Chapter 3. Arches National Park

Introduction

Arches National Monument was established in 1929 under the "Preservation of American Antiquities Act" of 1908. The enabling legislation stated:

> "these areas contain extraordinary examples of wind erosion in the form of gigantic arches, natural bridges, 'windows', spires, balanced rocks and other unique wind-worn sandstone formations, the preservation of which is desirable because of their educational and scenic value".

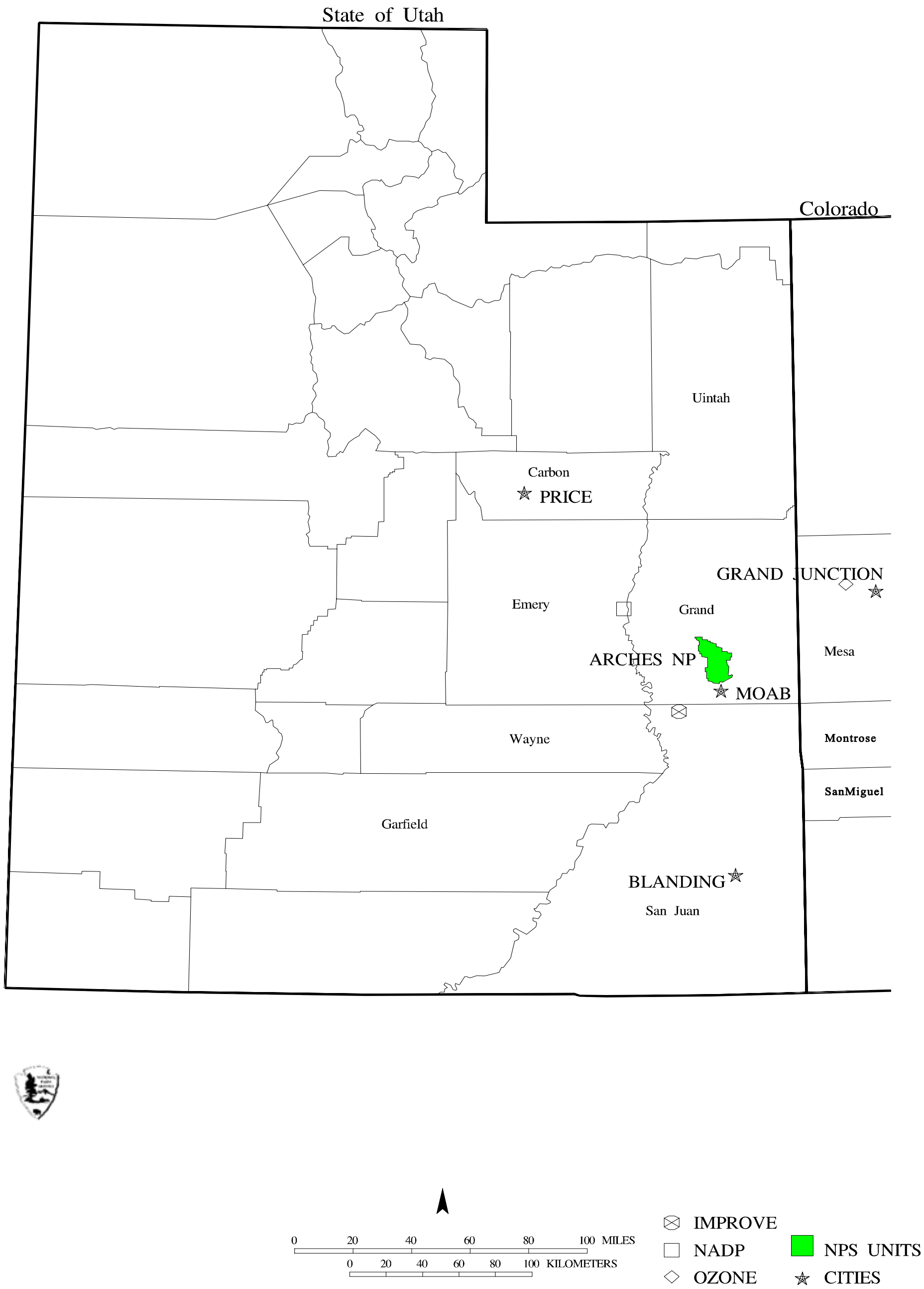
The Monument became a National Park in 1971 and today comprises 29,708 ha. About 90% of the Park is federally owned, and the remainder owned by the State of Utah and Grand County.

