABR, may also be applied to those parks. **Deposition and ozone data, however, cannot be extrapolated to ARCH and NABR.**

3.4.1 Class I parks overview

Arches and Canyonlands national parks were designated Class I air quality areas in 1977, receiving the highest protection under the Clean Air Act. Both local and distant air-pollutant sources affect air quality in ARCH and CANY. Power plants in Emery, Uintah, and Carbon counties, Utah, and Mesa County, Colorado, are the largest nearby point sources of both SO_2 and NOx. Pollutants also travel greater distances to the parks from both mobile and point sources throughout the southwest (NPS-ARD 2006c).

Surface waters in ARCH and CANY are generally well-buffered because of adequate amounts of cations, such as calcium and magnesium; therefore, they are not likely to be acidified by atmospheric deposition. Most soils are also likely to be well-buffered from acidification. However, there may be areas in the park where rock is resistant to weathering, where cation concentrations are low, and soils and water (e.g., in potholes) may be sensitive to inputs of acidic deposition. There is concern that soils and vegetation in the park may be sensitive to nutrient enrichment from nitrogen deposition. Studies are underway in CANY to investigate nitrogen effects on soil dynamics, susceptibility to exotic plant invasion, and biological soil crusts (NPS-ARD 2006c).

3.4.2 Atmospheric deposition

3.4.2.1 Wet deposition

Concentrations of nitrate and sulfate showed no trends in CANY from 1998 to 2007 (nitrate: slope = –0.04, p = 0.54; sulfate: slope = –0.13, p = 0.24) (Figures 3-13, 3-14). However, ammonium increased significantly during that time period (slope = 0.60, p = 0.04) (Figure 3-15), when there was a noted increase in ammonium in central and northern Utah. In 2007, nitrate, sulfate, and ammonium concentrations were 2.66, 1.08, and 0.53 kg/ha/year, respectively. Five-year averages from 2003 to 2007 were 2.68, 1.38, and 0.62 kg/ha for nitrate, sulfate, and ammonium, respectively. Total N was 0.90 kg/ha and total S was 0.32 kg/ha in 2007. Five-year averages from 2003 to 2007 were 0.94 kg/ha for nitrogen and 0.44 for sulfur.

Estimates for nitrogen and sulfur in CANY were both higher than natural background deposition levels (0.13 kg/ha for wet deposition) for the overall West. Nitrogen and sulfur levels are in good condition at the park (see Table 2-1). However, it is disturbing that ammonium has seen increasing trends over the past 10 years. CANY is one of eight parks (of 50) shown to have increasing trends of ammonium from 1998 to 2007 (NPS-ARD in press). If ammonium levels continue to increase, total nitrogen deposition amounts will be affected. CANY is not currently meeting its 2008 GPRA goal for deposition due to increasing trends in ammonium wet deposition.

3.4.2.2 Dry deposition

CASTNet reports trends in dry and total deposition for Canyonlands National Park. Figure 3-16 summarizes wet and dry (total) nitrogen and sulfur deposition from 1995 to 2007 in CANY. The amount of total sulfur recorded in 2007 was the lowest level recorded for the past 13 years.

Figure 3-17 depicts the composition of nitrogen and sulfur deposition at CANY during 2005–2007. Figure 3-18 depicts overall contributions of wet and dry deposition from 1995–2007. Although these estimates suggest that wet deposition exceeded dry deposition, the CASTNet method may underestimate dry deposition. Nitrate and ammonium contributed almost equally in total nitrogen deposition at the site.

Table 3-1. Ozone concentrations (parts per billion-ppb) and exposure indices summaries for Canyonlands National Park, 2007.

Site code	Number of days with 8-hr average O_3 values at >85 ppb	1st-highest 8-hr concentrations	2nd-highest 1-hr concentrations	4th-highest 8-hr concentrations	SUM06 (ppm-hr)b	W126 (ppm-hr)c	N100 (#hr>100 pp)d
CANY-IS	0	74	74	72	33	27.9	0

(Ray 2008)

[a]The National Ambient Air Quality Standard for Ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum 8-hour average ozone concentration. In March 2008, the standard was lowered to 75 ppb.

[b]SUM06 exposure index represents the 0800-2000 hourly ozone concentrations ≥0.06 ppm. The value reported here represents a three-month maximum value during the ozone season. Units are ppm-hr.

[c]W126 exposure index represents the sum of all hourly ozone concentrations where each concentration is weighted by a function that gives greater emphasis to the higher hourly concentrations while still including the lower ones. Units are ppm-hr. For more information on the W126 exposure index go to http://www.nature.nps.gov/air/maps/airatlas/docs/air_quality_glossary.pdf.

[d]N100 represents the number of hourly ozone concentrations ≥ 0.100 ppm (ppb).

3.4.3 Ozone

Ozone summary data from continuous samplers at CANY are provided in Table 3-1. CANY had no days that exceeded the eight-hour average of 85 ppb in 2007, and no hourly concentrations of ozone that exceeded >0.100 ppm (Ray 2008). The fourth-highest eight-hour ozone concentration for CANY was 72 ppb in 2007. The three-year average (2005–2007) of the fourth-highest daily eight-hour ozone concentration was 70 ppb. Since data collection began in 1993, CANY has only had one year in which the fourth-highest average exceeded 75 ppb (2000; 76 ppb), and no three-year averages have exceeded the 75-ppb threshold.

However, the fourth-highest eight-hour average (Figure 3-19), the SUM06 for annual maximum three-month period (Figure 3-20), and cumulative sum W126 for annual maximum three-month period (Figure 3-21) all had increasing (degrading air quality) trends from 1993 to 2007. None of these measurements showed a strong linear trend, and when only the most recent 10-year period was examined, the fourth-highest eight-hour average (Figure 3-19), showed no significant trends (slope = –0.13, p = 0.24) (NPS-ARD in press).

Ozone levels at CANY (70 ppb) are rated in moderate condition (61–75 ppb; see Table 2-2). Because the NPS-ARD's ozone risk assessment for CANY concluded that vegetation in the park was considered at low risk from ozone injury (NPS 2004), there is no reason to lower the ratings for moderate and significant concern at CANY, which is currently meeting its 2008 GPRA goal for ozone.

3.4.4 Visibility

In 2007, the average light extinction for the 20% clearest days was 4.88 Mm^{-1} and, for the 20% haziest days, 23.95 Mm^{-1}. Light-extinction trends for 20% clearest days decreased significantly based on three-year averages from 1998 to 2007 (slope = –0.20, p = 0.005), but showed no trend for the 20% haziest days (slope = –0.08, p = 0.19) (Figure 3-22).

Visibility impairment results largely from small particles in the atmosphere. Figure 3-23 shows the contributions made by different classes of particles toward haze. On days with best visibility (the bottom 20% of the distribution by deciview, or haze index), most haze was caused by sulfates, followed by OMC and nitrates. On the worst days (the top 20% of the distribution by deciview), OMC contributed most to haze, but sulfates and nitrates were still significant contributors. Most OMC comes from forest fires, which usually occur in the summer (Figure 3-24). As such, some seasonal patterns were evident in haze composition at CANY in 2007. The highest haze composition levels occurred in July, followed by several high levels in winter. Visibility was estimated to be 3.69 DV for CANY, 3.61 for ARCH, and 3.93 for NABR.

At present, visibility has been identified as the most sensitive AQRV in ARCH and CANY; other AQRVs may also be sensitive, but have not been sufficiently studied. Although visibility in southeast Utah is still superior to that in many parts of the country on clear days, visibility is rated as moderate at ARCH, CANY, and NABR (see Table 2-3), and is often impaired by light-scattering pollutants (haze) (NPS-ARD 2006c). Visibility on the clearest days has improved at CANY and has shown no trends on the haziest days. Therefore, ARCH, CANY, and NABR are currently meeting their 2008 GPRA goal for visibility.

3.5 Capitol Reef National Park

3.5.1 Class I park overview

Capitol Reef National Park was designated a Class I air quality area in 1977, receiving the highest protection under the Clean Air Act. Both local and distant air pollutant sources affect air quality in CARE. Nearby large point sources include power plants, refineries, and lime kilns in Coconino County, Arizona, and Clark County, Nevada. Pollutants also travel greater distances to the park from both mobile and point sources throughout the southwest (NPS-ARD 2006d).

The AQRVs of CARE are those resources that are potentially sensitive to air pollution, including vegetation, wildlife, water quality, soils, and visibility. At present, visibility has been identified as the most sensitive AQRV in the park; other AQRVs may also be sensitive, but have not been sufficiently studied. Although visibility in the park is still superior to that in many parts of the country, it is only rated as being in moderate condition, and visibility in the park is often impaired by light-scattering pollutants (haze) (NPS-ARD 2006d).

While there are no deposition sites in CARE, surface waters are well-buffered because of adequate amounts of cations, such as calcium and magnesium and, therefore, not likely to be acidified by atmospheric deposition. Most soils are also likely to be well-buffered from acidification. However, there may be areas in the park where rock is resistant to weathering, cation concentrations are low, and soils and water (e.g., in potholes) may be sensitive to inputs of acidic deposition.

A special study of rock pools was conducted at three locations in the park: Cottonwood Tanks, Muley Tanks, and Fountain Tanks. Although the small potholes may be insensitive to acidic deposition, they may experience nutrient enrichment from nitrogen deposition, resulting in algae blooms and oxygen depletion. All had very high acid-neutralizing capacity (500–1230 microequivalents per liter). Soils and vegetation in the park may be sensitive to nutrient enrichment from nitrogen deposition (NPS-ARD 2006d).

3.5.2 Visibility

For CARE, the average light extinction for the 20% clearest days was 4.83 Mm^{-1} and, for the 20% haziest days, 25.77 Mm^{-1} in 2007. Light-extinction trends from the CARE site cannot be determined due to the limited amount of data (Figure 3-25). However, the site at CANY is close enough to examine trends. Based on the CANY site, light-extinction trends for 20% clearest days decreased significantly based on three-year averages from 1998 to 2007 (slope = –0.13, p = 0.008), but showed no trend for the 20% haziest days (slope = 0.13, p = 0.19).

Visibility impairment results largely from small particles in the atmosphere. Figure 3-26 shows the contributions made by different classes of particles toward haze. On the 20% clearest days (the bottom 20% of the distribution by deciview,

Table 3-2. Ozone concentrations (parts per billion-ppb) and exposure indices summaries for Colorado National Monument.

Site code	Year	Number of days with 8-hr average O_3 values at >85 ppb	1st-highest 8-hr concentrations	2nd-highest 1-hr concentrations	4th-highest 8-hr concentrations	SUM06 (ppm-hr)b	W126 (ppm-hr)c	N100 (#hr>100 pp)d
COLM-MY	2007	0	67	67	67	9.2	9.1	0
	2006	0	78	76	73	48.3	43.8	0

(Ray 2008)

[a]The National Ambient Air Quality Standard for Ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum 8-hour average ozone concentration. In March 2008, the standard was lowered to 75 ppb.

[b]SUM06 exposure index represents the 0800-2000 hourly ozone concentrations ≥0.06 ppm. The value reported here represents a three-month maximum value during the ozone season. Units are ppm-hr.

[c]W126 exposure index represents the sum of all hourly ozone concentrations where each concentration is weighted by a function that gives greater emphasis to the higher hourly concentrations while still including the lower ones. Units are ppm-hr. For more information on the W126 exposure index go to http://www.nature.nps.gov/air/maps/airatlas/docs/air_quality_glossary.pdf.

[d]N100 represents the number of hourly ozone concentrations ≥ 0.100 ppm (ppb).

Table 3-3. Ozone concentrations (parts per billion-ppb) and exposure indices summaries for Dinosaur National Monument.

Site code	Year	Number of days with 8-hr average O_3 values at >85 ppb	1st-highest 8-hr concentrations	2nd-highest 1-hr concentrations	4th-highest 8-hr concentrations	SUM06 (ppm-hr)b	W126 (ppm-hr)c	N100 (#hr>100 pp)d
DINO-WE	2007	0	68	64	63	7.4	12.2	0
	2006	0	69	69	68	19.4	28.1	0
	2005	0	73	72	67	11.5	18.2	0

(Ray 2008)

[a]The National Ambient Air Quality Standard for Ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum 8-hour average ozone concentration. In March 2008, the standard was lowered to 75 ppb.

[b]SUM06 exposure index represents the 0800-2000 hourly ozone concentrations ≥0.06 ppm. The value reported here represents a three-month maximum value during the ozone season. Units are ppm-hr.

[c]W126 exposure index represents the sum of all hourly ozone concentrations where each concentration is weighted by a function that gives greater emphasis to the higher hourly concentrations while still including the lower ones. Units are ppm-hr. For more information on the W126 exposure index go to http://www.nature.nps.gov/air/maps/airatlas/docs/air_quality_glossary.pdf.

[d]N100 represents the number of hourly ozone concentrations ≥ 0.100 ppm (ppb).

or haze index), ammonium sulfate was the largest contributor to visibility impairment. On the 20% haziest days (the top 20% of the distribution by deciview), organic particles were the largest contributors to haze. This was likely a result of fire, which is often the source of organic particles in the West.

Some seasonal patterns were evident in haze composition at CARE in 2007 (Figure 3-27). The highest haze composition levels occurred in July, followed by several high levels in winter. Visibility for CARE was estimated to be 3.72. This level is deemed in moderate condition (see Table 2-3). Based on the interpolated data from the CANY site, visibility on the clearest days has improved and has shown no trends on the haziest days. Therefore, CARE is currently meeting its 2008 GPRA goal for visibility.

