Chapter 11. Mesa Verde National Park

Introduction

Mesa Verde National Park was established in 1906, three weeks after the passage of the 1906 Antiquities Act. The enabling legislation states that Mesa Verde National Park was established "to preserve from injury or spoilation the unusual and large number of ruins and other works and relics of prehistoric or primitive man, among which are the largest and most spectacular cliff dwellings in the United States." The Park's Anasazi cliff dwellings are some of the best preserved in the region.

Mesa Verde National Park is entirely within Montezuma County in southwestern Colorado, just west of the La Plata mountains, and southeast of the center of the Colorado Plateau (Figure 11-1). The Park is bounded to the north by the Montezuma Valley and the North Escarpment, to the east by the Mancos River Valley and to the south and west by the Ute Mountain Ute Indian Reservation. After several boundary changes in 1913, 1932 and 1963, the current size of the Park is 21,100 ha of which only 94 ha are non-federal. In 1976, 3,280 ha were given wilderness status and in 1978 Mesa Verde National Park was declared an World Heritage Site.

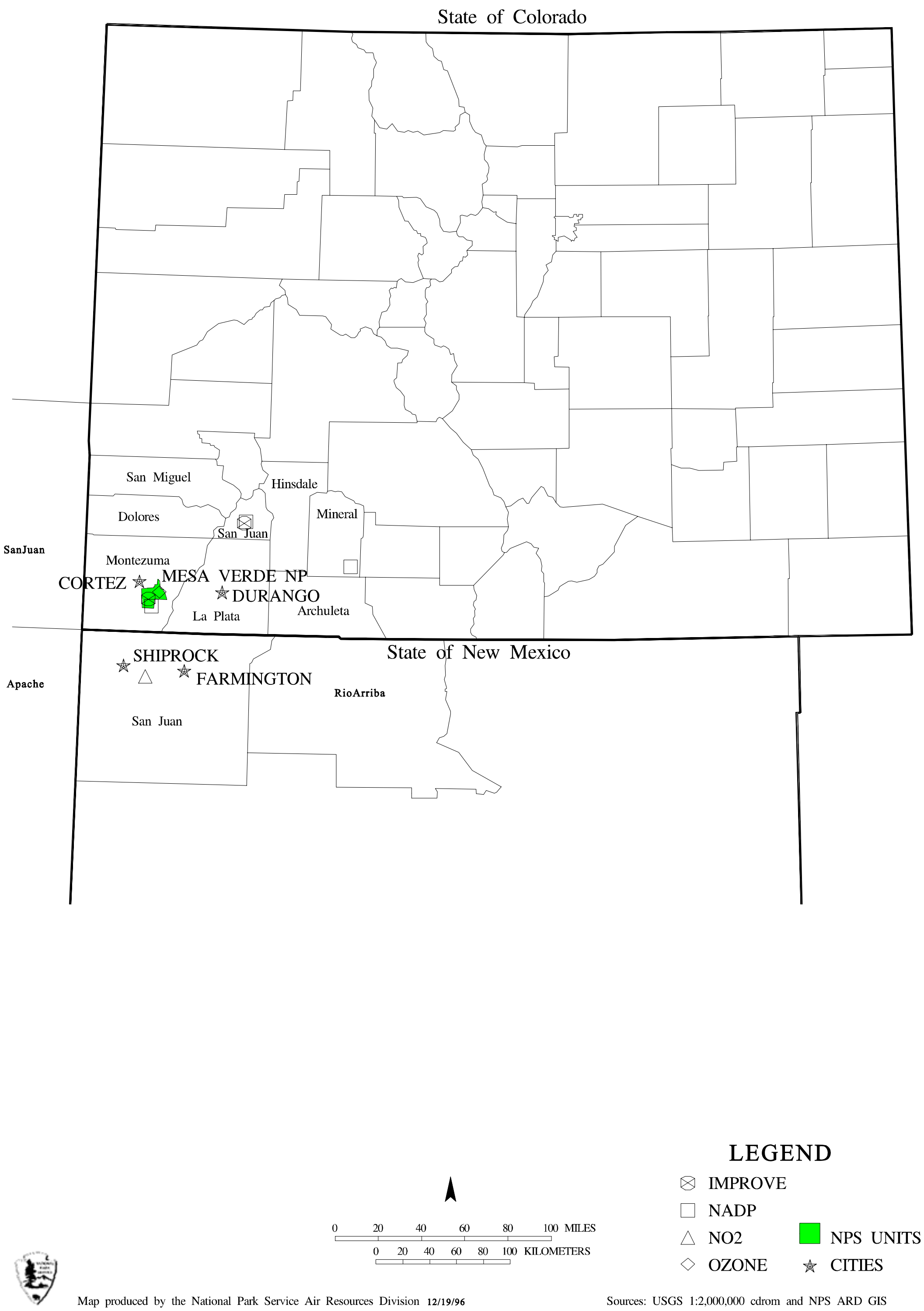
The archeological remains of the Anasazi are the main attraction for the Park. The Mesa Verde Branch of the San Juan Anasazi inhabited the four-corners region from 400 A.D. to almost 1300 A.D. They left some 4,000 archeological sites. Estimates for peak pre-historic population for the area put the number of inhabitants at around 15,000.