Arches National Park is in the high desert of southeastern Utah, with elevations ranging from 1200 m to 1725 m (Figure 3-1). The Park contains the largest concentration of natural rock arches in the world, with over 200 arches and 2000 catalogued natural openings, as well as many spectacular pink and red rock sandstone canyons, fins, slickrock terraces, towering monoliths and arches in varying stages of formation or collapse. The most well recognized formations include Landscape Arch, which spans over 91 m, Turret Arch and Delicate Arch. The Park contains many archeological features such as prehistoric pictographs and petroglyphs; the remains of at least four Native American cultures (the Archaic People, the Anasazi, the Freemont and the Utes); and the historical legacy of some of the earliest pioneer attempts to ranch and mine on the Colorado Plateau.

Geology and Soils

The geology of Arches developed from a regional collapse of horizontal layers of sedimentary rock along several northwest-trending anticlines (particularly the Salt Valley and Cache Valley anticlines). The Entrada Formation splits along these anticlines and forms many parallel joints that eventually weather into the free standing rock fins and arches. Exfoliation, chemical solution from carbonic acid in rainwater, frost wedging and water erosion weather the rock surfaces; acidic deposition should not have any significant effect on weathering of rocks in the Park (Smith and Saari 1983).

Figure 3-1. Location of Arches National Park.



Map produced by the National Park Service Air Resources Division

Sources: USGS 1:2,000,000 cdrom and NPS ARD GIS

The major exposed rock formations in Arches are from the Jurassic and Triassic Periods and include the massively crossbedded Navajo Sandstone, the Entrada and Wingate Sandstones and the limestones, shales and sandstones of the Kayenta and Chinle Formations. These sedimentary rock layers were deposited under a variety of climatic conditions and depositional environments that ranged from sparsely vegetated sandy deserts to shallow seas with densely vegetated shores. Seas advanced and retreated during periods of subsidence and uplift. Climate changes were also dramatic as continental-scale mountain building altered regional weather patterns and cut off the flow of moist air from the west (Chronic 1988). The regional climate today is dry (<150 mm/yr average precipitation) and warm, and so the Park is covered by bedrock, shallow soils, and only sparse vegetation. The soils of the Park reflect the geologic parent material; most are sandy and shallow, but soils developed from marine shales tend to be finer textured and high in salts.

Climate

The low precipitation (annual total about 160 mm) at Arches is relatively well distributed through the year, but the hottest months of June and July (24 ^{o}C) have relatively low precipitation

(Figure 3-2).