3.6 Colorado National Monument

3.6.1 Ozone

Ozone has been monitored in Colorado National Monument using POMS units since 2006; summary data are provided in Table 3-2. The fourth-highest eight-hour concentrations for 2007 and 2006 were 67 and 73, respectively. Both of these concentrations, and a two-year average of 70, are below the ozone standard threshold of 75 ppb for a three-year average of the fourth-highest eight-hour concentration. Ozone levels at COLM are rated in moderate condition (61–75 ppb; see Table 2-2). Because the NPS-ARD's ozone risk assessment for COLM concluded that vegetation in the park was considered at low risk from ozone injury (NPS 2004), there is no reason to lower the ratings for moderate and significant concern at COLM. No trends should be estimated until at least five years of data have been collected. Due to the limited data, it cannot be determined whether COLM is meeting its 2008 GPRA goal for ozone.

3.7 Dinosaur National Monument

3.7.1 Ozone

Ozone has been monitored in Dinosaur National Monument using POMS units since 2005; summary data are provided in Table 3-3. The fourth-highest eight-hour concentrations for 2007, 2006, and 2005 were 63, 68, and 67, respectively. All of these concentrations, and the three-year average of the fourth-highest eight-hour concentration (66), are below the ozone standard threshold of 75 ppb. Ozone levels at DINO are rated in moderate condition (61–75 ppb; see Table 2-2). Because the NPS-ARD's ozone risk assessment for DINO concluded that vegetation in the park was considered at low risk from ozone injury (NPS 2004), there is no reason to lower the ratings for moderate and significant concern at DINO. No trends should be estimated until at least five years of data have been collected. Due to the limited data, it cannot be determined whether DINO is meeting its 2008 GPRA goal for ozone.

3.8 Timpanogos Cave National Monument

3.8.1 Ozone

Ozone has been monitored near TICA (EPA site# 490495008442011) since 1998; summary data are provided in Table 3-4. The fourth-highest eight-hour concentrations for 2007, 2006, and 2005 were 78, 77, and 80, respectively. The current three-year average of 78.3 is above the ozone standard threshold of 75 ppb. Ozone levels at TICA are rated in a condition of significant concern (>75 ppb; see Table 2-2). However, based on data from 2000–2007, the fourth-highest eight-hour average showed a significant decline (improving air quality) (slope = –1.00, p = 0.002). Therefore, TICA is currently meeting its 2008 GPRA goal for ozone. Because the NPS-ARD's ozone risk assessment for TICA concluded that vegetation in the park was considered at low risk from ozone injury (NPS 2004), there is no reason to lower the ratings for moderate and significant concern at TICA.

Conditions favoring the uptake of ozone can occur under any levels of exposure and soil moisture. However, the probability of foliar injury developing may be greatest during years when (1) ozone exposure exceeds the thresholds and (2) soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. If ozone levels continue to be a concern at TICA, a program to assess the presence of ozone injury there could employ spreading dogbane (*Apocynum androsaemifolium*) (NPS 2004).

3.9 Zion National Park

3.9.1 Class I park overview

Zion National Park was designated a Class I air quality area in 1977, receiving the highest protection under the Clean Air Act. Both local and distant air pollutant sources affect air quality in Zion NP. Nearby large point sources include power plants, refineries, and lime kilns in Coconino County, Arizona, and Clark County, Nevada. Pollutants also travel greater distances to the park from both mobile and point sources throughout the southwest (NPS-ARD 2006e).

The AQRVs of Zion NP are those resources that are potentially sensitive to air pollution, including vegetation, wildlife, water quality, soils, visibility, and night skies. At present, visibility has been identified as the most sensitive AQRV in the park; other AQRVs may also be sensitive, but have not been sufficiently studied. Although visibility in the park is still superior to that in many parts of the country, it is only rated as being in moderate

Table 3-4. Ozone concentrations (parts per billion-ppb) and exposure indices summaries for Timpanogos Cave National Monument.

Site code	Year	Number of days with 8-hr average O_3 values at >85 ppb	1st-highest 8-hr concentrations	2nd-highest 1-hr concentrations	4th-highest 8-hr concentrations	N100 (#hr>100 pp)d
490495008442011	2007	6	85	81	78	2
	2006	5	81	78	77	2
	2005	7	95	88	80	8
	2004	0	72	68	68	0
	2003	9	103	81	79	5
	2002	11	85	83	82	7
	2001	5	77	77	76	0
	2000	4	78	77	86	4
	1999	8	85	84	83	3
	1998	21	95	93	90	16

(Ray 2008)

[a]The National Ambient Air Quality Standard for Ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum 8-hour average ozone concentration. In March 2008, the standard was lowered to 75 ppb.

[d]N100 represents the number of hourly ozone concentrations ≥ 0.100 ppm (ppb).

condition, and visibility in the park is often impaired by light-scattering pollutants (haze).

Surface waters in Zion NP are expected to be generally well-buffered because of adequate amounts of cations, such as calcium and magnesium and, therefore, not likely to be acidified by atmospheric deposition. Most soils are also likely to be well-buffered from acidification. However, there may be areas in the park where rock is resistant to weathering, where cation concentrations are low, and soils and water (e.g., in small ponds and potholes) may be sensitive to inputs of acidic deposition. Soils and vegetation in the park may also be sensitive to nutrient enrichment from nitrogen deposition (NPS-ARD 2006e).

3.9.2 Ozone

Ozone has been monitored in ZION since 2004; summary data are provided in Table 3-5. The fourth-highest eight-hour concentrations for 2007, 2006, 2005, and 2004 were 71, 75, 91, and 74, respectively. The current three-year average of 79 is above the ozone standard threshold of 75 ppb. Ozone levels at ZION are rated in a condition of significant concern (>75 ppb; see Table 2-2). Because the NPS-ARD's ozone risk assessment for ZION concluded that vegetation in the park was considered at low risk from ozone injury (NPS 2004), there is no reason to lower the ratings for moderate and significant concern at ZION. No trends should be estimated until at least five years of data have been collected. Due to the limited data, it cannot be determined if ZION is meeting its GPRA goal, but there is reason to be concerned because the NAAQS standard was exceeded in two of the four years of data.

Table 3-5. Ozone concentrations (parts per billion-ppb) and exposure indices summaries for Zion National Park.

Site code	Year	Number of days with 8-hr average O_3 values at >85 ppb	1st-highest 8-hr concentrations	2nd-highest 1-hr concentrations	4th-highest 8-hr concentrations	SUM06 (ppm-hr)b	W126 (ppm-hr)c	N100 (#hr>100 pp)d
ZION-DW	2007	0	77	77	71	34.9	24.5	0
	2006	2	138	137	75	49.5	51.6	4
	2005	4	109	100	91	43.0	50.2	12
	2004	0	80	78	74	41.1	48.2	0

(Ray 2008)

[a]The National Ambient Air Quality Standard for Ozone was 85 ppb until March 2008, based on the three-year average of the fourth-highest daily maximum 8-hour average ozone concentration. In March 2008, the standard was lowered to 75 ppb.

[b]SUM06 exposure index represents the 0800-2000 hourly ozone concentrations ≥0.06 ppm. The value reported here represents a three-month maximum value during the ozone season. Units are ppm-hr.

[c]W126 exposure index represents the sum of all hourly ozone concentrations where each concentration is weighted by a function that gives greater emphasis to the higher hourly concentrations while still including the lower ones. Units are ppm-hr. For more information on the W126 exposure index go to http://www.nature.nps.gov/air/maps/airatlas/docs/air_quality_glossary.pdf.

[d]N100 represents the number of hourly ozone concentrations ≥ 0.100 ppm (ppb).

3.9.3 Visibility

For ZION, the average light extinction for the 20% clearest days was 6.46 Mm^{-1} and, for the 20% haziest days, 28.11 Mm^{-1} in 2007. Light-extinction trends from the ZION site cannot be determined due to the limited amount of data (Figure 3-28). However, the site at BRCA is close enough to examine trends. Based on the BRCA site, light-extinction trends for 20% clearest days decreased significantly based on three-year averages from 1998 to 2007 (slope = –0.13, p = 0.008), but showed no trend for the 20% haziest days (slope = 0.13, p = 0.19).

Visibility impairment results largely from small particles in the atmosphere. Figure 3-29 shows the contributions made by different classes of particles toward haze. On days with best visibility (the bottom 20% of the distribution by deciview, or haze index), most haze was caused by sulfates, followed by OMC and nitrates. On the worst days (the top 20% of the distribution by deciview), OMC contributed most to haze, but sulfates and nitrates were still significant contributors. Most OMC comes from forest fires, which usually occur in the summer. As such, some seasonal patterns were evident in haze composition at ZION in 2007 (Figure 3-30). The largest cluster of high levels of haze composition occurred in the spring and summer months. Visibility for ZION is estimated to be 4.09. This level is deemed in moderate condition (see Table 2-3). Due to the increasing quality of visibility on clear days and no significant trends on the haziest days, ZION is meeting its 2008 GPRA goal for visibility.

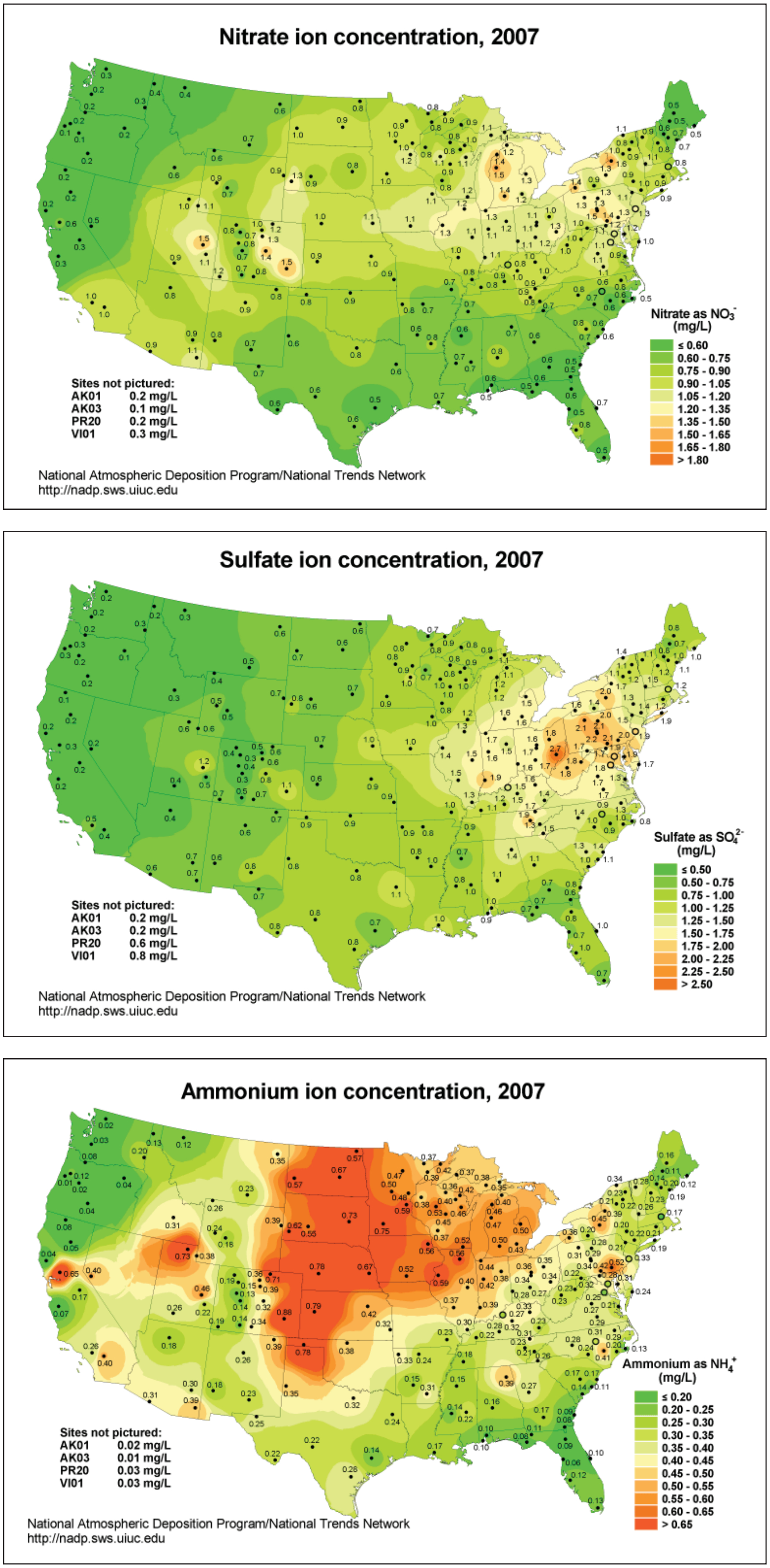
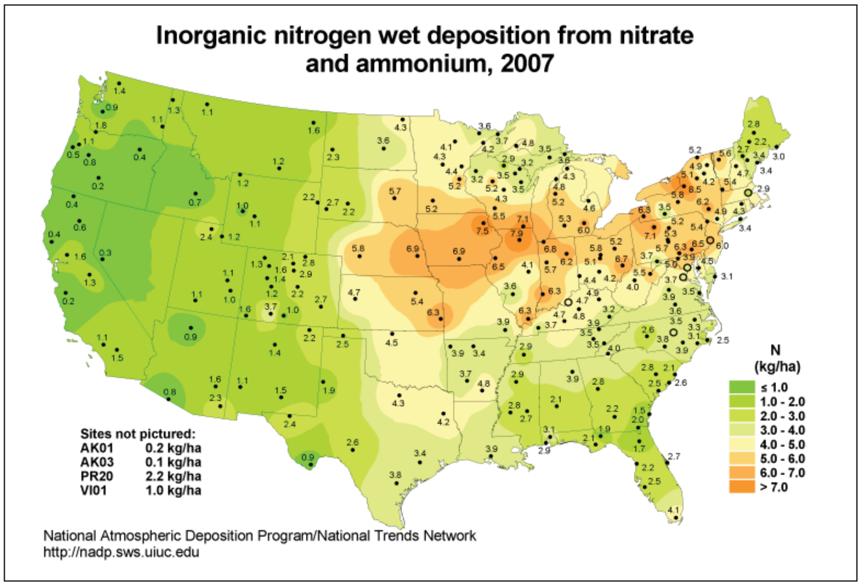


Figure 3-1. Spatial distribution of nitrate, sulfate, and ammonium concentrations for 2007 (http://nadp.sws.uiuc.edu/).