Geology and Soils

The Mesa Verde is an erosional remnant rising 500 to 650 m above the Dolores Plateau. The Mesa Verde itself ranges from about 2,000 to 2,800 m and includes about 3,000 square km of the San Juan Basin. This tableland is deeply incised with deep vertical-walled canyons that span the Menefee Formation, the Point Lookout Sandstone and the Mancos Shale. In some places, where erosion has been moderate, the Menefee is capped by the Cliff House Sandstone of marine origin. The Mesa Verde Group dates from the late Cretaceous Period, and is comprised of the 120 m thick Cliff House sandstone, the 100-250 m thick Menefee Formation (deposited in a floodplain or coastal swamp environment), and the 120 m thick Point Lookout Sandstone (marine deposit). The massive, soft, dark Mancos Shale is exposed along the North Escarpment of the Mesa; this formation was deposited in Cretaceous seas, and is characteristically barren of vegetation (Chronic

1988).

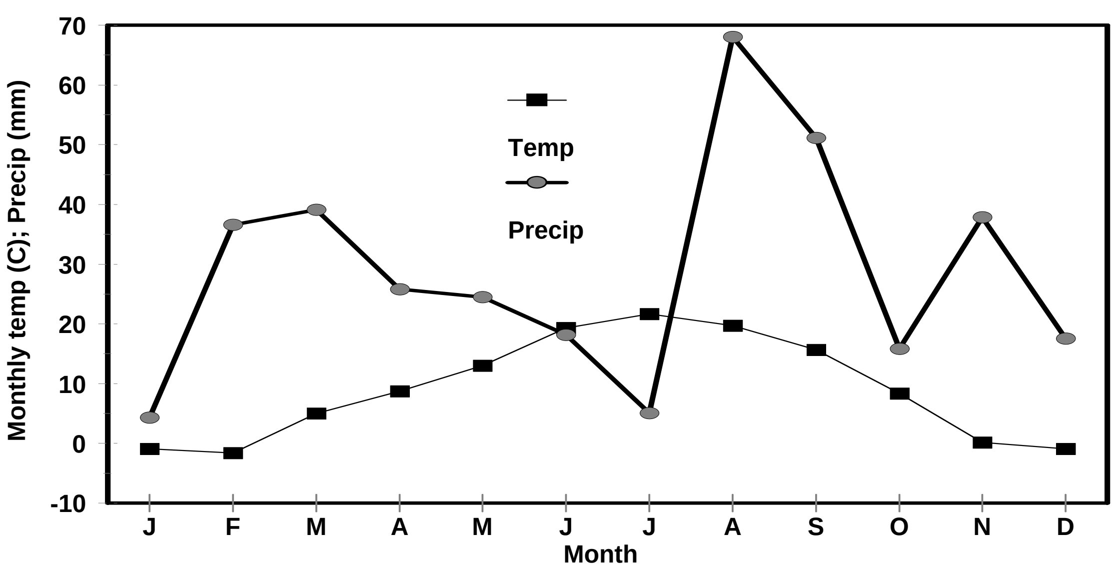
Figure 11-1. Location of Mesa Verde National Park.



The soils found in Mesa Verde National Park can be broken down into 4 main categories. The basalt rockland complex is composed largely of rocky outcrops, cliffs and steep talus slopes. The rough broken land complex is composed largely of infertile shallow soils, with some pockets of deeper, more fertile soil. This category provides sediment, through runoff, for the sandstone outcrop complex which is composed of highly stratified sandy soils with low moisture-holding capacity. Some of the soils in this complex are deeper, well developed and very fertile. The last category, the sandstone outcrop/stonyland complex, is composed of moderately deep to deep soils developed in place on the mesa bedrock with loess deposits. This complex offers the largest area of arable soil and maintains topsoil textures that range from fine and very fine sandy loams to loams. Clay loam subsoils predominate with sandy clay loams interspersed.