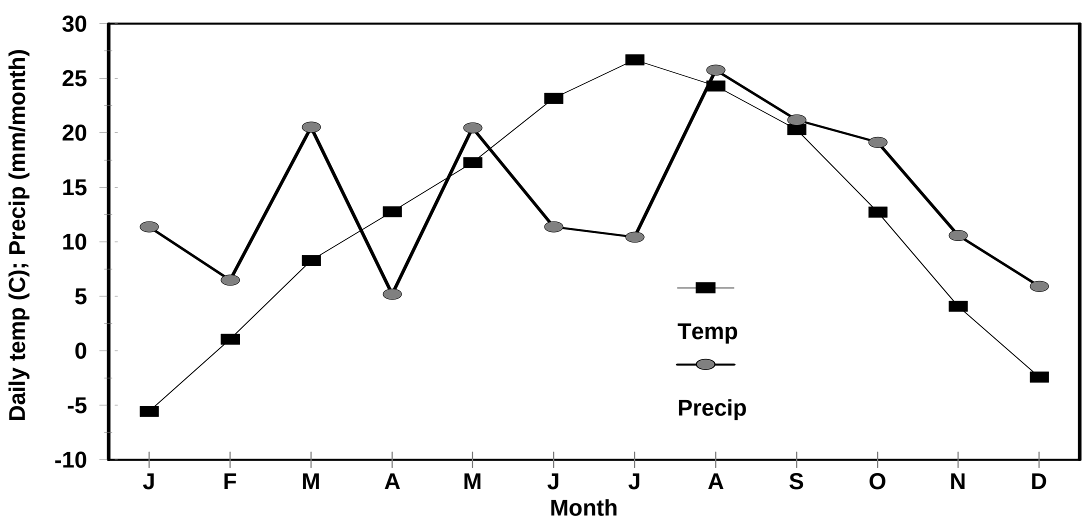
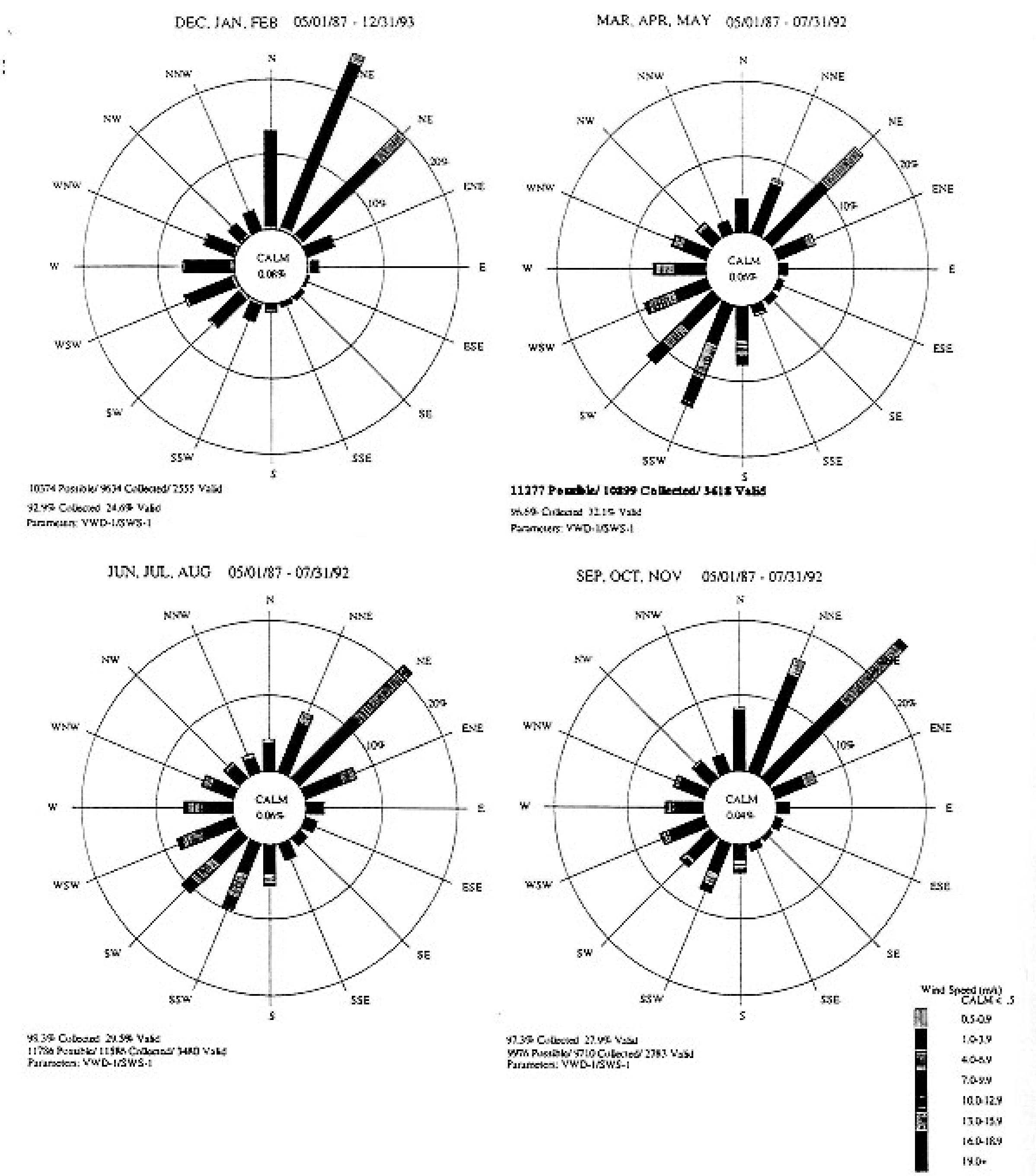


Figure 3-3. Seasonal wind roses for Arches National Park for 1987-1993.

Figure 3-3. Seasonal wind roses for Arches National Park for 1987-1993.



The prevailing wind direction for Arches is from the northeast for most seasons, with a shift towards winds from the southwest in the spring (Figure 3-3). Throughout the year, air masses moving in from the southwest have a higher velocity than the prevailing northeasterly winds.