Regional trends



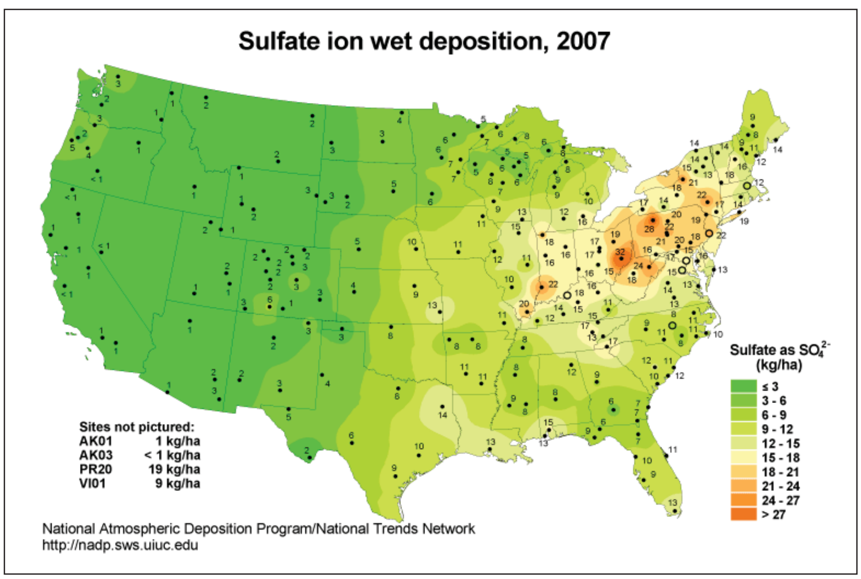


Figure 3-2. Spatial distribution of nitrogen and sulfate depositions for 2007 (http://nadp.sws.uiuc.edu/).

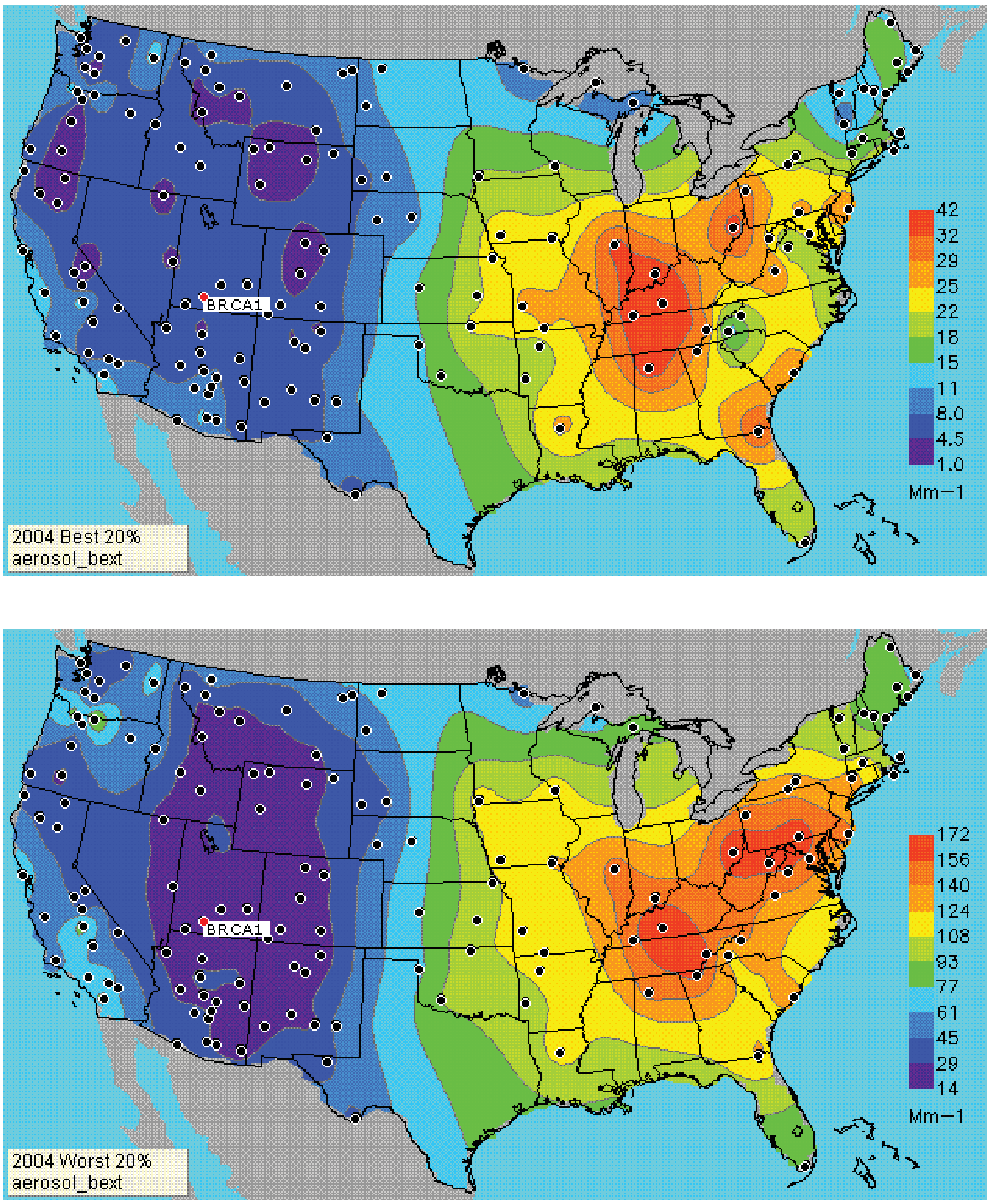


Figure 3-3. Spatial distribution of light extinction on the 20% best (clearest) days (above) and the 20% worst (haziest) days (below) in the U.S., 2004. Location of Bryce Canyon National Park is noted on the map.

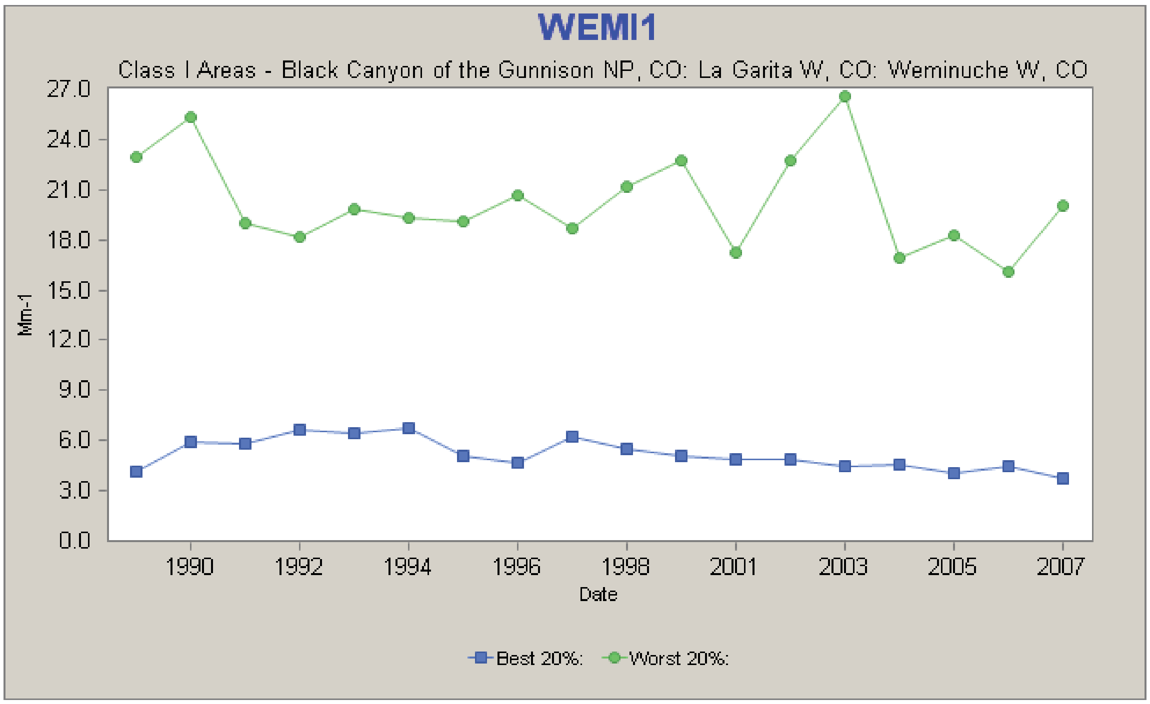


Figure 3-4. Trends in aerosol light extinction on the 20% best (clearest) days and 20% worst (haziest) days at the Weminuche Wilderness Area, San Juan National Forest, used to represent conditions at Black Canyon of the Gunnison National Park and Curecanti National Recreation Area.

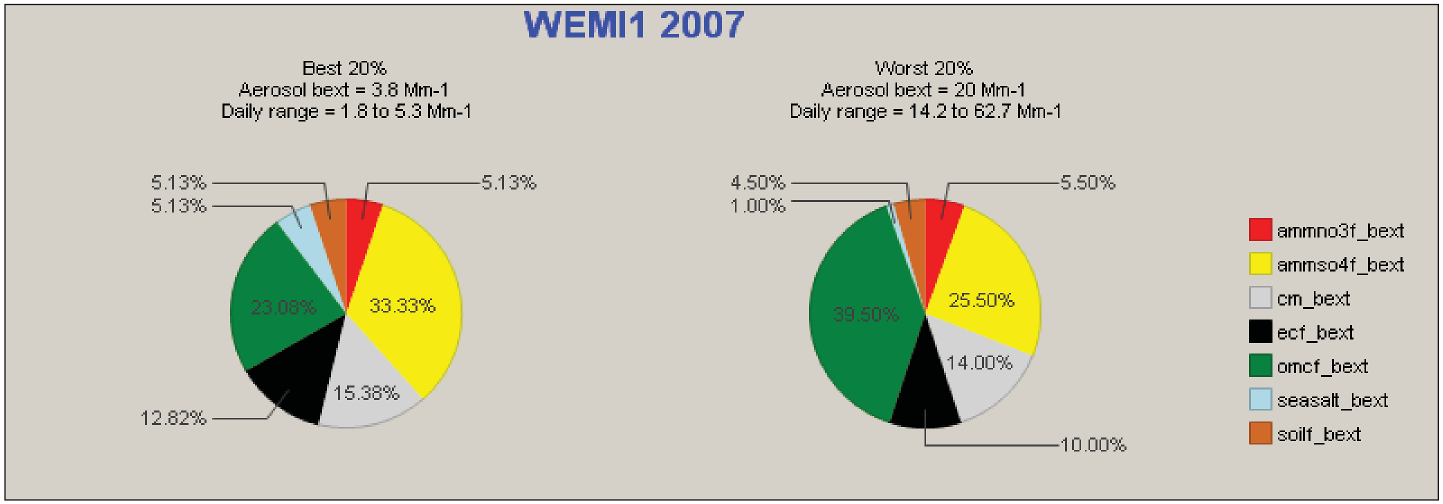


Figure 3-5. Composition of fine particles at the Weminuche Wilderness Area, San Juan National Forest, in 2007, used to represent conditions at Black Canyon of the Gunnison National Park and Curecanti National Recreation Area.

Legends refer to B extinction rates related to the following: ammno3f_bext = ammonium nitrate; ammso4f_bext = ammonium sulfate; cm_bext = coarse mass (particles 2.5–10 microns in size); ecf_bext = particles <2/5 microns in size (soot, black carbon); omncf = fine organic mass from carbon; sea salt_bext = sea salt; and soilf_bext = fine soil.