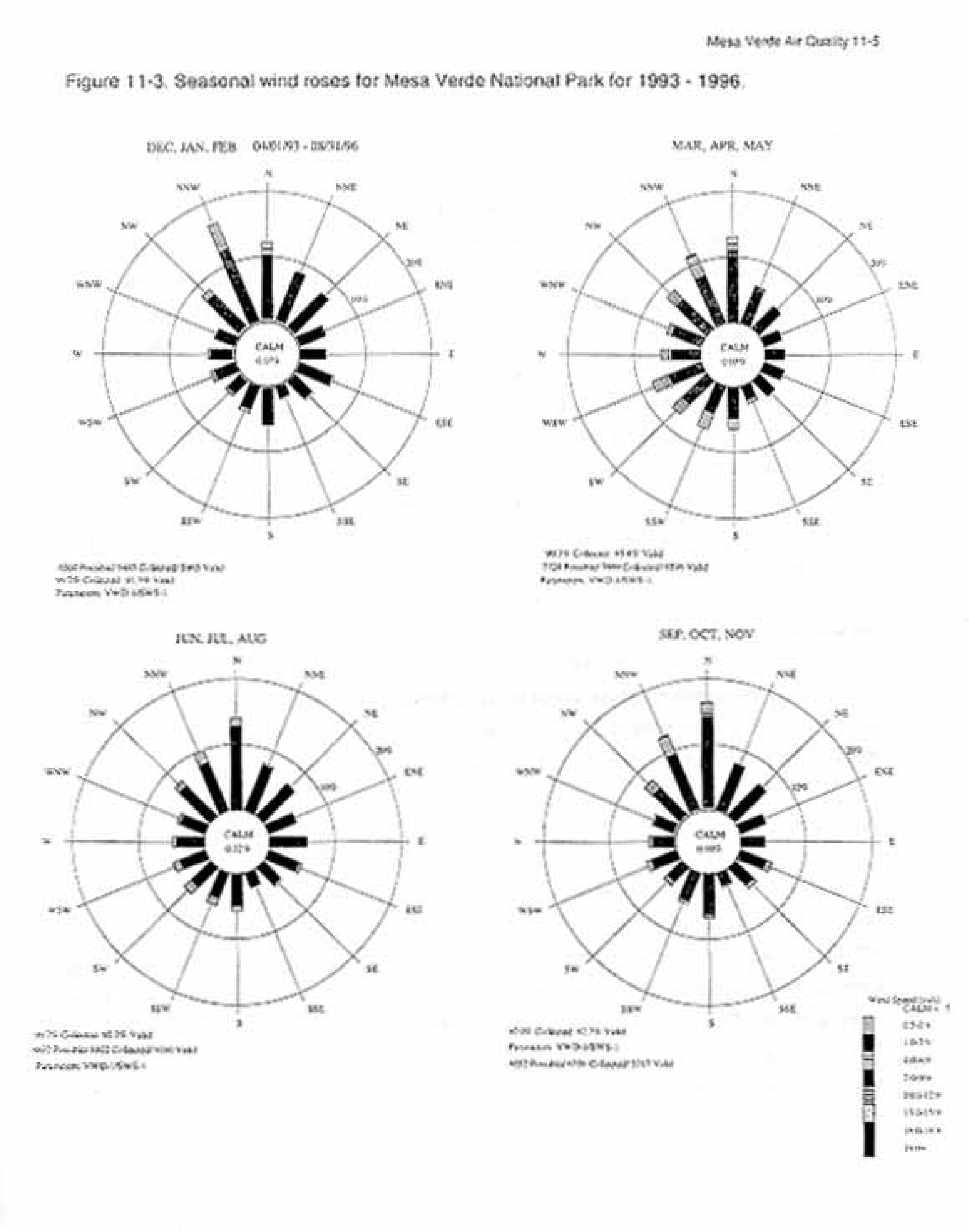
Climate

The climate of Mesa Verde is generally cool and semi-arid (Figure 11-2). Annual average precipitation is about 460 mm while monthly average temperatures range from 22 ^{o}C in July to -2 ^{o}C



in January. Highs can reach 37 ^{o}C in summer months. The annual average of 2 m of snowfall provides critical moisture for vegetation growth in spring and summer. Thunderstorms are common in the summer. Winds come primarily from the north/northwest, with little seasonal variation (Figure 11-3).

Figure 11-3. Seasonal wind roses for Mesa Verde National Park for 1993 - 1996.



Vegetation

The vegetation of Mesa Verde National Park is typical of the arid plateau regions of the southwestern U.S. Six distinct vegetation types are recognized in Mesa Verde. The two major community types are pinyon (*Pinus edulis*) / juniper (*Juniperus osteosperma*) and chaparral (dominated by Gambel oak (*Quercus gambelii*) and serviceberry (*Amelanchier alnifolia*)), each comprising almost half of the Park's vegetation. Minor portions of the Park are covered by Douglas-fir (*Pseudotsuga menzeisii*)/ ponderosa pine (*Pinus ponderosa*) woodlands; by grassland communities with western wheatgrass (*Pascopyrum smithii*), blue grama (*Bouteloua gracilis*), needle and thread grass (*Stipa comata*), and mutton grass (*Poa fendeleriana*); by upland sagebrush (*Artemisia tridentata*) communities; and by a semi-desert scrubland that resembles a sparse version of chaparral. Species of special concern for the NPS are *Astagalus schmolii*, *Astragalus deterior*, *Hachelia grassialenta*, and *Lliamna rivuraris* (M.Colyer, personal communication). Mesa Verde National Park may be somewhat unique in the region because grazing has been excluded from the Park boundaries for 60 yrs. NPFlora provides a complete listing of plant species found in the Park while NPLichen and Nash (1991) provide listings of lichen species.

Air Quality

Air quality monitoring for Mesa Verde National Park includes ozone data from 1993-present, NADP monitoring from 1981 to the present, sulfur dioxide measurements from 1991-1992, and IMPROVE monitoring for visibility from 1988 to the present.

Emissions

Table 11-1 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 11 counties surrounding Mesa Verde National Park. The greatest SO_x emissions come from San Juan County (Arizona Public Service's 4-Corners Plant and Public Service Company's San Juan Generating Plant). The high emissions in Apache County, Arizona, come primarily from a Salt River Project plant. No information is available to relate these emissions to local air quality at Mesa Verde, or to apportion Mesa Verde's air quality impairment to local and regional sources.

Table 11-1. Emissions (tons/day) for counties surrounding Mesa Verde National Park (Radian 1994).

County	CO	NH_3	NO_x	VOC	PM	SO_x
Archuleta, CO	11.5	0.7	1.2	15	6	0.1
Dolores, CO	4.0	0.5	1.1	10	34	0.1
Hinsdale, CO	1.6	0.4	0.1	5	1	0.0
La Plata, CO	57.6	1.4	16.8	16	79	0.6
Montezuma, CO	35.0	1.6	4.6	18	82	0.6
San Juan, CO	2.0	0.1	0.3	2	14	0.0
San Miguel, CO	11.5	0.7	1.3	11	45	0.1
San Juan, UT	40.8	0.7	3.9	103	405	0.5
Apache, AZ	138.5	3.2	83.3	118	554	64.0
San Juan, NM	166.6	1.2	196.6	50	372	175.5
Rio Arriba, NM	91.0	1.3	15.9	72	264	0.13

Air Pollutant Concentrations

The concentrations of ozone in 1993 and 1994 averaged about 43 ppb, with peak 1-hr concentrations of about 70 ppb (Table 11-2). The peak concentrations are at the lowest end of the range that may produce visible effects or growth effects on very sensitive species (see Chapter 2), but the cumulative (sum60) exposures are quite low. The concentrations of SO_2 were far below any threshold of suggested sensitivity for any plants.

Table 11-2. Concentrations of ozone and SO_2 for Mesa Verde National Park between May and September. For ozone, upper value is mean daily concentration (ppb); middle number is the maximum 3-month Sum60 exposure (ppb-hr for 12 hr/day); and bottom number is the maximum 1-hr concentration observed each year. SO_2 24-hr averages 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
1991	--	
Mean		0.2
Sum60		
Max		1.0
1992	--	
Mean		0.3
Sum60		
Max		1.9
1993		--
Mean	41	
Sum60	893	
Max	67	
1994		--
Mean	45	
Sum60	7023	
Max	72	

Visibility

Visual air quality in Mesa Verde National Park has been monitored using a transmissometer, aerosol sampler and a camera. The transmissometer operated (near Spruce Canyon) from September 1988 to June 1993, the aerosol sampler began operation in March 1988 (also near

Spruce Canyon), and the camera operated from September 1979 to April 1995 (from Navajo Hill). The data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for the period September 1988 through February 1994, based on seasons of spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February).

Optical Data - Transmissometer

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The atmospheric extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and that measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Weather factors such as clouds and rain can affect transmissometer measurements, but these can be "filtered out" by removing data points with high relative humidities (RH>90%).

The data are presented by season and annual median values, with and without meteorological factors, in Table 11-3. The data are presented in units of extinction coefficient in Mm^{-1} and standard visual range in km. Extinction coefficients represent the ability of the atmosphere to scatter and absorb light. Median values with large differences between the extinction values "including weather" and "excluding weather" indicate periods dominated by precipitation. Higher extinction coefficients signify lower visibility. Similarly, season and annual medians with nearly equal "including weather" and "excluding weather" extinctions indicate visibility reduction caused principally by particles.

Table 11-3. Transmissometer data summary for Mesa Verde National Park for 1988-1993. (SVR = standard visual range; b_{ext} = light extinction coefficient.)

Season Year	Excluding Weather		Including Weather	
	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})
Autumn 1988	141	27	131	29

Winter 1989	158	24	146	26
Spring 1989	123	31	113	34
Summer 1989	109	35	106	36
Autumn 1989	106	36	104	37
Annual 1989	119	32	113	34
Winter 1990	136	28	127	30
Spring 1990	113	34	106	36
Summer 1990	98	39	94	41
Autumn 1990	--	--	--	--
Annual 1990	123	31	109	35
Winter 1991	--	--	--	--
Spring 1991	--	--	--	--
Summer 1991	127	30	127	30
Autumn 1991	131	29	123	31
Annual 1991	131	29	123	31
Winter 1992	165	23	136	28
Spring 1992	131	29	127	30
Summer 1992	113	34	113	34
Autumn 1992	119	32	116	33
Annual 1992	127	30	119	32
Winter 1993	127	30	68	57
Spring 1993	116	33	109	35

Visibility tends to be highest in winter for low-humidity days, and lowest during the summer (Table 11-4).

Table 11-4. Standard visual range for Mesa Verde National Park. Seasonal averages for median standard visual range in km from September 1988 - May 1993.

Season	Excluding Weather	Including Weather
Winter	146	119
Spring	121	114
Summer	112	110
Autumn	124	118

Aerosol Data

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient from experimentally determined extinction efficiencies of certain species (Table 11-5). To compare this table with the data from Table 11-3 and 11-4, the "excluding weather" values should be used. In Table 11-5 the data are presented as seasonal and annual 50th and 90th percentile standard visual range for Mesa Verde. 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 estimated visual ranges and light extinction coefficients are similar for both the transmissometer measurements and the reconstructed values based on aerosol concentrations.

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. The measured extinction data are used to verify the calculated reconstructed extinction and can also be used to run plume and regional haze models and to analyze visibility trends and conditions. Because of the larger spatial and temporal range of the aerosol data, the use of the reconstructed extinction data are preferred.

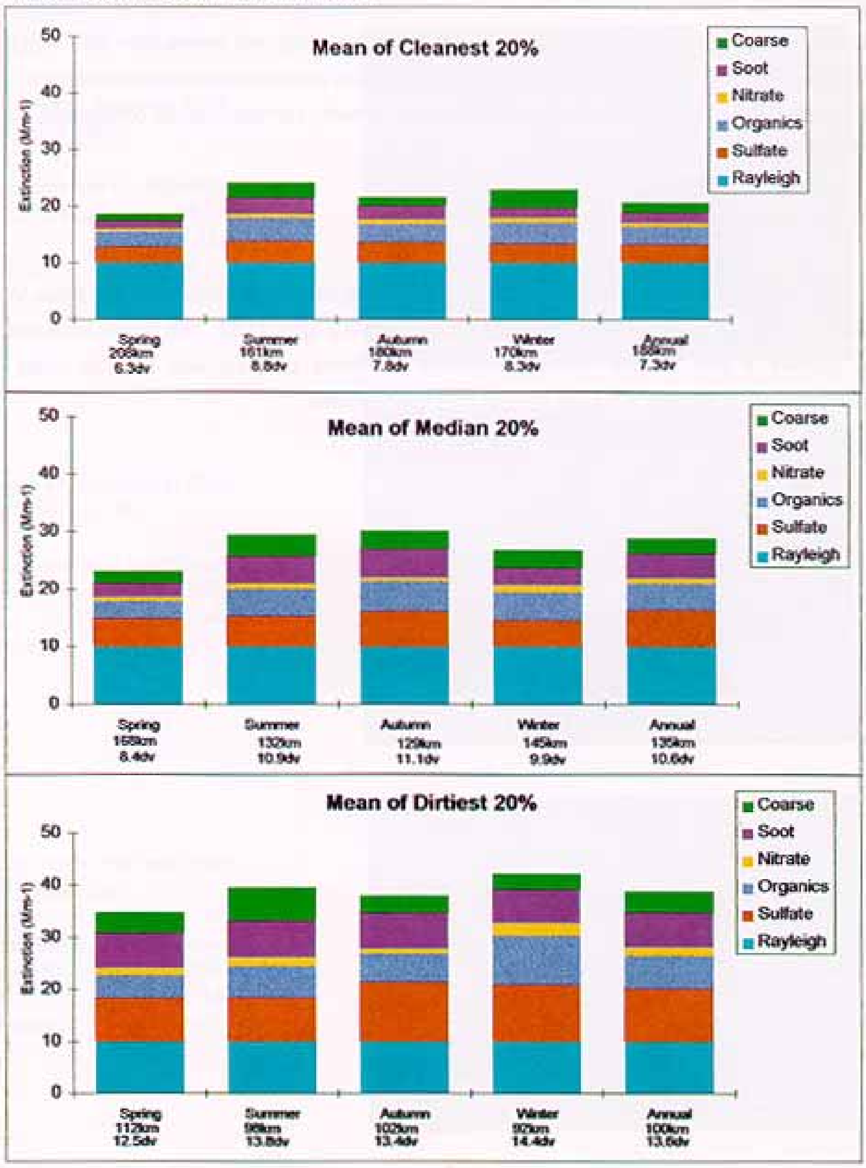
Table 11-5. Reconstructed visual range and light extinction coefficients for Mesa Verde National Park, based on IMPROVE aerosol sampler, seasonal and annual average 50th and 90th percentile by season, March 1988 - February 1994.

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	136	28.7	194	20.2
Spring	148	26.3	199	19.6
Summer	128	30.4	144	27.2
Autumn	137	28.6	180	21.7
Annual	136	28.8	192	20.4

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at Mesa Verde to specific aerosol species (Figure 11-4). 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 days, mean of median 20% of days, and mean of dirtiest 20% of 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. Each budget includes the corresponding extinction coefficient, SVR, and haziness in 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 gases. Higher fractions of extinction due to Rayleigh scattering indicate cleaner conditions.

Figure 11-4. Reconstructed extinction budgets for Mesa Verde National Park, March 1993 through February 1994.

Figure 11-4. Reconstructed extinction budgets for Mesa Verde NP, March 1993 through February 1994.



Atmospheric light extinction at Mesa Verde National Park, like many rural western areas is largely due to sulfate, organic, and soot aerosols. In pre-industrial times, visibility would vary with patterns in weather, winds (and the effects of winds on coarse particles), and 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 to represent the range of visibility conditions for the Mesa Verde National Park transmissometer cumulative frequency data (Figure 11-5). The photos were chosen to provide a feel for the range of visibility conditions possible and to help relate the SVR/extinction/haziness numbers to what the observer sees.

Figure 11-5. Photographs representing visibility conditions at Mesa Verde National Park.

Figure 11-5. Photographs representing visibility conditions at Mesa Verde National Park.

Mesa Verde National Park
on a "clear" day.

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

Mesa Verde National Park
on a "average" day.

Representative Conditions:
Visual Range: 250 - 300 km
b_{ext}: 16 - 13 Mm^{-1}
Haziness: 4 - 3 dv

Mesa Verde National Park
on a "dirty" day.

Representative Conditions:
Visual Range: 180 - 220 km
b_{ext}: 22 - 18 Mm^{-1}
Haziness: 8 - 6 dv

Visibility Projections

The Grand Canyon Visibility Transport Commission (GCVTC 1996) projected likely visibility for Mesa Verde through 2040, and the major species responsible for visibility impairment (Figures 11-6, 11-7). Reduced emissions from utilities were projected to reduce light extinction by approximately 1 Mm^{-1}. Light extinction caused by vehicle emissions was projected to decline until approximately 2005, and then increase through 2040. The dirtiest days have more than twice the visibility impairment than the cleanest days, and the bulk of the change results from human-related sources.

Figure 11-6. Projected "baseline" light extinction for Mesa Verde National Park (GCVTC 1996).

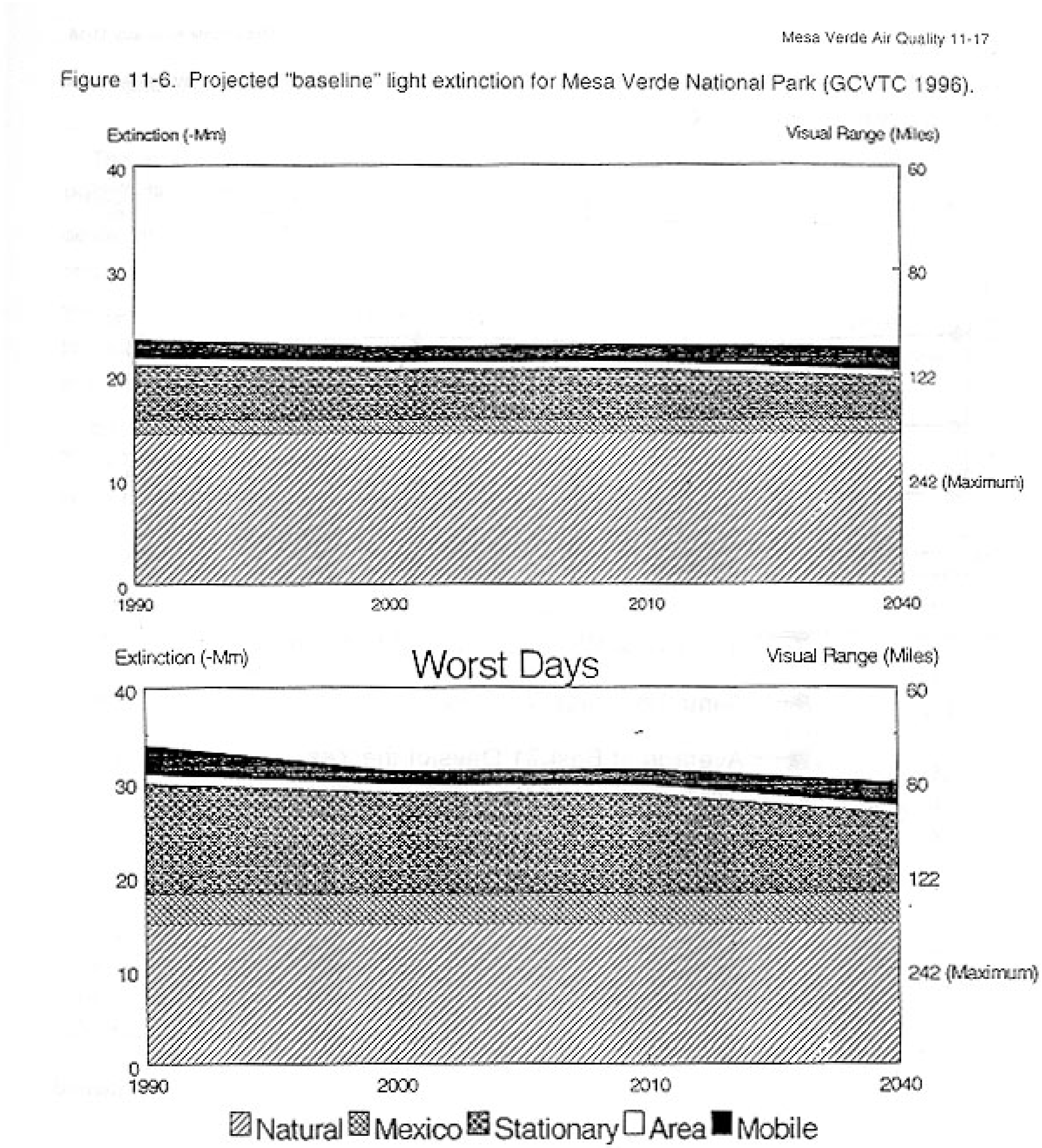
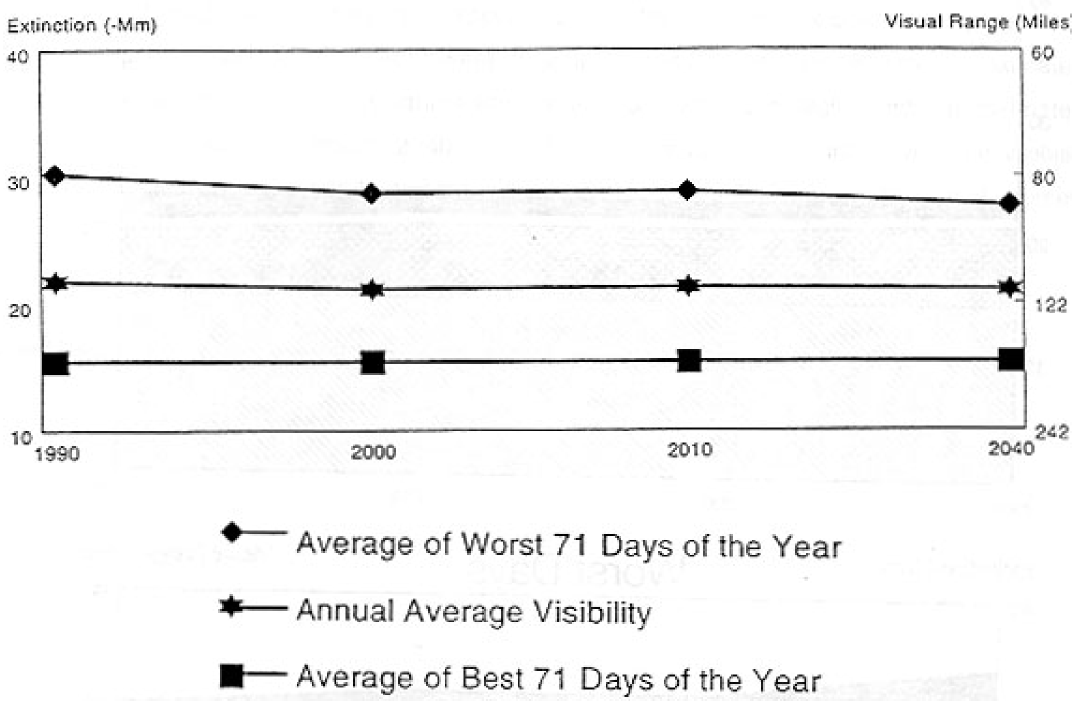


Figure 11-7. Projected "baseline" visibility for Mesa Verde National Park for good, average, and poor visibility conditions (GCVTC 1996).

Figure 11-7. Projected "baseline" visibility for Mesa Verde National Park for good, average, and poor visibility conditions (GCVTC 1996).



Graph starts at 10-Mm Which is Blue Sky or Rayleigh Extinction.

Atmospheric Deposition

The rates of atmospheric deposition for Mesa Verde National Park are relatively low (Table 11-6). Precipitation pH averages about 4.9. Deposition of N averages about 1.5 kg N ha^{-1} yr^{-1}, and S deposition averages about 2 kg S ha^{-1} yr^{-1}. No trend is apparent for the concentration or deposition of N, but S deposition declined by an average of 8 mg S m^{-2} yr^{-1} (0.08 kg S ha^{-1} yr^{-1}; $r^2 = 0.5$, $p < 0.01$; see also Lynch et al. 1996). There is no evidence that such low levels of deposition pose any threat to plants (see Chapter 2), and recent assessments indicate no risk for archeological sites (Petuskey et al. 1995).

Table 11-6. Atmospheric deposition for Mesa Verde National Park (NADP). Note the values for N and S compounds include the whole molecule and not just the N or S atoms.

	Concentrations (mg/L)			Deposition (kg ha^{-1} yr^{-1})				Conductivity (μS/mm)	Precipitation (mm/yr)
year	NH_4	NO_3	SO_4	NH_4	NO_3	SO_4	pH		
1981	0.15	1.30	2.14	0.46	3.95	6.51	4.73	1.89	304
1982	0.13	0.89	1.43	0.84	5.78	9.29	4.69	1.40	649
1983	0.09	0.70	0.96	0.52	4.01	5.50	4.88	0.95	573
1984	0.17	1.23	1.51	0.69	5.02	6.17	4.75	1.57	408
1985	0.07	0.72	1.07	0.37	3.85	5.72	4.91	1.01	535
1986	0.09	0.72	0.95	0.58	4.61	6.08	4.89	0.96	640
1987	0.13	0.94	1.08	0.63	4.57	5.25	4.80	1.09	486
1988	0.07	1.04	1.14	0.29	4.26	4.67	4.82	1.23	410
1989	0.21	1.29	1.20	0.56	3.41	3.17	4.96	1.15	265
1990	0.18	1.20	1.31	0.77	5.12	5.59	4.87	1.39	427
1991	0.10	0.88	1.01	0.49	4.36	5.00	4.86	1.10	495
1992	0.17	0.87	0.90	0.85	4.34	4.49	4.94	0.89	498
1993	0.11	0.74	0.77	0.58	3.88	4.03	5.02	0.76	524
1994	0.15	1.10	1.02	0.69	5.08	4.71	4.80	1.15	462

Sensitivity of Plants

No signs of injury signs from air pollution have been reported for vegetation in or near Mesa Verde National Park. Only a few of the Park's species have been tested under controlled conditions for sensitivity to pollutants, and none of these tests included genotypes representative of the plants in the Park. Based on the ozone concentrations required to affect very sensitive plants (such as aspen), we expect that current ozone exposures could be high enough to affect some species. Current levels of ozone are probably too low to affect the conifers, and levels of SO_2 are far below any demonstrated threshold of sensitivity for any plants. In the absence of empirical evidence of any effects, no substantial problem is likely.

Water Quality and Aquatic Organisms

Mesa Verde National Park is situated on a sandstone plateau with deeply cut drainages that flow into the Mancos River, which forms part of the eastern boundary of the Park. Surface water bodies are few and mainly ephemeral in nature. This hydrogeological setting and potential buffering by soils and sediments are similar to many of the other park units on the Colorado Plateau; therefore we would expect that surface water bodies have high ANCs. We were not able to locate any surface water chemistry data for the Park.

Amphibians

Although we could locate few aquatic system data from Mesa Verde National Park, there is a published species list for amphibians found in the park (Douglas 1966): Utah tiger salamander (*Ambystoma tigrinum utahense*), Red-spotted toad (*Bufo punctatus*), Rocky Mountain toad *(Bufo woodhousei woodhousei*), and the Western leopard frog (*Rana pipiens brachycepala*). There is no evidence of sensitivity of amphibians to atmospheric deposition at rates experienced in Mesa Verde.

Recommendations for Future Monitoring and Research

General recommendations for Class I NPS areas of the Colorado Plateau are provided in Chapter 14, and many of these apply to Mesa Verde National Park. Air quality monitoring at Mesa Verde includes continuous monitoring of ozone, IMPROVE sampler, and sampling of atmospheric deposition (NADP). We have no recommendations for additional monitoring of air quality.

No water quality data are available for the Park. We do not recommend that these data be collected unless Park staff are able to locate areas having both resistant bedrock geology and important habitat for vertebrate or invertebrate species. If such a situation is found, then we recommend reconnaissance monitoring for pH, ANC, sulfate, and nitrate in these waters.

Park Summary

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

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.

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