Vegetation

Geologic substrate and soil type greatly influence the type and distribution of plant communities in the Park. The dominant vegetative cover type is the pinyon (*Pinus edulis*)/ juniper *(Juniperus osteosperma*) community, covering about 40% of Arches National Park. Co-occurring species include blackbrush (*Coleogyne ramosissima*), squawbush (*Rhus* spp.), singleleaf ash (*Fraxinus anomala*), and serviceberry (*Amelanchier utahensis*). The blackbrush/shrubland community covers about 20% of the Park and is restricted to shallower soils and drier sites with blackbrush occurring in almost pure stands on the shallowest sites. Grassland plant communities cover about 11% of the Park, mostly on deeper sandy soils. This grass community includes Indian ricegrass (*Achnatherun hymenoides*), needle and thread grass (*Stipa comata*), galleta grass (*Pleuraphis jamesii*), and Mormon tea (*Ephedra* spp.). Saline soils cover about 2% of the Park, and these sites are dominated by the saltbush community, with saltbush (*Atriplex* spp.), snakeweed (*Gutierrezia* spp.), seepweed *(Suaeda* spp.), and greasewood (*Sarcobatus vermiculatus*). Riparian communities include such woody plants as cottonwood (*Populus fremontii*), willow (*Salix* spp.), big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus* spp.), and greasewood. Hanging gardens are a unique plant community type at seeps and springs on rock canyon walls (described in detail by May et al. 1995, Fowler 1996, Fowler et al. 1996). Arches National Park supports a variety of lichens and micro-biotic soil crust communities which may be important contributors of ecosystem nitrogen and stabilizers of soil surfaces. Important exotics in the Park are Russian thistle (*Salsola tragus*), tamarisk (*Tamarix ramossisima*), and cheatgrass (*Bromus tectorum*). Complete species lists for the Park can be found in NPFlora, Harrison et al. (1964) and Sharpe (1993). NPLichen provides a listing of lichen species found in the park.

There are no known Threatened and Endangered Plant Species (Threatened and Endangered Species Information Institute 1993), but National Park Service species of concern include: canyonlands biscuit root (*Lomatium latilobum*), alcove death camas (*Zigadenus vaginatus*), and alcove bog-orchid (*Habenaria zothecina*).

Air Quality

Monitoring of air quality at Arches included ozone and SO_2 concentrations from 1988-1992, NADP monitoring at Green River from 1985-present, and IMPROVE monitoring of visibility properties from 1988-1992. The IMPROVE particle monitor is near the campground at Skyline Arch, and the camera is near the turnoff for Cove and Turret Arches.

Emissions

Table 3-1 provides summaries for emissions of carbon monoxide (CO), ammonia (NH_3), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM), and sulfur oxides (SO_x) for 10 counties surrounding Arches National Park. The largest sources of SO_x in Emery and Carbon Counties in Utah are three Pacificorp plants (Huntington, Hunter, and Gate), and the largest source in Mesa County, Colorado is the Public Service Company's Cameo plant.

No estimates have been made for the influence of various regions on local air quality in Arches, but studies from nearby Canyonlands National Park probably characterize the Arches area well. Eatough et al. (1996) apportioned the SO_x in Canyonlands to emission sources over a 3-month period from January through March in 1990, based on “fingerprints” of ratios of compounds in the air, and air mass trajectories. For example, emissions from 2 coal-fired power plants had high ratios of spherical aluminosilicate particles to sulfate, but very low ratios of arsenic to sulfate. Air from Arizona was characterized by low ratios of these aluminosilicate particles to sulfate, and high ratios of arsenic to sulfate. They concluded that SO_x in Canyonlands derived from a wide range of regional sources rather than from a dominant source; about 37% (during a 21 day period) came from the southwest, 20% from the south/southeast, 19% from the north/northeast, and 23% from the northwest. Eatough et al. (1996) concluded that the major sources of SO_2 were from the southwest, while major sources of particulate sulfate were from the southeast. To the northwest at Green River, Eatough et al. (1996) found a larger portion of the SO_x came from the southeast, and substantially less from the Utah Power and Light (now Pacificorp) generating stations to the North in the Green River Basin.

Table 3-1. Emissions (tons/day) for counties surrounding Arches National Park (Radian 1994).