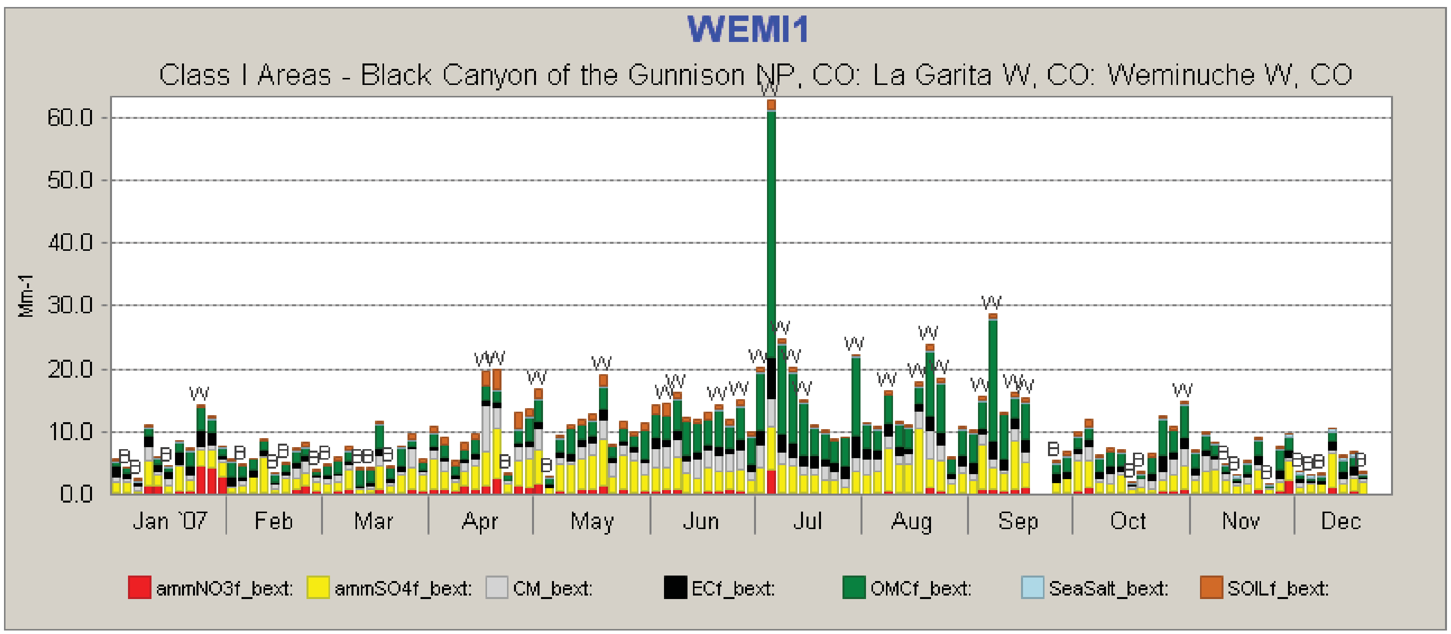


Figure 3-6. Seasonal patterns in haze composition at the Weminuche Wilderness Area, San Juan National Forest, in 2007, used to represent conditions at Black Canyon of the Gunnison National Park and Curecanti National Recreation Area.

BRCA

Figure 3-7. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of nitrate in wet deposition at Bryce Canyon National Park, 1985–2007.

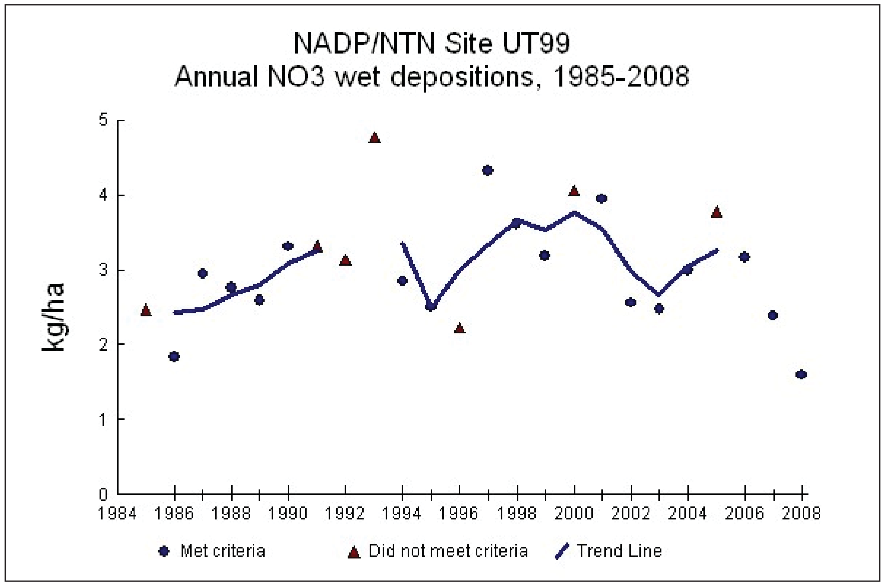


Figure 3-8. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of sulfate in wet deposition at Bryce Canyon National Park, 1985–2007.

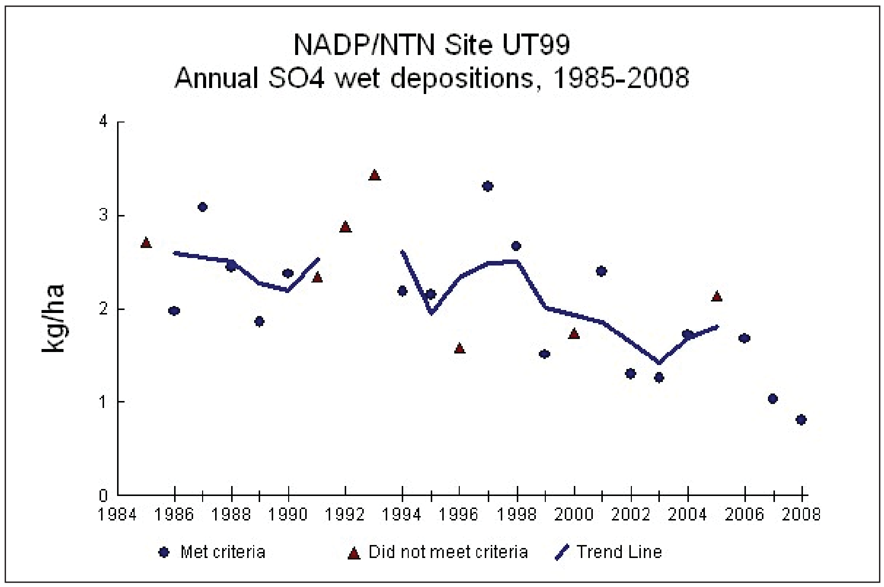
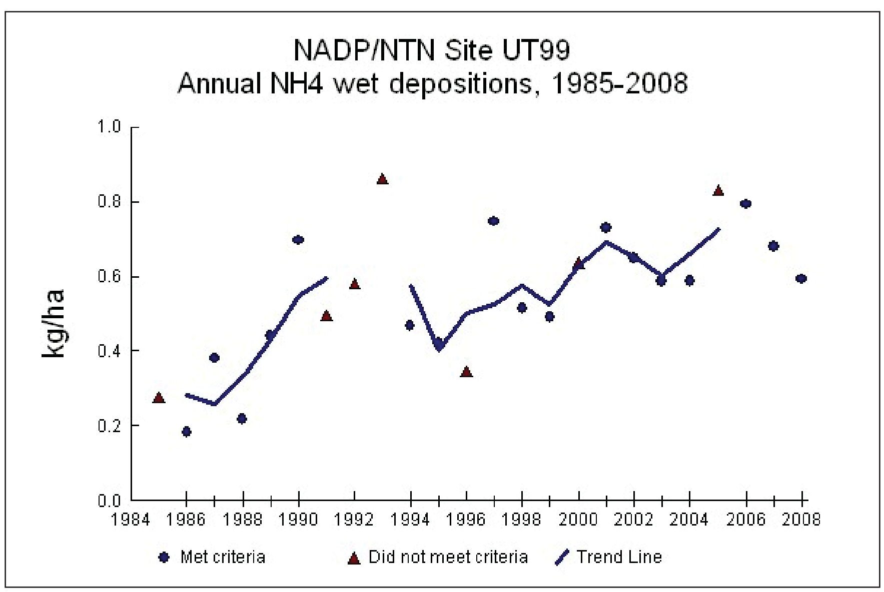


Figure 3-9. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of ammonium in wet deposition at Bryce Canyon National Park, 1985–2007.



Note: Figures from http://nadp.sws.uiuc.edu. "Met/Did not meet criteria" refers to data-completeness criteria in each year.

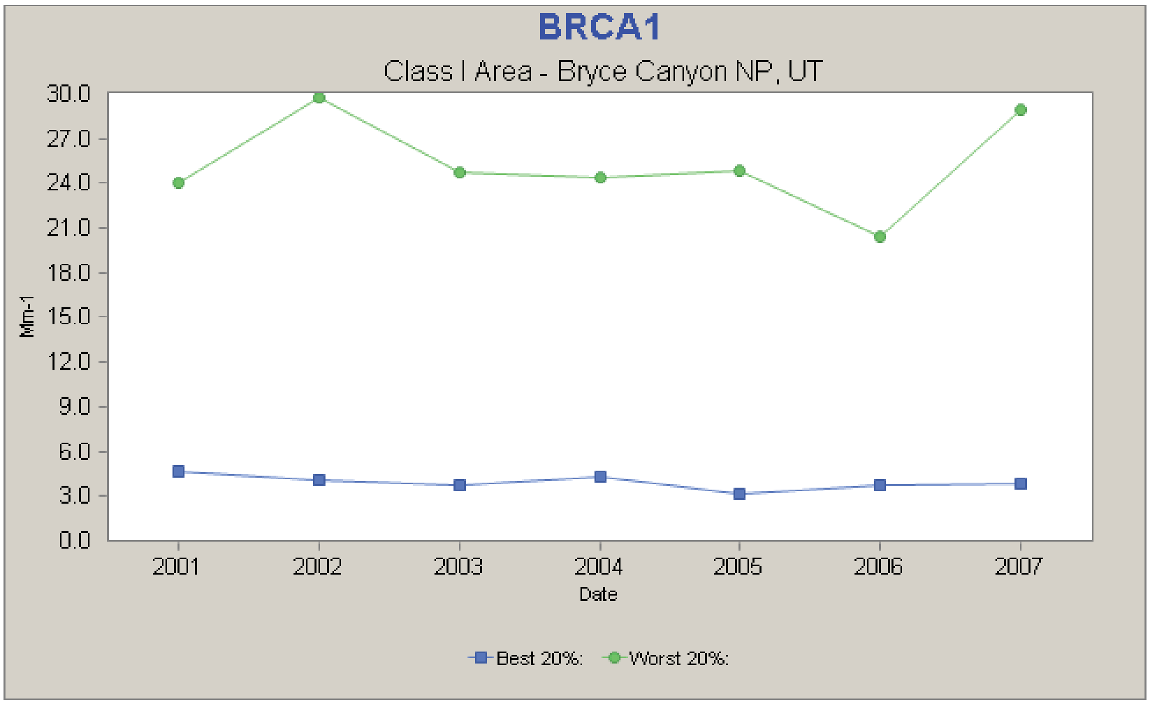


Figure 3-10. Trends in aerosol light extinction on the 20% best (clearest) days and 20% worst (haziest) days at Bryce Canyon National Park.

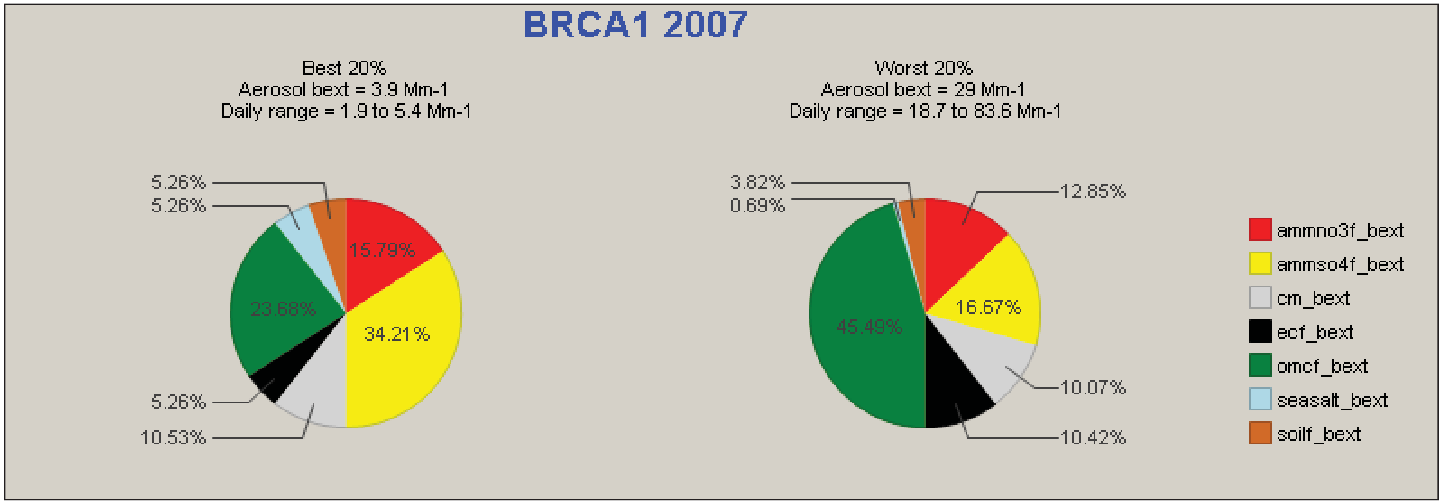


Figure 3-11. Composition of fine particles at Bryce Canyon National Park, 2007.

Legends refer to B extinction rates related to the following: ammno3f_bext = ammonium nitrate; ammso4f_bext = ammonium sulfate; cm_bext = coarse mass (particles 2.5–10 microns in size); ecf_bext = particles <2/5 microns in size (soot, black carbon); omncf = fine organic mass from carbon; sea salt_bext = sea salt; and soilf_bext = fine soil.

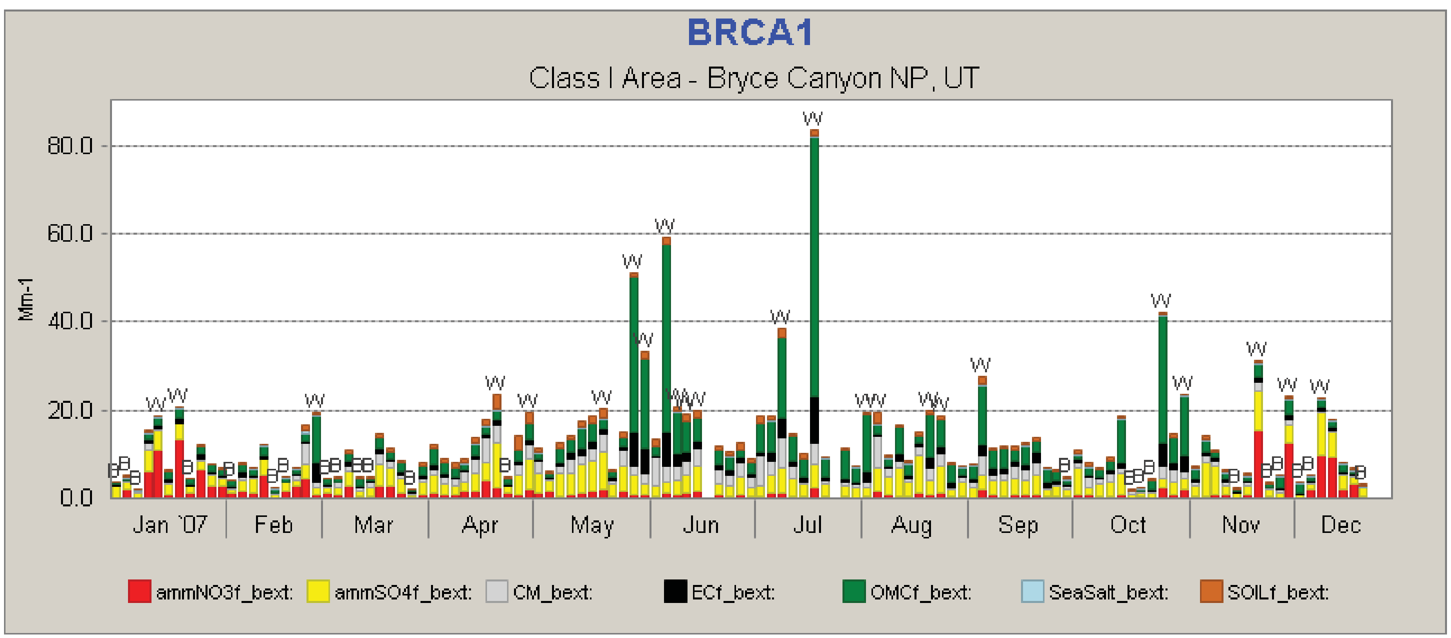


Figure 3-12. Seasonal patterns in haze composition at Bryce Canyon National Park, 2007.

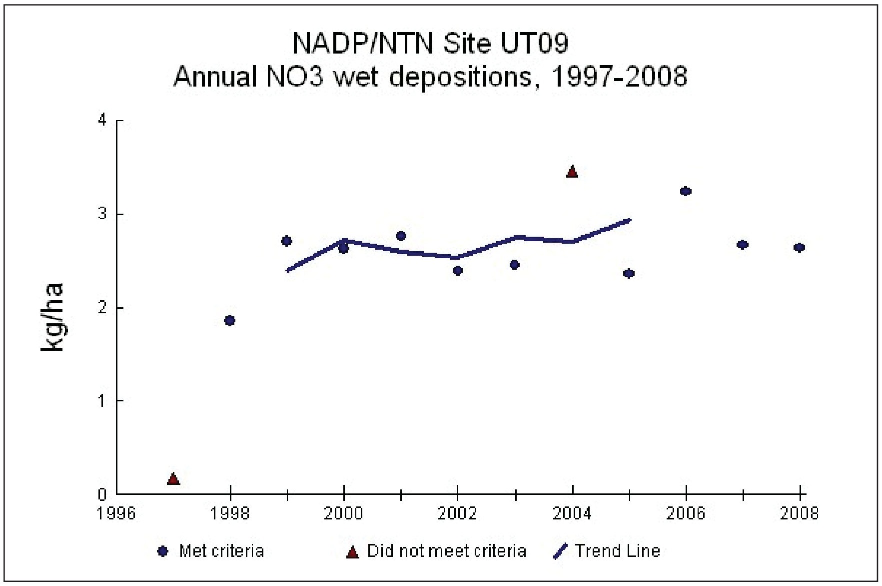


Figure 3-13. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of nitrate in wet deposition at Canyonlands National Park, 1997–2007.

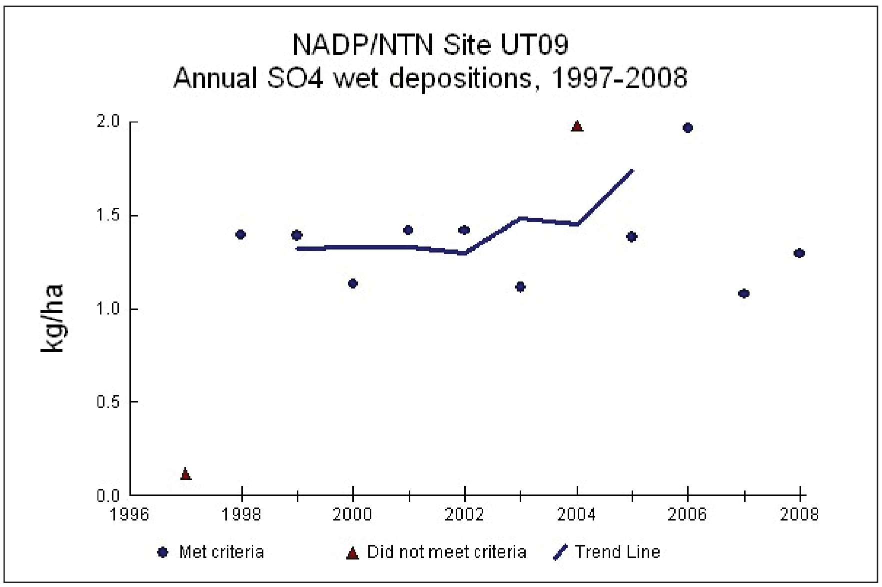


Figure 3-14. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of sulfate in wet deposition at Canyonlands National Park, 1997–2007.

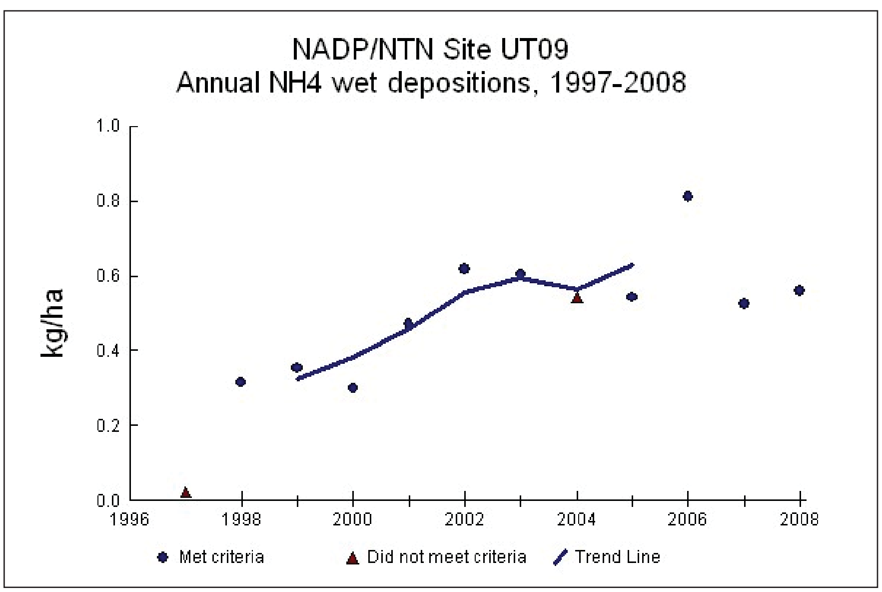
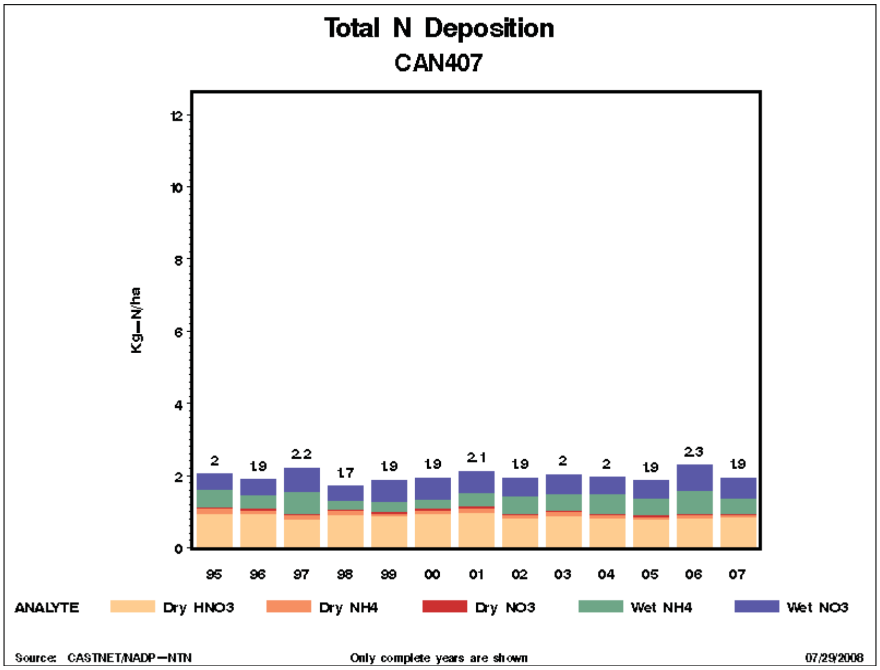


Figure 3-15. Trend lines (composed of a three-year, centered, weighted, moving-average value) for concentrations of ammonium in wet deposition at Canyonlands National Park, 1997–2007.

Note: Figures from http://nadp.sws.uiuc.edu. "Met/Did not meet criteria" refers to data-completeness criteria in each year.



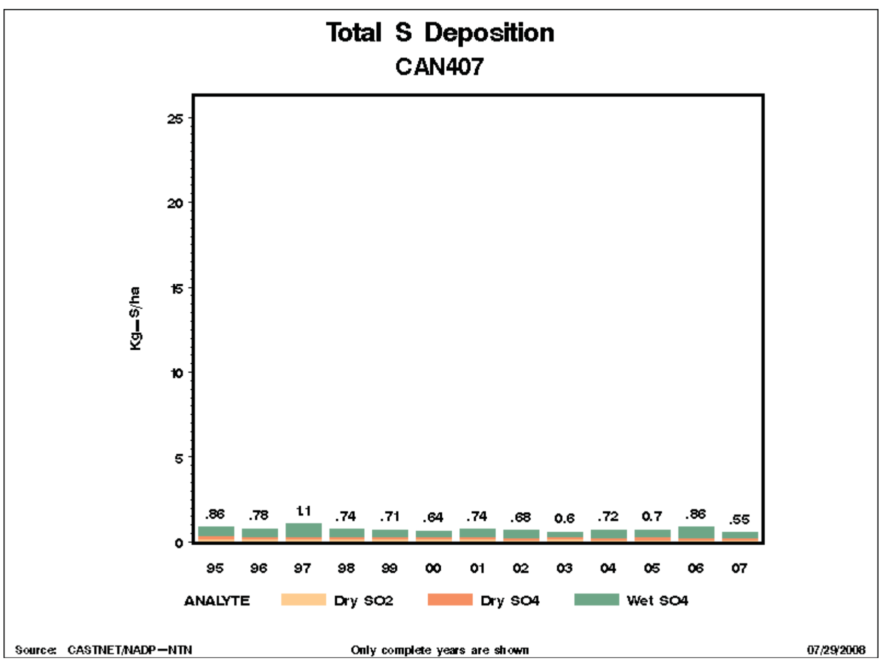


Figure 3-16. Trends in total nitrogen and sulfur deposition at Canyonlands National Park, 1995–2007 (CASTNET 2009).