County	CO	NH_3	NOx	VOC	PM	SO_x
Carbon, UT	43.3	0.5	17.1	17.5	131.9	16.8
Emery, UT	40.5	0.7	113.8	56.0	273.5	51.7
Garfield, UT	13.7	0.6	1.5	63.0	252.6	0.2
Grand, UT	17.0	0.2	1.6	47.4	184.7	0.2
San Juan, UT	40.8	0.7	3.9	102.7	405.4	0.5
Uintah, UT	55.2	1.5	6.2	44.5	286.2	0.8
Wayne, UT	6.3	0.6	0.7	30.3	122.4	0.1

Mesa, CO	118.4	2.9	25.6	32.8	196.7	9.0
Montrose, CO	49.7	2.3	6.6	22.0	95.2	1.9
San Miguel, CO	11.5	0.7	1.3	10.6	45.2	0.1

Air Pollutant Concentrations

The concentrations of ozone in 1988 to 1992 averaged between 30 and 45 ppb, with peak 1-hr concentrations of 55 to 90 ppb (Table 3-2).

Table 3-2. Concentrations of ozone and SO_2 for Arches National Park between May and September. For ozone, upper value is mean daily concentration (ppb); middle number is the Sum60 exposure (ppb-hr in excess of 60 ppb for 12 hr/day for 3 months); and bottom number is the maximum 1-hr concentration observed each year. SO_2 measured 24-hr/day by IMPROVE filter samplers (ppb) (1 $\mu g/m^3$ approximately equals 0.38 ppb). Ozone data from the NPS Air Resources Division's Quick Look Annual Summary Statistics Reports (provided by D. Joseph, NPS-ARD).

Year	Ozone	SO_2
1988		
Mean	44	0.2
Sum60	7596	
Max	70	0.6
1989		
Mean	45	0.2
Sum60	6117	
Max	87	1.0
1990		
Mean	28	0.2
Sum60	0	
Max	56	1.2
1991		
Mean	36	0.2
Sum60	--	
Max	74	0.6
1992		
Mean	46	0.2
Sum60	--	
Max	76	0.5

Visibility

Visual air quality was monitored at Arches from March 1988 through May 1992, using the aerosol sampler of the IMPROVE project. The data from this IMPROVE site have been summarized based on seasons of spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). Visual air quality was also monitored using a camera from July 1986 through November 1991.

Aerosol Data

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient (b_{ext}) from experimentally determined extinction efficiencies of certain species (Table 3-3). Table 3-3 provides a summary of the reconstructed extinction from the aerosol sampler data, presented as seasonal and annual 50th and 90th percentile standard visual range for Arches. The 50th percentile means that visual range is this high or lower 50% of the time. This is an average 50th percentile for each season. The 90th percentile means that the visual range is this high or lower 90% of the time. This is an average 90th percentile for each season.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions.

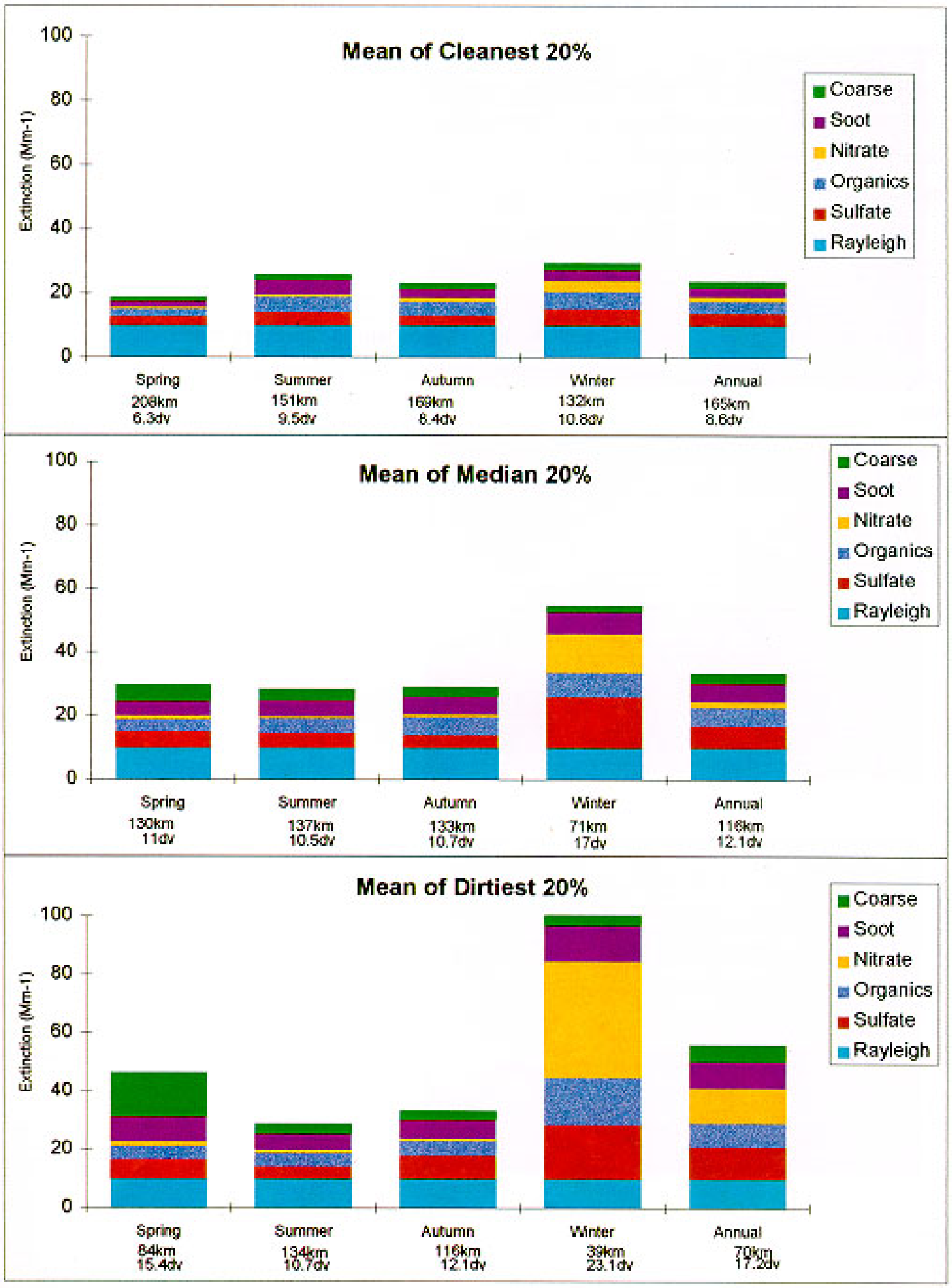
Table 3-3. Reconstructed visual range and light extinction coefficients for Arches National Park, based on IMPROVE aerosol sampler, seasonal and annual average 50th and 90th percentiles, March 1988 - May 1992.

Season/Annual	50th Percentile Visual Range (km)	50th Percentile b_{ext} (Mm^{-1})	90th Percentile Visual Range (km)	90th Percentile b_{ext} (Mm^{-1})
Winter	82	47.7	140	27.9
Spring	136	28.8	179	21.8
Summer	132	29.6	160	24.4
Autumn	131	29.8	173	22.6
Annual	120	32.6	163	23.9

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at Arches to specific aerosol species (Figure 3-4). Visibility impairment is attributed to atmospheric gases (Rayleigh scattering), sulfate, nitrate, organics, soot, and coarse particles. The extinction budgets are listed by season and by mean of cleanest 20% of the days, mean of median 20% of the days, and mean of dirtiest 20% of the days. The "dirtiest" and "cleanest" signify highest fine mass concentrations and lowest fine mass concentrations respectively, with "median" representing the 20% of days with fine mass concentrations in the middle of the distribution of all days. Each budget includes the corresponding extinction coefficient, standard visual range (SVR), and haziness in deciviews (dv). The sky blue segment at the bottom of each stacked bar represents Rayleigh scattering which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gasses. Higher fractions of extinction due to Rayleigh scattering indicates cleaner conditions.

Figure 3-4. Reconstructed extinction budgets for Arches National Park, March 1988 through May 1992.

Figure 3-4. Reconstructed extinction budgets For Arches NP, March 1988 through May 1992.



Atmospheric light extinction at Arches, like many rural western areas is largely due to sulfate, organic, and soot aerosols. The best visibility (excluding weather) occurs during the summer seasons.

In pre-industrial times, visibility would vary with patterns in weather, with winds (and the effects of winds on coarse particles), and with smoke from fires. We have no information on how the distribution of visibility conditions at present differs from the profile under “natural” conditions, but the cleanest 20% of the days probably approach natural conditions (GCVTC 1996).

Photographs

Three photos are provided from the Arches camera data to represent the range of visibility conditions at the park (Figure 3-5). The photos were chosen to provide an idea of the range of visibility conditions possible and to help relate the SVR/extinction/haziness numbers to what an observer sees.

Figure 3-5. Photographs representing visibility conditions at Arches National Park.

Figure 3-5. Photographs representing visibility conditions at Arches National Park.

Arches National Park
on a "clear" day.

Representative Conditions:

Visual Range:	340 - 391 km
b_{ext}:	12 - 10 Mm^{-1}
Haziness:	1 - 0 dv

Arches National Park
on a "average" day.

Representative Conditions:

Visual Range:	210 - 250 km
b_{ext}:	19 - 16 Mm^{-1}
Haziness:	6 - 4 dv

Arches National Park
on a "dirty" day.

Representative Conditions:

Visual Range:	110 - 140 km
b_{ext}:	36 - 28 Mm^{-1}
Haziness:	13 - 10 dv

Atmospheric Deposition

The rates of atmospheric deposition for Green River, Utah (about 70 km northwest of Arches) are relatively low (Table 3-4). Precipitation pH averages about 5.2. Deposition of N averages about 1 kg N ha^{-1} yr^{-1}, which is slightly higher than the rate of S deposition. The deposition of both ammonium and nitrate showed significant increasing trends from 1985 through 1994. Ammonium-N deposition increased by about 0.04 kg N ha^{-1} yr^{-1} (r^2=0.53, p<0.02) while nitrate-N deposition increased at a rate of 0.03 kg N ha^{-1} yr^{-1} (r^2 = 0.44, p<0.04). However, the significance of these trends depends completely on the very low values for the first year of monitoring (1985) when data completeness averaged only 54%. Even if these values were doubled, we suspect the data would be unreliable, being far lower than any other year. We conclude that N deposition probably has not been increasing at Green River. Sulfate deposition showed no trend during this period. There is no evidence that such low levels of deposition pose any threat to plants (see Chapter 2).

Table 3-4. Atmospheric deposition for Green River, Utah (NADP). Note the values for N and S compounds include the whole molecule and not just the N or S atoms.

	Concentration (mg/L)			Deposition (kg ha^{-1} yr^{-1})				Conductivity	Precipitation
year	NH_4	NO_3	SO_4	NH_4	NO_3	SO_4	pH	(μS/mm)	(mm/yr)
1985	0.01	0.30	0.49	0.01	0.22	0.37	5.55	0.64	75
1986	0.17	1.19	1.36	0.31	2.10	2.40	5.78	1.57	177
1987	0.48	1.27	1.40	0.86	2.26	2.49	5.35	1.18	178
1988	0.48	1.75	1.47	0.63	2.30	1.94	5.22	1.42	132
1989	0.94	2.13	1.94	0.59	1.35	1.23	6.83	2.68	63
1990	1.00	2.04	2.17	0.66	1.35	1.43	5.82	2.40	66
1991	0.43	1.42	1.22	0.83	2.72	2.34	5.74	1.32	192
1992	0.90	1.50	1.54	1.50	2.51	2.58	5.90	1.54	167
1993	0.53	1.33	1.33	1.10	2.77	2.77	5.58	1.14	208
1994	0.40	1.35	1.05	0.61	2.06	1.60	5.44	1.45	150

Sensitivity of Plants

No visible injury signs of any air pollution damage have been reported for vegetation in or near Arches. Almost none of the Park's species have been tested under controlled conditions for sensitivity to pollutants. Based on the ozone concentrations required to affect very sensitive plants in controlled environments, it is possible that current ozone exposures could be high enough to affect some species. However, in the absence of empirical evidence of any effects, no substantial problem is likely.

Water Quality and Aquatic Organisms

The Colorado River forms 17.5 km of Arches National Park's eastern and southern boundaries, from the mouth of Salt Wash. The ephemeral streams in the park drain into the Colorado River. Because of high sediment loads the conductivity and acid-neutralizing capacity of this river is very high, providing extreme resistance to acidification. However, the Park also has small pothole aquatic systems that are of interest relative to their potential sensitivity to acidification.

Graham (1991) and Gladney et al. (1993) studied the ecology and chemistry of rock pools in Arches during 1988; the potholes ranged in volume from 1700 L to 8200 L. The pH of pothole waters ranged from 6.5-9.5, with a total alkalinity ranging from 17-47 mg/L (340-940 μeq/L). The measured nitrate-N varied in the rock pools from less than 0.2 to 1.5 mg/L.

During rock pool acidification experiments (lowering the pH to 5.5, 5.0 and 4.5), sediments and suspended particles in the rock pools tended to buffer the introduced acidity rapidly (within 24 hours) (Graham 1991). These sediment-water interactions lessen the sensitivity of rock pools to acidification. Many of the experimental systems were located on sandstone bedrock. It was suggested that rock pools situated on bedrock more resistant to weathering could be more susceptible to acid inputs.

Dodson (1991) speculated that atmospheric deposition of nitrogen compounds to rock pools may result in nutrient enrichment leading to algal blooms and oxygen depletion. However, no data are available to test this idea, or to gauge the magnitude of N and C inputs from deposition vs. allochthonous litter sources.

Aquatic Invertebrates

Dodson (1987) and Graham (1991) report on the types of organisms found in rock pools in Arches National Park. Three types of biological communities can be found in these rock pools:

- gnats, mosquitoes, and frog tadpoles occur in the most ephermeral pools,
- fairy shrimp occur in slightly longer-lived pools,
- insects, cladocerans, copepods, and salamander larvae occur in permanent pools.

Experiments with acidification of rock pools found near Arches caused mortality to larval crustacea (pH reduced from 7.0 to 4.5); dipteran larvae and ostracods did not appear to be affected at pHs as low as 4.5.

Amphibians

Graham (1991) stated that potholes on the Colorado Plateau are used by the red-spotted toad (*Bufo punctatus)* and the Great Basin spadefoot toad (*Scaphiopus intermontanus)* for egg laying and larval development. Pierce (1991) conducted a series of acidification experiments in potholes to determine the response of these amphibian larvae to acidity. *Bufo punctatus* larvae were relatively insensitive to lowered pHs, with 100% survival at all treatments except pH 3.5. However, *Scaphiopus intermontanus* larvae hatching success was significantly reduced at pH 5.0. These experimental results need to be interpreted with caution because of the short duration of the experiments and the limited number of individuals tested *in situ*.

Recommendations for Future Monitoring and Research

General recommendations for NPS Class I areas of the Colorado Plateau are presented in Chapter 14, and these apply to Arches National Park. The two most important recommendations relative to Arches are:

- Reinstitute monitoring of air quality. Air quality monitoring stopped in 1992 at Arches, even though Arches National Park remains a federally designated Class I area. Levels of pollution monitored at Canyonlands National Park may approximate the levels that occur in Arches, but the special legislative status of Class I designation warrants on-site monitoring at Arches. The IMPROVE network is designed to provide regional information on air pollution, and sampling at Canyonlands and Bryce Canyon is sufficient to meet IMPROVE's goals. However, any influence of local pollution sources or air masses that do not reach the IMPROVE sites would not be monitored at present. Therefore, smaller-scale monitoring of visibility would provide some valuable on-site data for determining conditions at Arches.

- Two levels of vegetation surveys for visible injury on plant leaves should be conducted. The first level would be a reconnaissance by an expert in pollution injury symptoms in late summer. If signs of injury are apparent, then a detailed survey program could be developed. If no signs of injury are found, then the survey could be repeated following any summer with unusually high ozone concentrations. Unfortunately, the state-of-knowledge is too poorly developed for us to identify which species at Arches might be most sensitive to ozone, but we expect that cottonwood (*Populus fremontii*), single-leaf ash (*Fraxinus anomala*), and squawbush (*Rhus trilobata*) might be among the more sensitive species.
- None of the pothole systems monitored in the Park had ANCs less than 200 ueq/l, so acidification is unlikely for pools located on sandstone substrates. We recommend that the geology of Arches be reviewed to determine if rock pools exist on bedrock more resistant to weathering. If such systems are identified by map inspection and field surveys, we recommend that grab samples for water chemistry analysis be collected and analyzed for pH, ANC, conductance, and major anions and cations.

Park Summary

Visibility is currently the only AQRV known to be impacted by pollution, as with the other NPS Class I areas of the Colorado Plateau. Current levels of pollution in southern Utah are high enough to produce haze and obscure the important vistas of Arches and surrounding areas. Any increase in aerosols will undoubtedly impair visibility further; substantial reductions in aerosols would be needed to restore pristine conditions at Arches National Park.

Little information has been collected on air pollution effects on the Park's biota. No sign of air pollution impacts on plant or animal species has been reported; ozone concentrations are high enough that some impact is possible for sensitive plants, but SO_2 concentrations are too low to affect plants. A reconnaissance survey should be done in late summer to look closely for any signs of foliar injury that might result from ozone exposure.

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