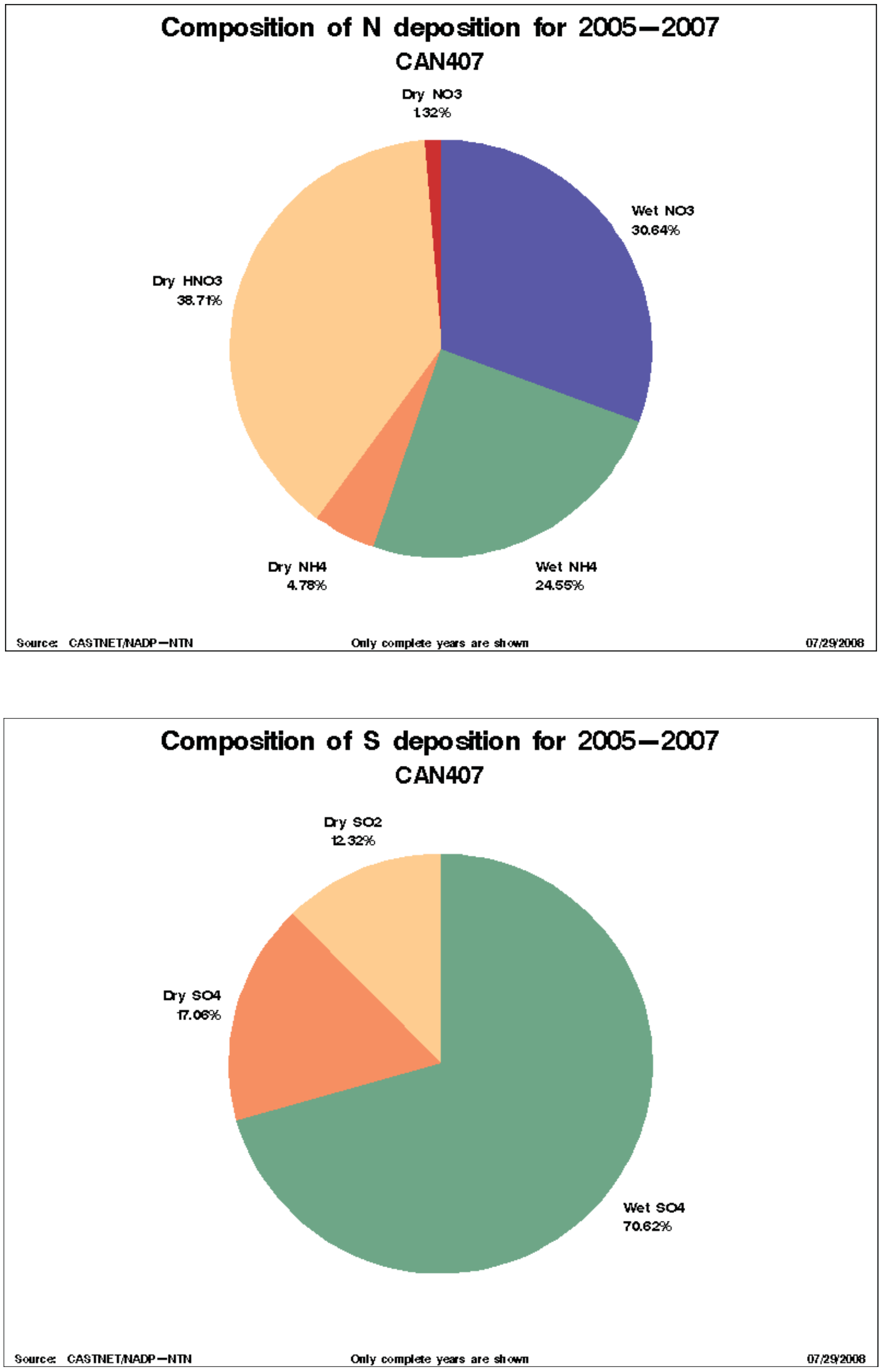
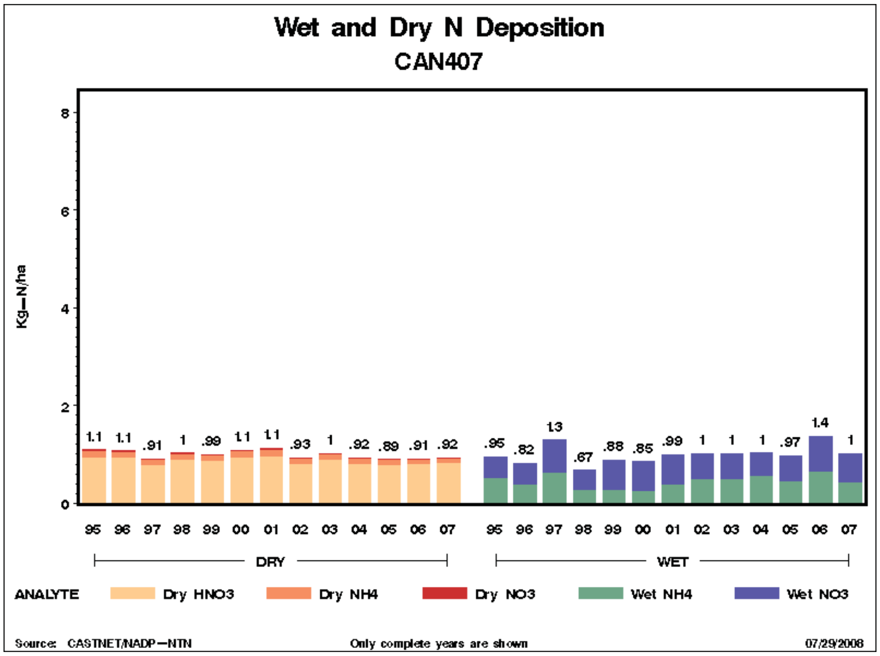


Figure 3-17. Contributions of wet and dry chemical species in total deposition at Canyonlands National Park, 2005-2007 (CASTNET 2009).

CANY



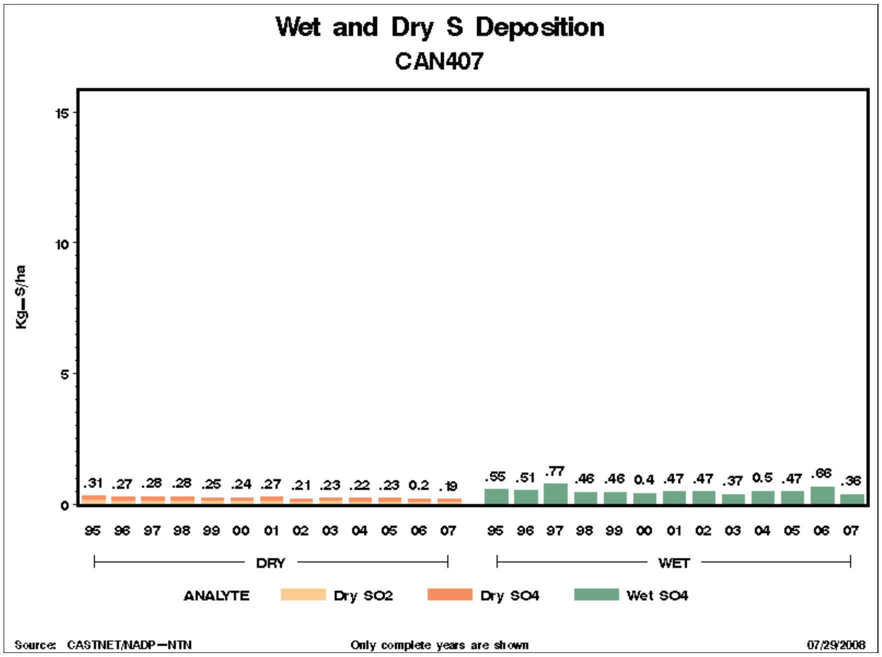


Figure 3-18. Wet and dry deposition of nitrogen and sulfur at Canyonlands National Park, 1995–2007 (CASTNET 2009).

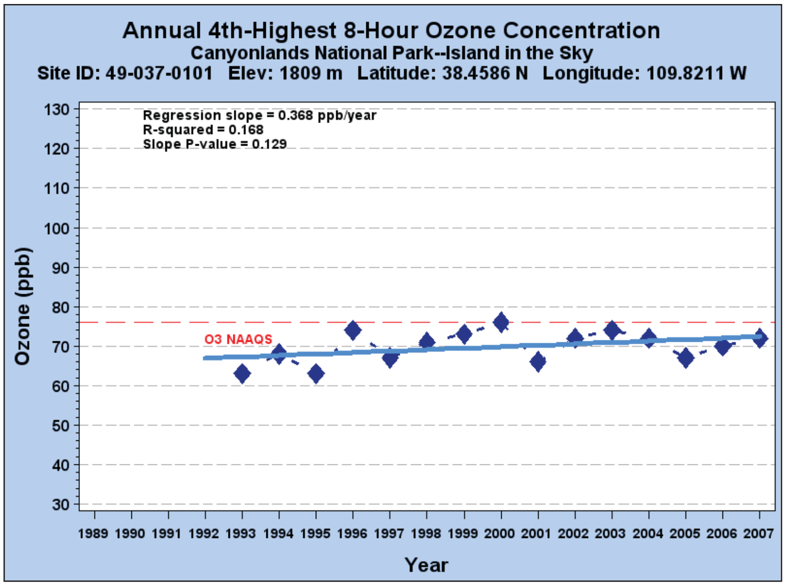


Figure 3-19. Fifteen-year trend, annual fourth-highest daily maximum eight-hour ozone concentration, Canyonlands National Park.

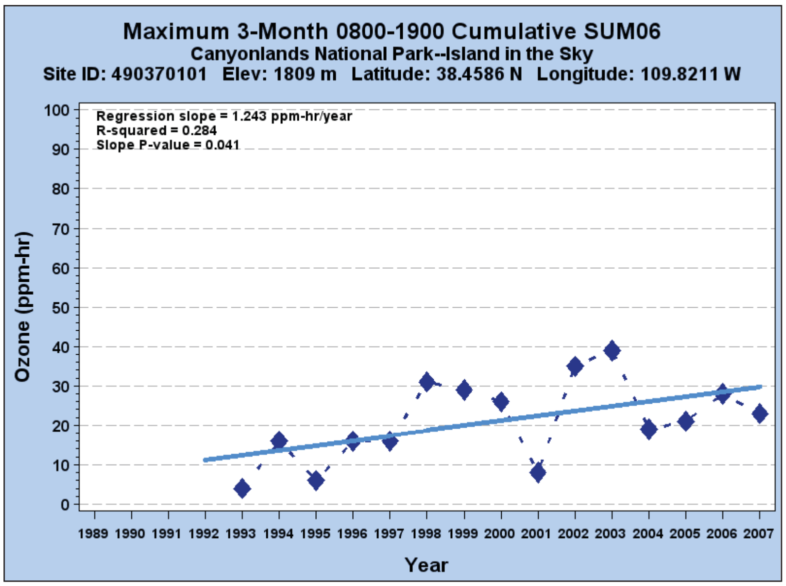


Figure 3-20. Fifteen-year trend, SUM06 for annual maximum three-month period, daytime hours, Canyonlands National Park.

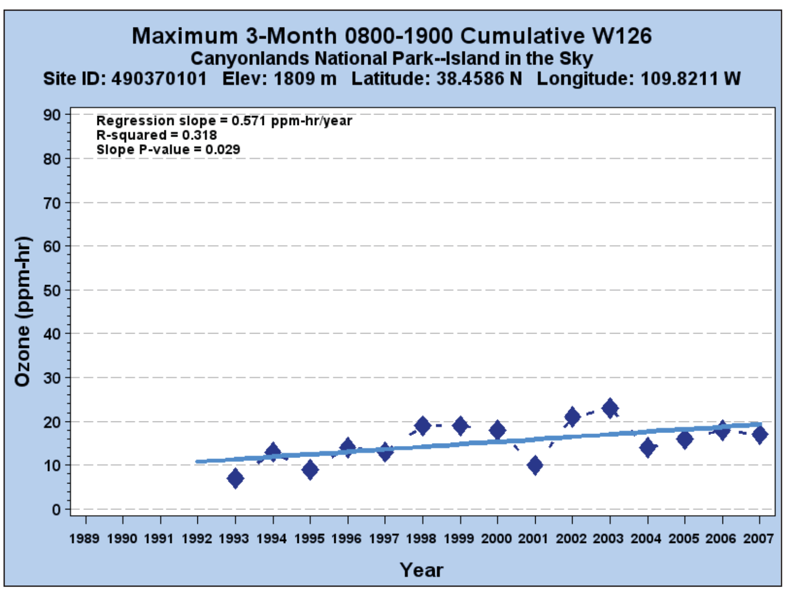


Figure 3-21. Fifteen-year trend, cumulative sum W126 for annual maximum three-month period, daytime hours, Canyonlands National Park.

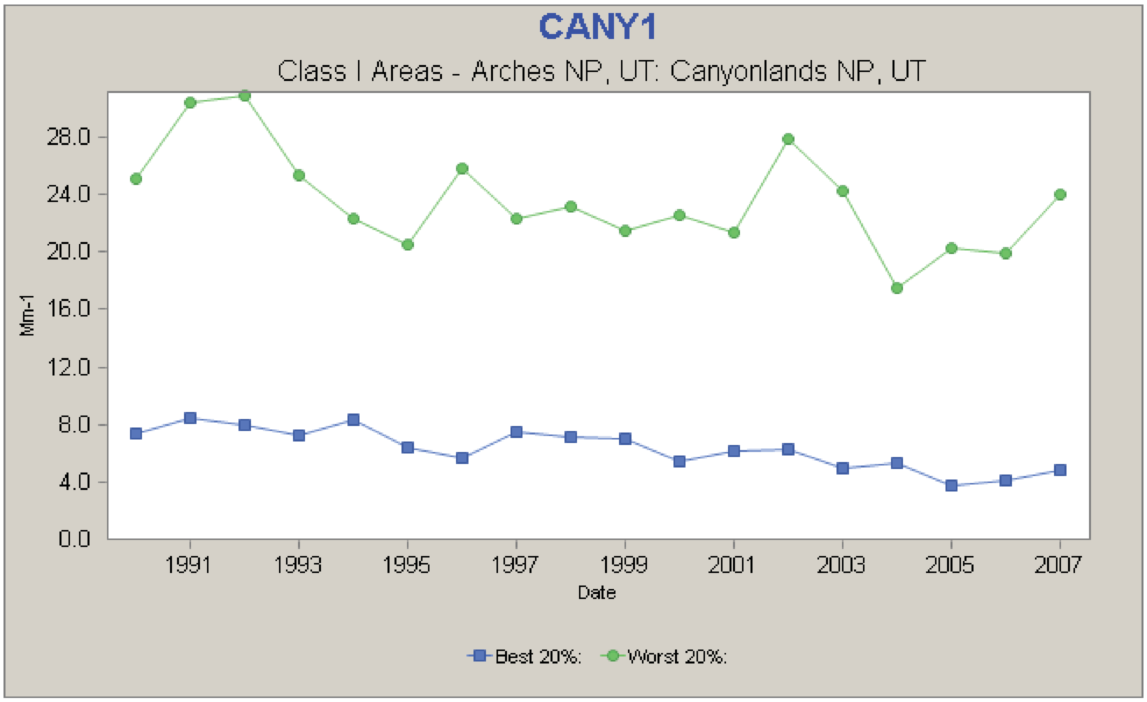


Figure 3-22. Trends in aerosol light extinction on the 20% best (clearest) days and 20% worst (haziest) days at Canyonlands National Park (VIEWS 2009).

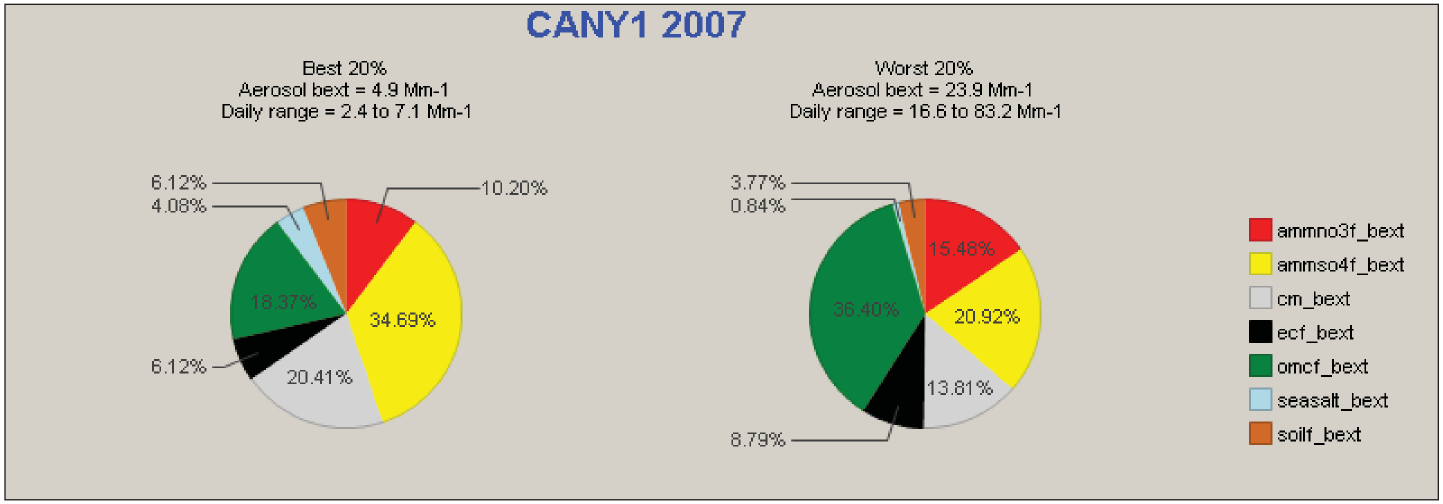


Figure 3-23. Composition of fine particles in Canyonlands National Park, 2007 (VIEWS 2009).

Legends refer to B extinction rates related to the following: ammno3f_bext = ammonium nitrate; ammso4f_bext = ammonium sulfate; cm_bext = coarse mass (particles 2.5–10 microns in size); ecf_bext = particles <2/5 microns in size (soot, black carbon); omncf = fine organic mass from carbon; sea salt_bext = sea salt; and soilf_bext = fine soil.

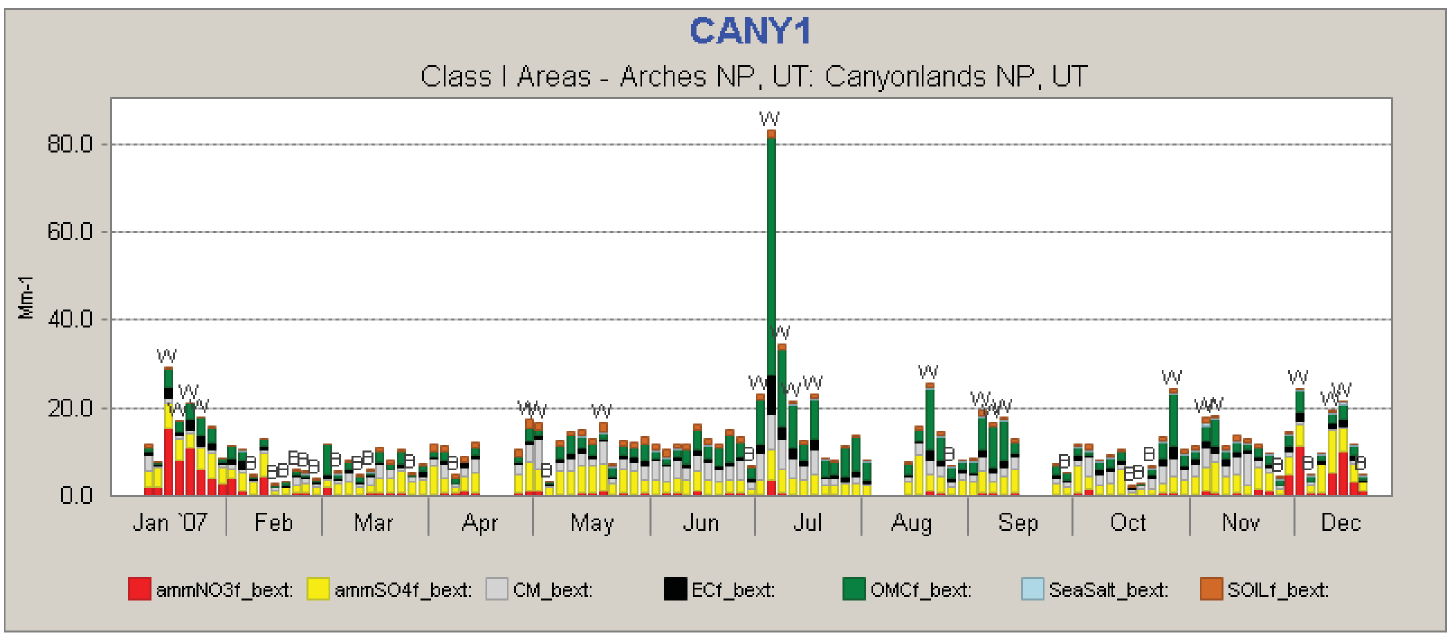


Figure 3-24. Seasonal patterns in haze composition at Canyonlands National Park, 2007 (VIEWS 2009).

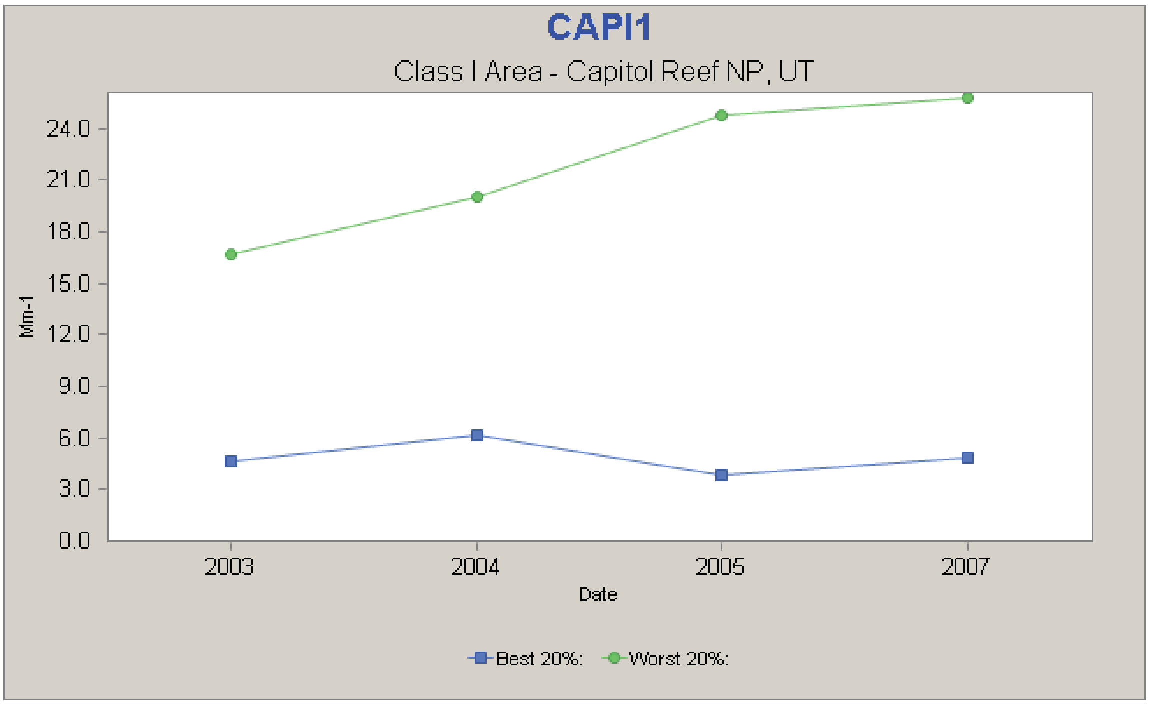


Figure 3-25. Trends in aerosol light extinction in the 20% clearest days and the 20% haziest days at Capitol Reef National Park (VIEWS 2009).

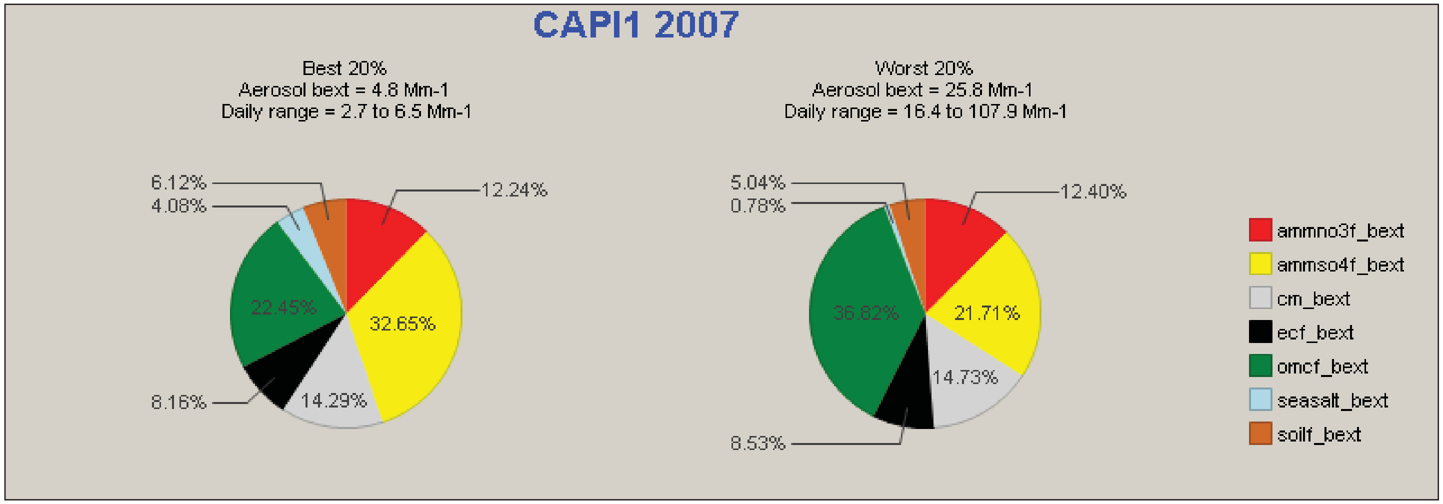


Figure 3-26. Composition of fine particles at Capitol Reef National Park, 2004 (VIEWS 2009).

Legends refer to B extinction rates related to the following: ammno3f_bext = ammonium nitrate; ammso4f_bext = ammonium sulfate; cm_bext = coarse mass (particles 2.5–10 microns in size); ecf_bext = particles <2/5 microns in size (soot, black carbon); omncf = fine organic mass from carbon; sea salt_bext = sea salt; and soilf_bext = fine soil.

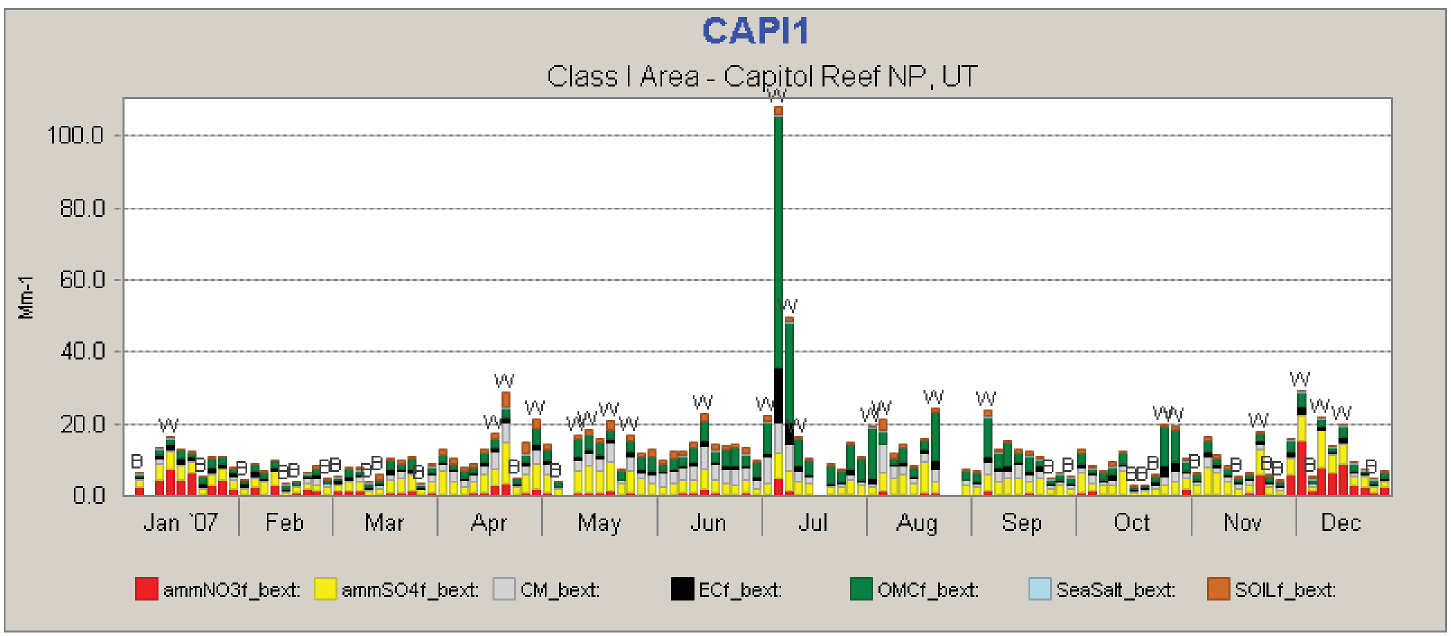


Figure 3-27. Seasonal patterns in haze composition at Capitol Reef National Park, 2004 (VIEWS 2009).

ZION

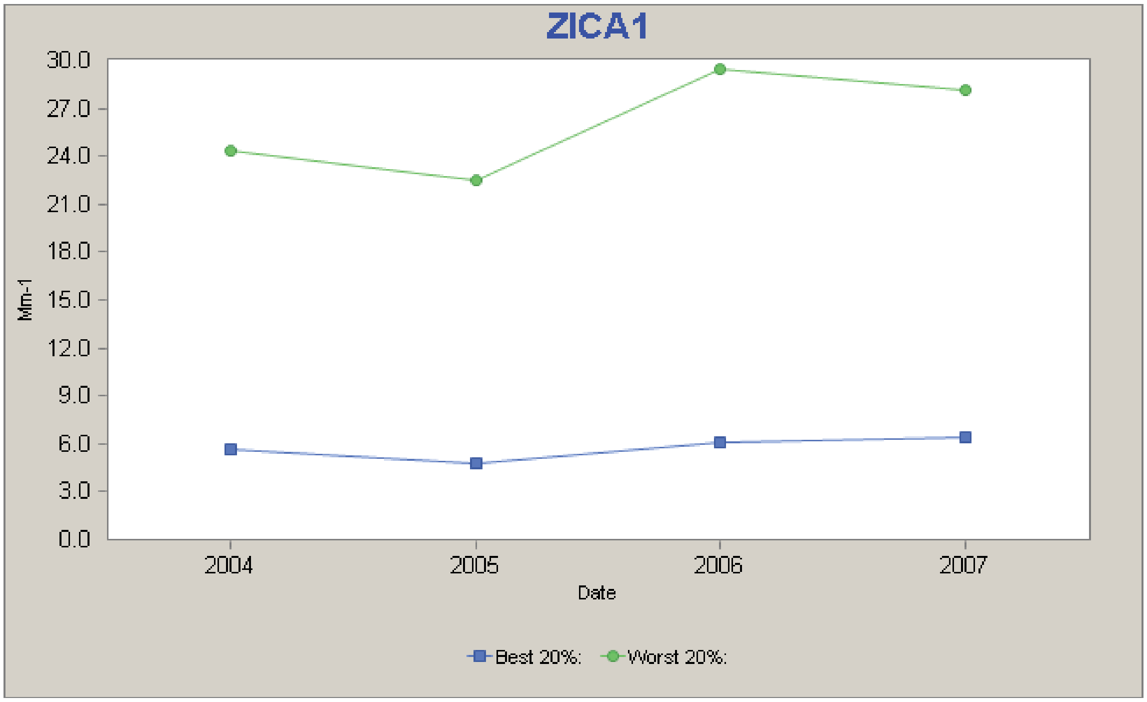


Figure 3-28. Trends in aerosol light extinction on the 20% best (clearest) days and 20% worst (haziest) days, Zion National Park (VIEWS 2009).

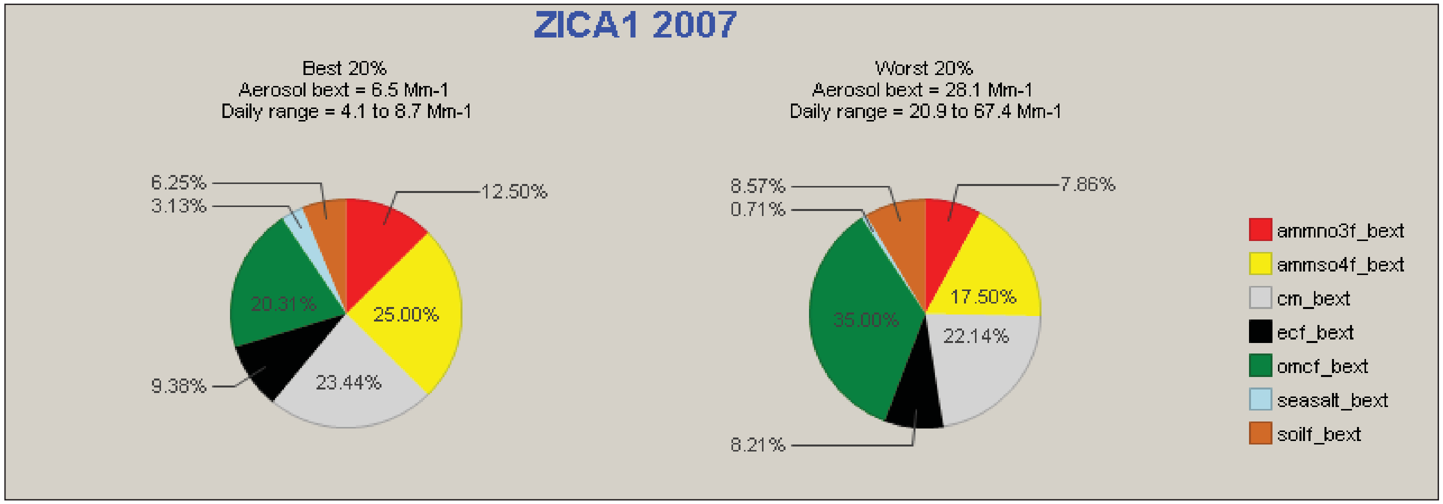


Figure 3-29. Composition of fine particles at Zion National Park, 2007 (VIEWS 2009).

Legends refer to B extinction rates related to the following: ammno3f_bext = ammonium nitrate; ammso4f_bext = ammonium sulfate; cm_bext = coarse mass (particles 2.5–10 microns in size); ecf_bext = particles <2/5 microns in size (soot, black carbon); omncf = fine organic mass from carbon; sea salt_bext = sea salt; and soilf_bext = fine soil.

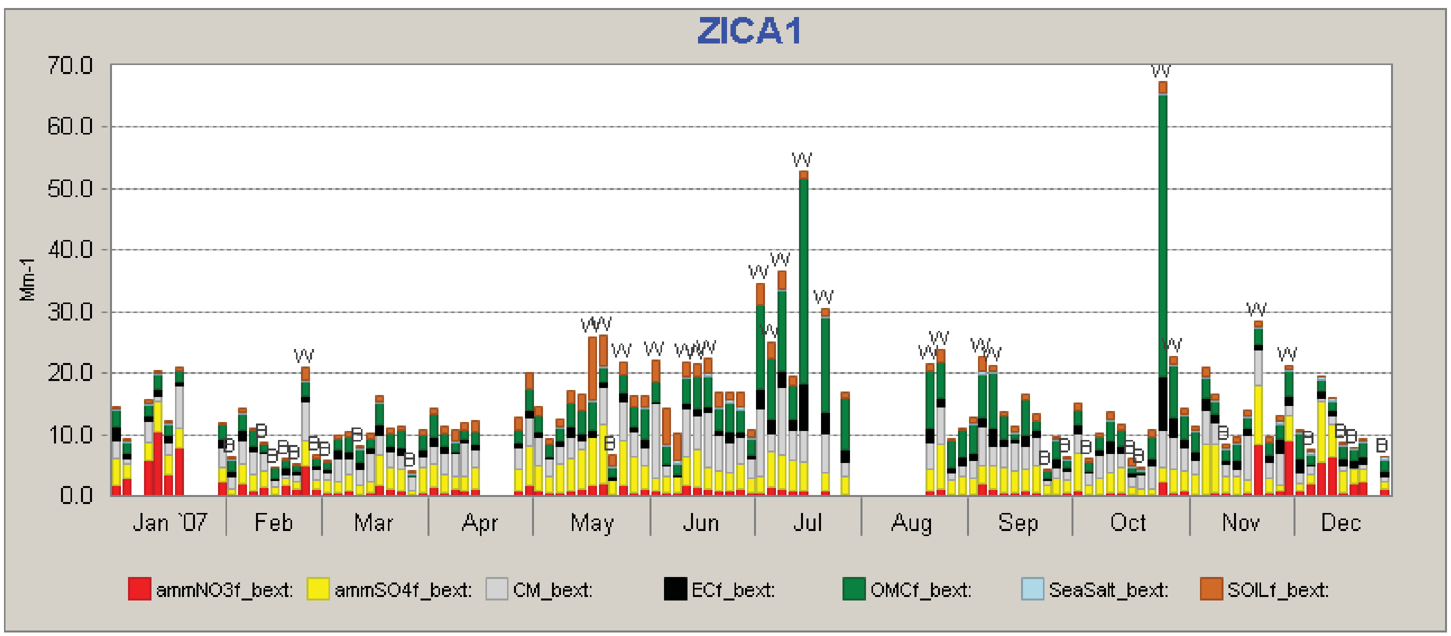


Figure 3-30. Seasonal patterns in haze composition at Zion National Park, 2007 (VIEWS 2009).

4 Discussion

Nationwide, the NPS is exceeding air quality performance goals for 2008, with 99% of reporting parks showing stable or improving trends in visibility, 94% showing stable or improving trends in ozone concentrations, and 83% showing stable or improving trends in atmospheric deposition (NPS-ARD in press). NCPN parks generally follow this trend, with parks meeting 14 of the 15 GPRA goals (93%). Currently, 100% of reporting NCPN parks show stable or improving trends in visibility (9 parks), 100% show stable or improving trends in ozone concentrations (3 of 3 parks; 2 could not be determined due to limited data), and 50% show stable or improving trends in atmospheric deposition (2 parks). Ammonium was increasing at CANY, which corresponds with increasing ammonium concentrations found in the vicinity of the Colorado Plateau and the Intermountain West (NPS-ARD in press).

Sites in the West, including the Colorado Plateau, are generally reporting increasing (improving) visibility on clear days. The NPS-ARD expects air quality in parks to improve as regulations aimed at reducing tailpipe emissions from motor vehicles and pollution from electric-generating facilities take full effect over the next few years. In addition, state and tribal governments, with assistance from regional planning organizations, are in the process of developing programs to improve visibility in national parks and wilderness areas in response to EPA regulations (NPS-ARD in press).

Ozone concentrations in some western parks outside the NCPN have been increasing, and ozone could become a concern in NCPN parks. However, little is known about the effects of ozone on plants in the southwest. Research suggests that plants in drier climates take in less ozone through their stomates and are therefore able to tolerate higher ozone exposures. However, in riparian areas where plants are well watered, ozone uptake may be significant and injury may occur.

Relative to atmospheric deposition, NCPN parks should be aware of power plants that have been proposed for and are operating on the Colorado Plateau. The NPS is collaborating with states and industry to encourage the adoption of 21st century technology, negotiate tighter pollution controls (including mercury), and secure emission-offset agreements. For instance, a mitigation agreement was negotiated with the owners and operators of a proposed new power plant in the Four Corners area to offset the impact of the facility on several NPS units (NPS-ARD in press). As a result, Sithe Global, Inc., has proposed to construct and operate its Desert Rock Energy Project using two new, 750-megawatt, supercritical pulverized coal boilers (which are more efficient and less polluting than older technologies; DOE 2007) near the existing Four Corners power plant on the Navajo Reservation, near Farmington, New Mexico.

In addition, the Four Corners power plant, a significant contributor to visibility impairment at park units on the Colorado Plateau, has succeeded in increasing the efficiency of its sulfur dioxide (SO_2) emission reduction technology, resulting in an 88% total removal rate and more than 20,000 fewer tons of SO_2 pollution. Discussions with the Arizona Public Service (APS, the plant operator), the NPS, EPA, and environmental groups resulted in a voluntary agreement to test methods for improving pollution control from 75 to 85% removal efficiency. The test program exceeded expectations, and APS has agreed to maintain the 88% SO_2 total removal rate (NPS-ARD in press).

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National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov