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Project Summary

Visibility Investigative Experiment in the West (VIEW)

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In response to the growing concern over impairment of visibility in parklands of the West and requirements of the Clean Air Act of 1977, the U. S. Environmental Protection Agency's (EPA's) Environmental Monitoring Systems Laboratory, Las Vegas, in cooperation with the National Park Service (NPS), established the VIEW (Visibility Investigative Experiment in the West) program. Regional scale monitoring networks were established to measure visibility and airborne particle composition and concentrations. Statistical and case study analyses are being applied to these data. This summary presents a brief discussion of preliminary results from these analyses. Highlights include a significant decline in summer visibilities in the south-west, well-defined seasonal cycles, a determination of the relative contribution of fine and coarse particulates and of the relative contribution of fine sulfur to visibility impairment, and the significant contribution of copper smelter emissions to southwest regional visibility impairment.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Las Vegas, NV, to announce key findings of the research project that is fully documented in two separate reports (see Project Report ordering information at back).

Introduction

During the past decade, there has been growing concern over the impairment of visibility in the western national parks due to man-made pollutants. The West enjoys extremely good visibility compared to other regions of the country, with an annual median standard visual range exceeding 140 kilometers (km) over a large geographical area (Figure 1). Because of its relatively clear air, this region is also particularly sensitive to future visibility impairment. Concern has been heightened by anticipated energy resource development that may significantly increase airborne pollution concentrations in the region.

Congress, in the Clean Air Act of 1977, established as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I federal areas which impairment results from man-made air pollution." Mandatory class I areas include International Parks, National Wilderness Areas and National Memorial Parks exceeding 5000 acres, and National Parks exceeding 6000 acres. Subsequent regulations (40 CFR Part 51) defined *visibility impairment* as "any humanly perceptible change in visibility (visual range, contrast, coloration) from that which would have existed under natural conditions." Under these regulations, certain states are required to develop and implement programs to address the congressionally declared goal. Visibility monitoring is required for:

1. Identification of visibility impact from existing sources.
2. Visibility assessment for new source review.
3. Demonstration of progress towards achieving the national goal.

In response to the congressional mandate, in 1977 the EPA's Environmental Monitoring Systems Laboratory in Las Vegas inititated a cooperative research program with the National Park Service (NPS) known as the Visibility Investigative Experiment in the West (VIEW). The program has had the following monitoring objectives.

1. Development and evaluation of improved visibility monitoring ap-

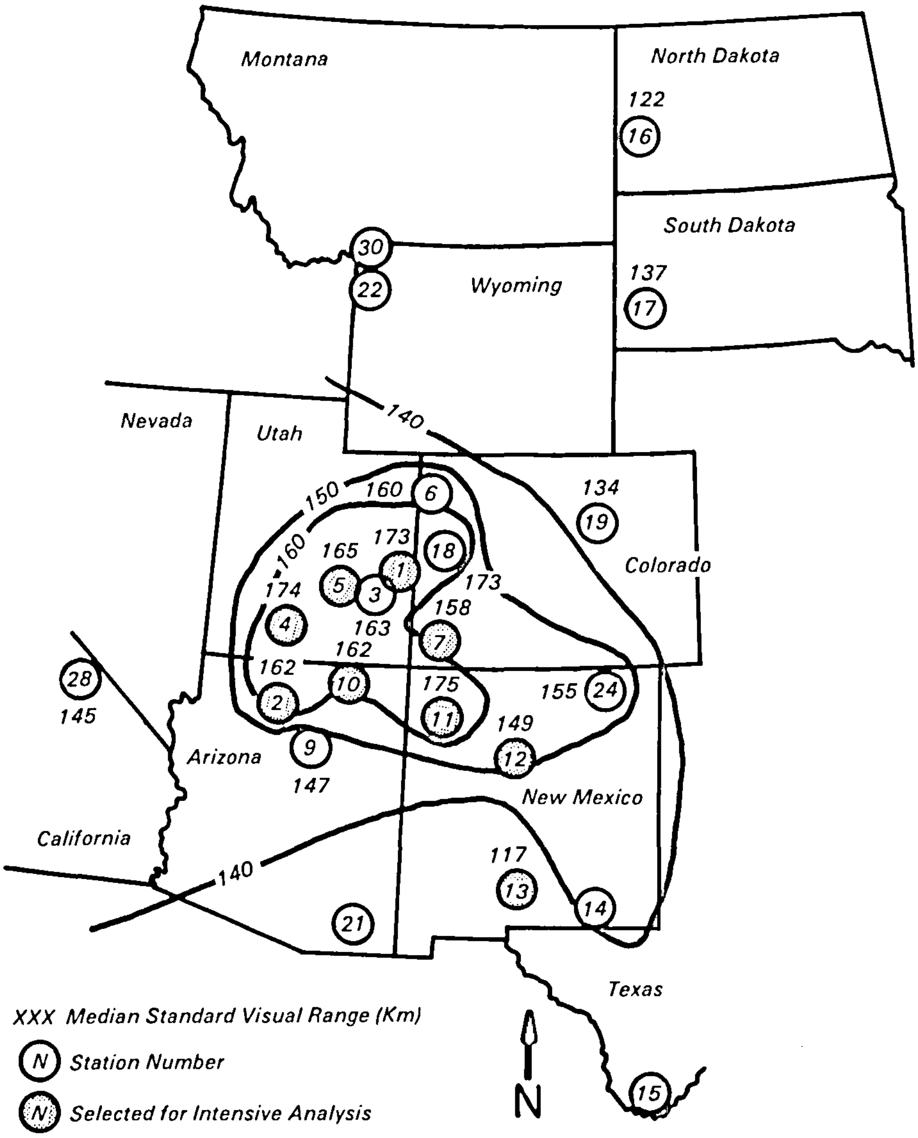

Figure 1. *Regional visibility monitoring network, showing median standard visual range.*[1]

proaches.

2. Characterization of the temporal and spatial dynamics of visibility impairment in the West.
3. Identification of major sources of visibility impairment in the West.

A regional scale monitoring program was established which included visibility and atmospheric particulate monitoring. These data are now yielding significant insight into the sources and nature of visibility impairment in the West.

Procedure

The study of visibility and its relationship to meteorology and atmospheric aerosol content is a complex and, in many cases, a semi-quantitative science. Traditionally, visibility has been defined in terms of visual range: the maximum distance from an object at which the contrast between that object and some appropriate background is perceptible, i.e., above threshold contrast. Threshold contrast refers to the smallest difference between two stimuli that the human eye can distinguish. The measurement of these quantities depends on the nature of the observer, his or her physical health, and his or her mental attitudes of attention or distraction due to effects such as boredom and fatigue.

Although visibility defined in terms of visual range of a distant target is a meaningful definition, visibility also includes being able to appreciate the details of line, texture, color, and form of vistas at shorter distances. Therefore, it is not reasonable or even possible to define visibility in terms of any one physical variable. It is necessary to measure a set of variables that: 1) relate directly to what the eye-brain system perceives, 2) can be monitored directly, and 3) can be related to the atmospheric constituents controlling visibility.

Improving Visibility Monitoring Methods

Evaluation of methods to characterize visibility was one of the earliest tasks of the VIEW program. Initially, an extensive review was made of instruments that can measure optical parameters in the atmosphere.[2] This review led to establishment of research stations employing several types of visibility monitoring devices. The basic measurement techniques utilized included:

photography - documents perceived visual air quality;
multiwavelength telephotometer - measures apparent contrast between target and horizon or other objects and is useful over long path, up to 50 to 100 km;
transmissometer - measures transmission and extinction of light over a fixed path, 10 to 20 km;
nephelometer - measures light scattering by particles at a single point and estimates extinction coefficient.

The use of these and other instruments in the field served the dual purpose of building a valuable visibility data base while allowing the instruments and procedures to be evaluated and improved.

Visibility Baseline

To characterize visibility throughout the western United States, a regional network of visibility monitoring stations was established. The network was operated by the Visibility Research Center of the John Muir Institute with field support from the NPS. The network consisted of 23 stations, shown in Figure 1 and listed in Table 1. Three additional stations were operated outside the VIEW network (Olympic National Park, Washington, Shenandoah National Park, Virginia, and Acadia National Park, Maine). Visibility measurements were made at each station using a teleradiometer, measuring the light received from a 'target' (i.e., a point on a distant mountain) and from the adjacent sky at four wavelengths: 405 nanometers (nm),

Table 1. *Regional Visibility Monitoring Network, Standard Visual Range (km): Seasonal Geometric Mean and Station Median*[1]

Station		1978			1979				1980				1981			
Number	Location	S	F	W	S	S	F	W	S	S	F	W	S	S	F	Median
1	Island in the Sky, UT		200	251	169	189	190	194	182	190	206	241	192	165	205	173
2	Grand Canyon, AZ	172	208	248	159	178	194	276	130	159	219	264	180	138	203	162
3	Canyonlands, Hans Flat, UT				136	166	176	206	151	158	180	174				163
4	Bryce Canyon, UT	178	208	259	144	170	195	289	129	138	223	280	192	159	206	174
5	Capital Reef, UT	190	215	ND	171	175	189	216	164	164	206	159	204	160	207	165
6	Dinosaur, CO	192	ND	205	168	177	192	ND	102	151	203	209	166	145	ND	160
7	Mesa Verde, CO	207	185	ND	153	182	184	189	139	176	201	235	190	153	172	158
9	Wupatki, AZ	166	122	188	201	159	162	215	141	158	180	165	170	140	176	147
10	Navajo, AZ	192	191	ND	160	164	175	264	145	168	230	256	192	152	218	162
11	Chaco Canyon, NM	187	203	ND	188	198	198	298	176	180	213	257	177	163	208	175
12	Bandelier, NM	172	155	226	284	148	149	186	174	164	176	221	187	147	176	149
13	White Sands, NM	118	125	190	143	114	115	159	132	119	139	177	141	112	133	117
14	Carlsbad, NM	157	179	245	151	139	142	206	197							144
15	Big Bend, TX	148	130	212	163	154	146	174	168	128	146	208	183	139	143	126
16	Theodore Roosevelt, ND				120	113	154	230	100	131	195	211	130	115	135	122
17	Wind Cave, SD				123	145	179	ND	111	163	194	209	185	159	128	137
18	Colo. Nat'l Mon., CO									177	204	235	190	171	183	173
19	Rocky Mt. N.P., CO									157	239	278	221	193	199	134
21	Chiricahua, AZ													145	244	138
22	Grand Tetons, WY									152	172			147	151	137
24	Capulin, NM								137	139	207	273	180	160	201	155
28	Death Valley, CA							250	171	145	235	294	204	142	220	145
30	Yellowstone, WY													177	161	141

ND = No Valid Data.
F = Fall, W = Winter, S = Spring or Summer.
Blanks signify no data available.
Seasonal geometric mean calculated from edited data.
Median derived from cumulative frequency graph.

(violet), 450 nm (blue), 550 nm (green), and 630 nm (red). The wavelengths were chosen to cover the visible spectrum and avoid the strong reflection beyond 650 nm from vegetation. Up to six targets were sighted, in a variety of directions, at each observation station. Where possible, the targets were selected at distances between 10 and 75 percent of the estimated mean visual range. Within these distances apparent contrast (perceived contrast of an object against its background) is particularly sensitive to changes in air quality. Measurements were made three times a day (9:00 am, noon, and 3:00 pm local time). Measurements are expressed as standard visual range. Standard visual range is visual range normalized to a reference Rayleigh scattering coefficient of 0.01 km^{-1}. Rayleigh scattering is that caused by air molecules in an unpolluted atmosphere. At a Rayleigh scattering coefficient of 0.01 km^{-1}, the visual range is 391 km. In addition to teleradiometer measurements, color photographs were taken.

Figure 1 depicts median standard visual range for stations with a minimum of one full year of data. Table 1 summarizes available data for the study period and indicates seasonal geometric mean visual range. Data for individual stations are available in a variety of formats. Examples of data for Grand Canyon National Park are shown in Figures 2 and 3.

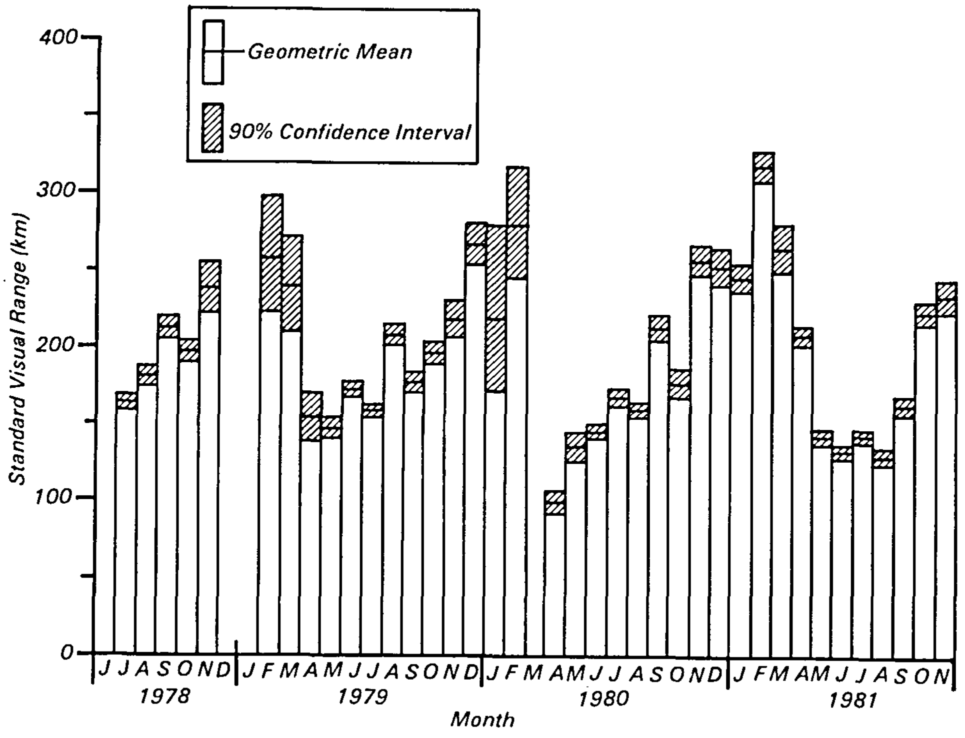

Figure 2. *Grand Canyon National Park, monthly standard visual range, geometric mean (km).*[1]

Particulates

In addition to visibility monitoring, a network for airborne particulate sampling

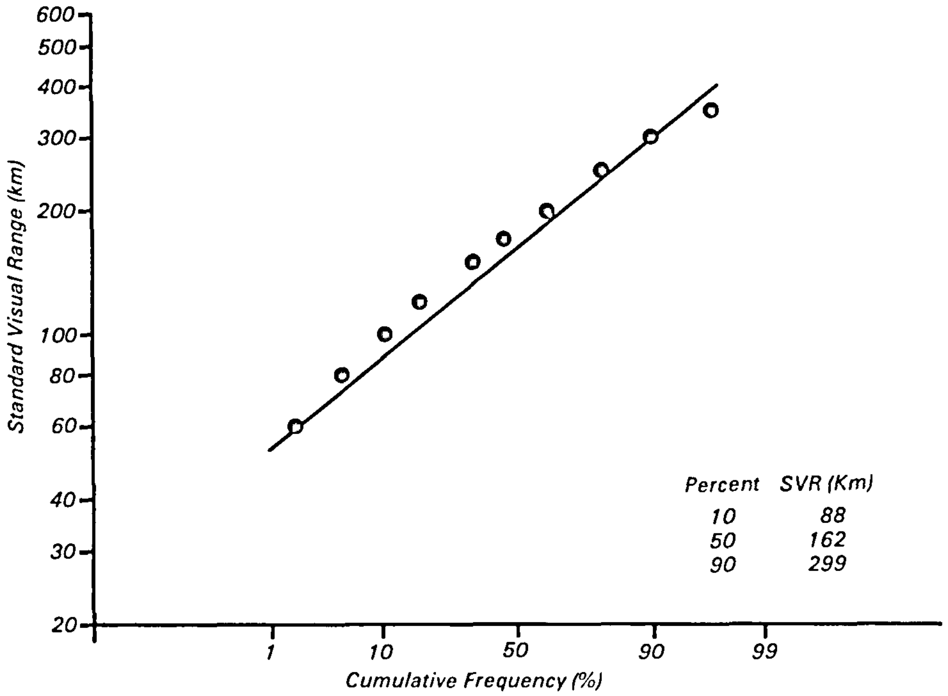

Figure 3. *Grand Canyon National Park, cumulative frequency of standard visual range (km), July 1978 through November 1981.*[1]

was also established. The network is shown in Figure 4. Station names and data are listed in Table 2. The network was operated by the Air Quality Group of the University of California at Davis, with field support from the NPS and other agencies. Although the particulate network covered a larger area than the visibility network, particulate samplers were colocated with visibility stations where possible.

Particulates were samples with a stacked filter sampler which separates particles into two size ranges: less than 2.5 μm diameter and 2.5 to 15 μm. The samplers were operated for 72 hours, twice per week. This sampling scheme yielded data representing six of every seven days. All samples were analyzed gravimetrically and by particle-induced x-ray emission (PIXE) for elements heavier than sodium. The trace elements analysis allows the association of visibility impairment with types of sources through case studies and statistical analyses.

Sampling began at some sites in August 1979 and the network was fully operational by October 1979. Sampling ended on October 1, 1981. Eighty-eight percent data recovery was obtained over the network for the study period. Table 2 summarizes the average coarse and fine mass and fine sulfur for the study period. Figure 4 depicts the average fine sulfur concentration over the network for the entire sampling period.

Quality Assurance

A rigorous quality assurance program was instituted to assess the performance of visibility and particulate measurement techniques. The program consisted of both systems audits and performance audits. Annual systems audits were intended to ensure the application of documented operating and maintenance procedures and to evaluate the reliability of the data handling and reporting system. Semi-annual performance audits served to evaluate the accuracy and precision of monitoring instruments and laboratory analyses.

Results

These data were analyzed to identify the major causes of visibility impairment and to establish the relationships between visibility impairment and particulates. At the same time the monitoring techniques themselves were evaluated. Both statistical and case study approaches have been applied.

Monitoring Methods

It has become clear that several types of instruments are needed to determine visibility impairment and to relate such impairment to sources.[4] Optical instruments are essential for the characterization of visibility impairment. Instruments to measure particulate composition and concentration are critical in source identification. A measurement of apparent vista contrast, which relates well to human perception of visual air quality, can be converted into ground level extinction coefficient (a measure of the light attenuation characteristic of a parcel of air) or fine particulate concentration only with restrictive assumptions concerning uniform concentrations along horizontal sight paths. Conversely, a measurement of ground level fine particulate concentration or extinction coefficient will not allow an accurate computation of visual air quality in terms of target contrast. However, when site intercomparisons are required (such as for establishing regional trends) it is useful to use visual range as a normalizing variable. Also, because of its historical popularity, it remains a useful concept to indicate atmospheric 'clarity' to the lay person.

Experience gained from the VIEW program led to the publication of "Interim Guidance for Visibility Monitoring."[5] The recommended minimum visibility monitoring program is shown in Table 3.

Results from the quality assurance program indicated a standard error for teleradiometer measurements ranging from 5.87% for high contrast targets to 24.2% for low contrast targets.[6] Standard Error is defined as the deviation about zero for the difference in measured contrast between paired measurements. Flow audits for particulate samplers showed that 60% of the samplers had an absolute percent difference between sampler and audit flows of 15%, with 80% of the flows being within 25%. Audits of gravimetric analysis over the period of study showed an average absolute percent difference between measured and audit weights of 0.08%. Filter trace element analysis audits showed a precision of ±8.0% for PIXE analysis. Interlaboratory agreement on split samples was generally within ±20% for all elements.

Visibility Baseline

Nine stations (12 targets) were selected from the network for more intensive analysis. These stations are shown in Figure 1 as shaded circles. Target selection was based on the following criteria:

1. Data available from the summer 1978 through September 1981.
2. Optimum target distance of between 45 and 75 km.

Table 2. *Western Fine Particulate Monitoring Network*[3]

Station Number	*Location*	*Average Concentration* Coarse Mass $\mu g/m^3$	Fine Mass $\mu g/m^3$	Fine Sulfur $\mu g/m^3$
1	*Murphy Lake, MT*	*4.3*	*4.7*	*0.271*
2	*Malta Airport, MT*	*8.9*	*3.2*	*0.216*
3	*Medicine Lake NWR, MT*	*8.2*	*3.9*	*0.330*
4	*Upper Souris NWR, ND*	*13.0*	*4.5*	*0.315*
5	*Belt Creek Ranger Station, MT*	*3.3*	*2.3*	*0.169*
6	*Jordan Airport, MT*	*19.3*	*4.5*	*0.280*
7	*Theodore Roosevelt NMP, ND*	*8.7*	*4.1*	*0.352*
8	*Bald Hill Dam, ND*	*13.1*	*4.1*	*0.275*
9	*Big Hole Valley, MT*	*3.0*	*2.0*	*0.155*
10	*Bluewater Fish Hatchery, MT*	*5.9*	*2.7*	*0.275*
11	*Charlie Odell's Ranch, MT*	*10.8*	*2.8*	*0.222*
12	*Lake Hiddenwood State Park, SD*	*8.9*	*3.7*	*0.327*
13	*Yellowstone NP, WY*	*2.4*	*1.6*	*0.123*
14	*Buffalo Airport, WY*	*8.7*	*2.9*	*0.214*
15	*Mount Rushmore MN, SD*	*4.8*	*2.7*	*0.273*
16	*Lake Andes NWR, SD*	*13.7*	*5.1*	*0.403*
17	*Lander Airport, WY*	*8.9*	*3.9*	*0.216*
18	*Fort Laramie NHS, WY*	*8.7*	*3.7*	*0.321*
19	*Fossil Butte NW, WY*	*5.5*	*3.4*	*0.291*
20	*Saratoga, WY*	*5.0*	*2.5*	*0.214*
21	*Fish Springs NWR, UT*	*6.1*	*2.4*	*0.198*
22	*Brown's Park NWR, CO*	*4.5*	*2.6*	*0.242*
23	*Rocky Mountain NP, CO*	*3.5*	*2.5*	*0.250*
24	*Cedar Mountain, UT*	*4.9*	*2.8*	*0.288*
25	*Delta County Airport, CO*	*10.2*	*3.7*	*0.182*
26	*La Junta, CO*	*7.7*	*4.0*	*0.304*
27	*Bryce Canyon NP, UT*	*4.1*	*2.7*	*0.320*
28	*Canyonlands NP, UT*	*4.5*	*2.6*	*0.299*
29	*Great Sand Dunes NM, CO*	*5.7*	*2.4*	*0.223*
30	*Grand Canyon NP, AZ*	*3.4*	*2.2*	*0.262*
31	*Chaco Canyon NM, NM*	*4.9*	*2.5*	*0.304*
32	*Fort Union NM, NM*	*4.2*	*2.7*	*0.273*
33	*Montezuma Castle NM, AZ*	*8.2*	*4.0*	*0.412*
34	*Petrified Forest NP, AZ*	*3.8*	*2.9*	*0.365*
35	*Grand Quivira NM, NM*	*5.8*	*2.9*	*0.368*
36	*Organ Pipe Cactus NM, AZ*	*9.4*	*4.6*	*0.586*
37	*Tonto NM, AZ*	*6.8*	*4.4*	*0.596*
38	*Gila Cliff Dwelling NM, NM*	*4.2*	*3.5*	*0.472*
39	*Carlsbad Caverns NP, NM*	*7.4*	*3.3*	*0.389*
40	*Fort Bowie NHS, AZ*	*7.4*	*4.3*	*0.664*
ALL		*7.0*	*3.3*	*0.306*

NWR - National Wildlife Refuge, NMP - National Memorial Park, NP - National Park, NM - National Monument, NHS - National Historic Site.

3. Target inherent contrast at 550 nm equal to or greater than 0.7 for all times of day.

In order to satisfy the assumption of data independence for statistical testing, the data set was randomly sampled. A temporal plot of seasonal arithmetic mean visual range for a random sampling of the nine stations shows several major characteristics (Figure 5). The most obvious is the seasonal cycle showing lower visibility during the summer and greater visibility during the winter months. Figure 2 shows this cycle more clearly for Grand Canyon. This same cycle is seen with particulate sulfate data (Figure 6). Less obvious, but more important, is the apparent decrease in summer visibility over the four-year study period (Figure 5). Analysis of variance (Student-Newman-Keuls Stepwise Multiple Regression) shows that the trend in summer data is significant at the 95% confidence level. There is no significant trend discernable for the other seasons within the period of the study although significant differences are noted between seasons for different years. The fall of 1980, for example, shows significantly greater visibility than 1979 or 1981. This may indicate the impact of the copper smelter strike of 1980 (discussed in a later section).

It is important to note that although the decreasing trend in summer visibility is statistically significant, the cause for the trend is not understood at this time. Further investigation is required.

Particulate

Analysis of particulate data shows that coarse particulate makes up, on the average, 67% of the total mass sampled.[3] The correlation coefficient between total coarse mass and soil-derived mass is 0.90, indicating that the coarse fraction is soil related.

Fine particulate (i.e., less than 2.5 μm) constituted 33% of the total mass and was dominated by sulfur and soil components. Ammonium sulfate accounted for 38% of the fine mass while fine soil contributed 23% (Figure 7). Estimated smoke mass (from K/Fe ratios) was 9% with light elements making up approximately 30%. The light elements are those below the atomic number of sodium. These are not detected by PIXE analysis or accounted for as assumed oxides.

Eighty-eight percent of the sulfur collected was on the fine stage. A temporal plot of sulfate for selected stations is shown in Figure 6. Although significant spatial and temporal variability are apparent, a coherent regional fine sulfur pattern still emerges (Figure 4).

Visibility Particulate Correlations

A regression analysis was performed on visibility and particulate data from seven selected stations for which both visibility and particulate data were available. This analysis indicates that the coarse and fine particle data explain more than 75% of the variations in the particle extinction coefficient and that coarse particles may contribute from 30% to as much as 80% of the particle extinction coefficient.[7] In general, it is found that coarse particles are more dominant in summer than in winter. Data from Grand Canyon are shown in Figure 8. Principle component analysis indicates that fine sulfur also shows a significant correlation with visibility.[8]

It should be noted that data from other regions in the United States show significantly different extinction budgets. Data from Lake Tahoe were collected in a separate study and indicated negligible coarse particulate contribution to extinction.

Case Studies

The statistical analyses cited above treat the data sets in their entirety and may tend to obscure or ignore some of the available information. For this reason an objective case study approach to data interpretations is also being undertaken.

Trajectory analysis using National Weather Service upper air measure-

Table 3. *Recommended Minimum Visibility Monitoring Program*[5]

Instrument	*Parameter*	*Frequency*
ELECTRO-OPTICAL MEASUREMENT		
Manual or continuous multi-wavelengths teleradiometer	*Target and sky radiance*	*Manual: three measurements/day* *Continuous: daylight hourly averages*
Camera (color photography)	*Vista appearance*	*Three photographs/day*
Integrating nephelometer	*Scattering coefficient*	*Continuous (hourly average)*
SUPPLEMENTAL MEASUREMENTS		
Particulate samples	*Mass concentration of particulates, elemental constituents, in two size ranges*	*Two samples/week*
Meteorological sensors	*Wind speed and direction, humidity*	*Continuous (hourly average)*

ments and the Air Research Laboratory Atmospheric Transport and Dispersion (ATAD) model is being applied to episodal periods. Figure 9, for example, shows wind trajectories for the 11 worst visibility days at Grand Canyon between September 1978 and October 1979. The time extent of the trajectory in hours is shown at the origin of the trajectory path along with the date of arrival at Grand Canyon. The trajectories indicate transport from southern California, Arizona, New Mexico and western Texas, raising the question of copper smelter emission impact on regional visibility. Fine sulfur and silicon concentrations for these periods were in the top 10 percent and 20 percent of annual values measured, respectively.[9]

Time series analysis is also being used to evaluate the network data. Preliminary analysis indicates that visibility and particulate concentrations sometimes behave in unison over large regional areas, whereas during other periods unique site specific episodes are apparent. Figure 6 shows a long-term temporal plot of sulfate data for several selected stations. Of particular interest is the impact of the copper smelter strike from July through September of 1980. Table 4 shows the maximum and average sulfate levels for stations within 650 km of major smelters for 1979, 1980, and 1981.[10] During the strike, sulfate concentrations at remote sites throughout Arizona, western New Mexico, and southern Utah were less than one-half of the maximum levels of the non-strike summers of 1979 and 1981. Statistically significant changes in the summer mean concentrations were observed within 600 km. Using the mean levels of 1980 to estimate the non-smelter background, it appears the smelters increased the mean sulfate levels 2 to 3 g/m^3 at sites within 100 km and about 1 g/m^3 at sites between 200 km and 600 km. On the average, the smelters may have been responsible for about 70% of the sulfate at near sites and 50% of the sulfate throughout the rest of the region. An analysis of meteorological parameters concluded that surface winds were nearly identical for the summers of 1980 and 1981. For the two months in 1979 when samples were collected, winds from the southeast were more frequent than they were in 1980 and 1981. This may account for the higher smelter contributions in 1979 compared to 1981.

Conclusions

1. Visibility in the Four Corners region of the Southwest averages above 140 km, with standard visual ranges commonly approaching the Rayleigh limit of 391 km.
2. Summer visibility in the Southwest decreased from 1978 through 1981. No visibility trend is evident for the other seasons.
3. Trajectory analysis for the Grand Canyon area shows the worst visibility conditions occurring with winds from the south and southwest, indicating possible particulate transport from southern California, Arizona, New Mexico, and western Texas.
4. Both visibility and particulate concentrations show a well-defined seasonal cycle. The coarse particles are more prevalent in the summer as compared to winter.
5. Fine particulate (<2.5 μm) constituted approximately 33% of the

Table 4. *Summer Sulfate Concentrations and Smelter Contributions ($\mu g/m^3$)*

	Km to	*Maximum Sulfate*			*Mean Sulfate*			*Mean Smelter Contribution*[a]					
	major	*Concentration*			*Concentration*			*Concentration*			*Percentage*		
Site	*smelter*	*1979*	*1980*	*1981*	*1979*	*1980*	*1981*	*1979*	*1981*	*both*	*1979*	*1981*	*both*
Ft. Bowie	*80*	*5.8*	*2.4*	*5.9*	*3.3*	*1.3*	*3.4*	*2.1*	*2.1*	*2.1*	*62*	*62*	*62*
Tonto	*100*	*5.8*	*1.3*	*5.7*	*3.9*	*0.6*	*2.5*	*3.3*	*2.0*	*2.5*	*86*	*78*	*82*
Gila Cliff Dwelling[b]	*110*	-	*2.2*	*5.9*	-	*1.1*	*2.4*	-	*1.3*	-	-	*55*	-
Montezuma Castle	*200*	*6.0*	*2.1*	*4.5*	*2.8*	*1.1*	*1.9*	*1.7*	*0.8*	*1.1*	*61*	*42*	*51*
Organ Pipe Cactus	*220*	*4.4*	*2.4*	*4.2*	*2.5*	*1.1*	*2.1*	*1.3*	*1.0*	*1.1*	*54*	*46*	*49*
Petrified Forest	*250*	*5.2*	*2.1*	*4.5*	*2.2*	*1.0*	*1.5*	*1.2*	*0.5*	*0.8*	*54*	*31*	*43*
Gran Quivira	*350*	*4.8*	*2.2*	*4.2*	*2.2*	*1.0*	*1.5*	*1.2*	*0.5*	*0.8*	*57*	*35*	*59*
Chaco Canyon	*400*	*3.7*	*1.5*	*1.9*[c]	*2.2*	*0.7*	*1.2*[c]	*1.5*	*0.5*	*1.1*	*68*	*41*	*45*
Grand Canyon	*400*	*3.8*	*2.3*	*3.3*	*2.1*	*0.6*	*1.1*	*1.4*	*0.4*	*0.8*	*70*	*42*	*57*
Bryce Canyon	*600*	*6.1*	*2.2*	*4.3*	-	*0.9*	*1.5*	-	*0.6*	*0.9*[d]	-	*41*	*52*[d]
Canyonlands	*650*	*5.0*	*1.8*	*2.0*	-	*0.7*	*1.0*	-	*0.3*	*0.5*[d]	-	*30*	*44*
Ft. Union	*550*	*1.6*	*1.5*	*1.5*	-	*1.0*	*1.0*	-	*0.0*	-	-	*1*	-
Average uncertainty					*0.3*	*0.1*	*0.2*	*0.3*	*0.2*	*0.2*	*13*	*14*	*11*

[a] *Mean during 1979, 1981 or both 1979 and 1981 minus mean during 1980.*

[b] *No samples July-September 1979.*

[c] *Collected less than 50% of possible samples in 1981.*

[d] *Mean for both summers include 3 samples in late September 1979.*

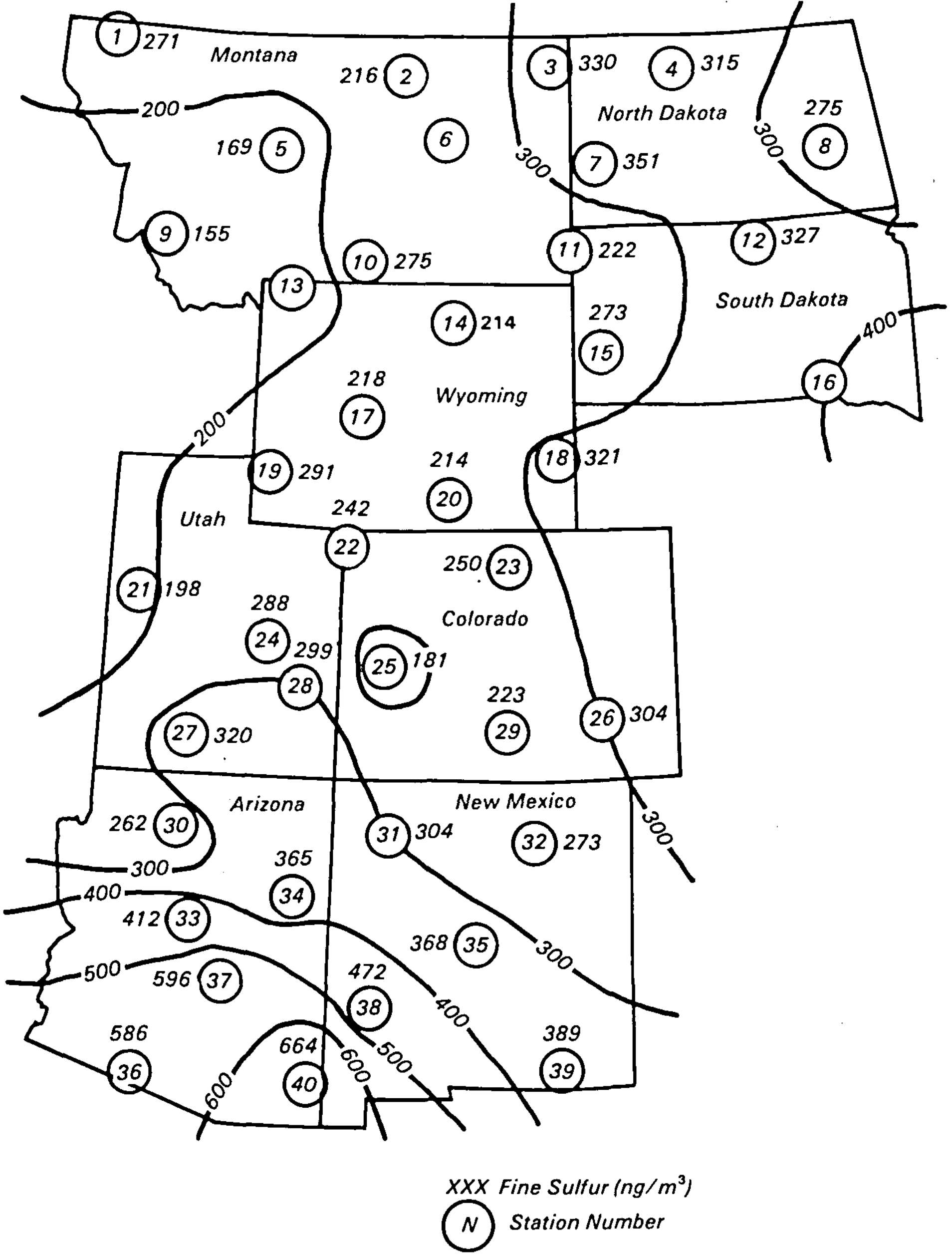

Figure 4. *Western Fine Particulate Network, average fine sulfur concentration (ng/m^3)[3].*

total mass (<15 µm) for the desert Southwest and northern Great Plains.

6. Coarse particulate was primarily soil material.
7. Twenty-three percent of the fine particulate was soil material.
8. Sulfate accounts for approximately 38% of the fine particulate mass in the Western Fine Particulate Network. Eighty-eight percent of the particulate sulfate is found in the fine fraction.
9. Coarse and fine particulate explain more than 75% of the variation in particle extinction coefficient. Coarse particulate accounts for 30 to 80% of the particle extinction coefficient for the southwest desert.
10. Mean sulfate concentrations measured at locations throughout the Southwest during July through September of 1979 and 1981 ranged from 1.0 to 3.9 µg/m^3. A detailed analysis of the impact of the copper smelter strike during July through September, 1980 indicates that the smelters may be responsible for at least 50% of the sulfate measured throughout the Southwest during that period.

Recommendations

Although data from visibility and fine particulate monitoring are yielding significant insight into the nature and causes of visibility impairment in the West, further analysis is required to better characterize the cause and effect relationships.

Because decreasing trends in summer visibility in the Southwest are evident, continued monitoring is required to confirm and define the cause of the trend.

Additional monitoring is required to identify the light element component of the fine particulate mode in order to fully define the total extinction budget.

Standardized methods are required for measurements and data analysis of visibility.

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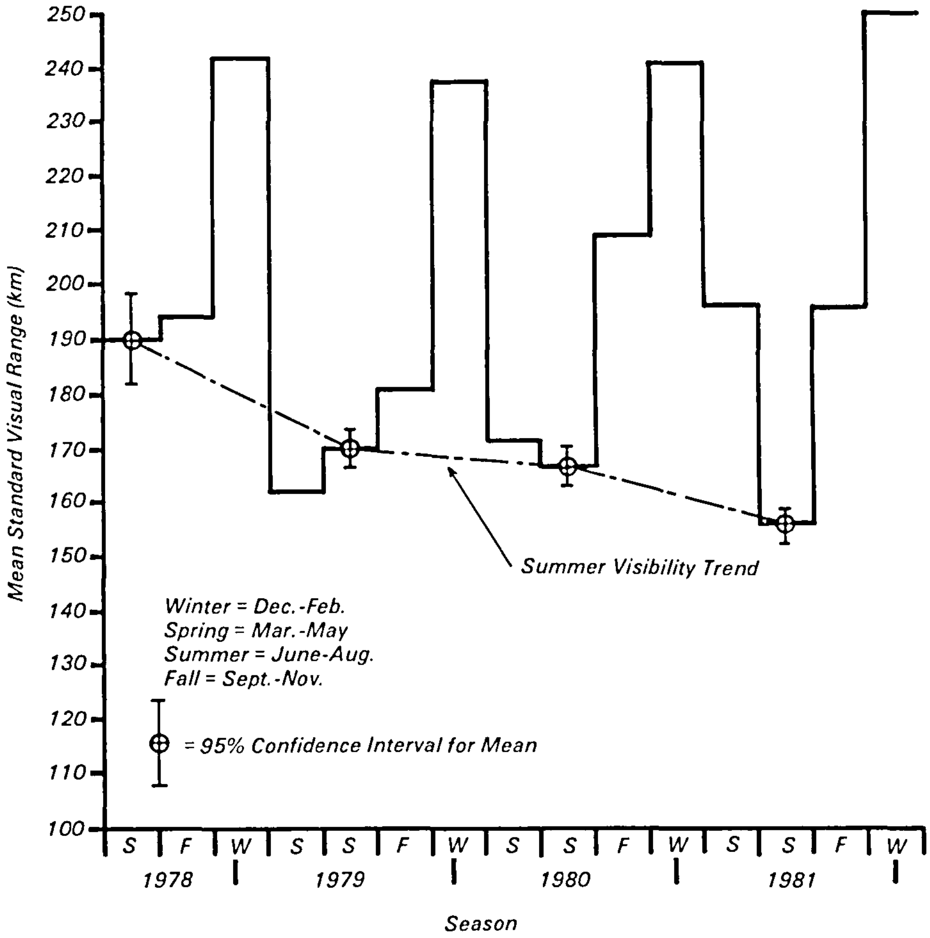


Figure 5. *Mean seasonal visibility (km) for selected stations.*

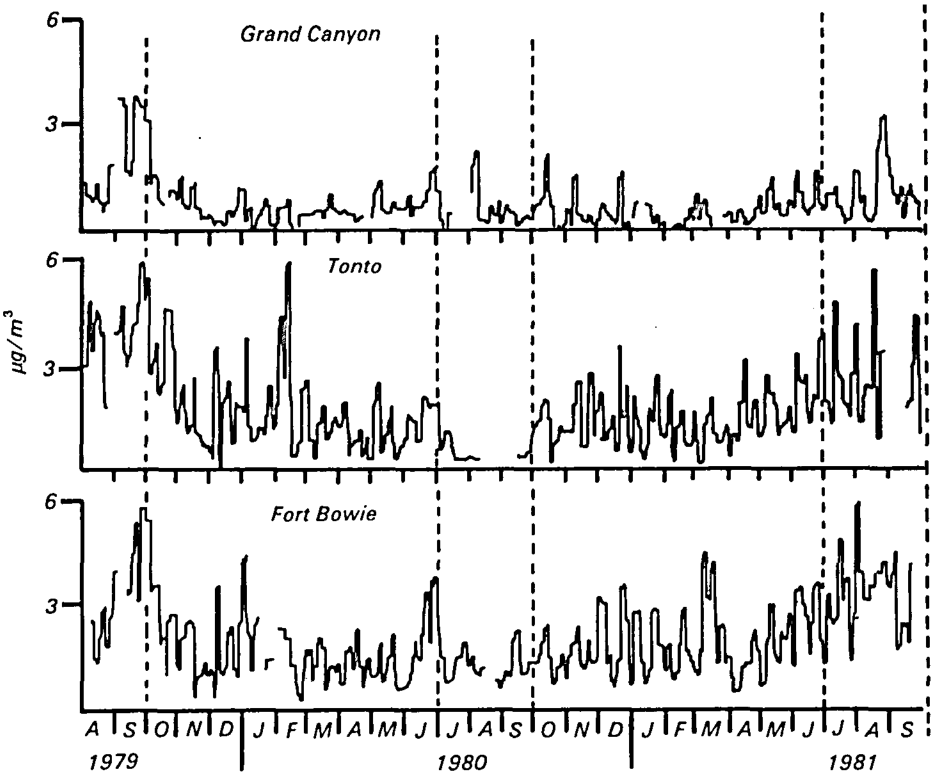


Figure 6. *Time plot of fine sulfate at selected stations.*[3] *Summer periods are bracketed by dashed lines.*

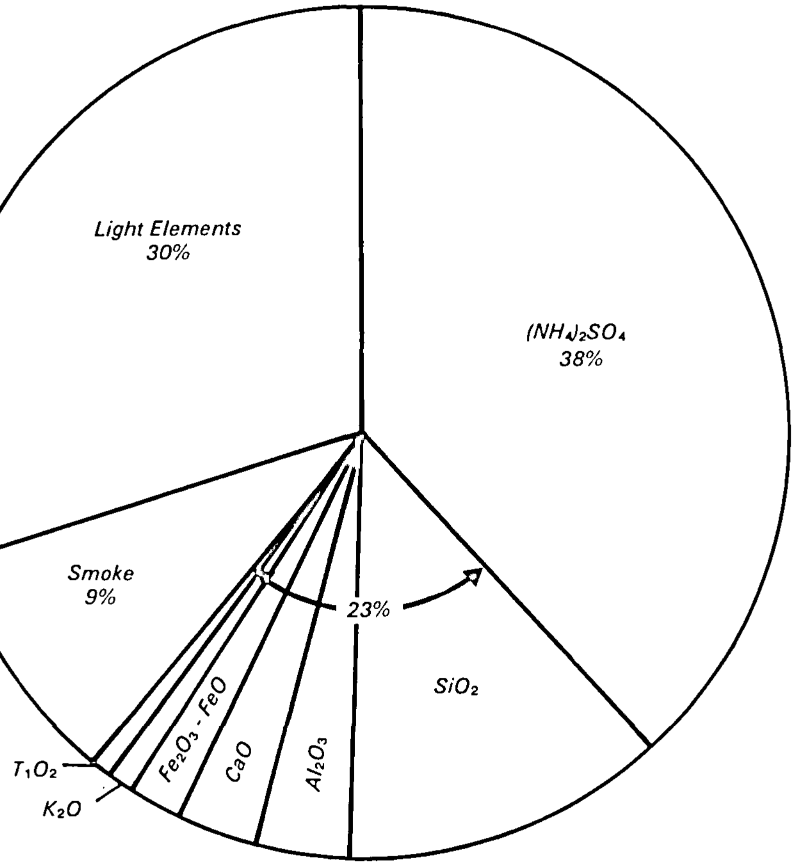


Figure 7. Average composition of fine particulate mass for the Western Fine Particle Network.[3]

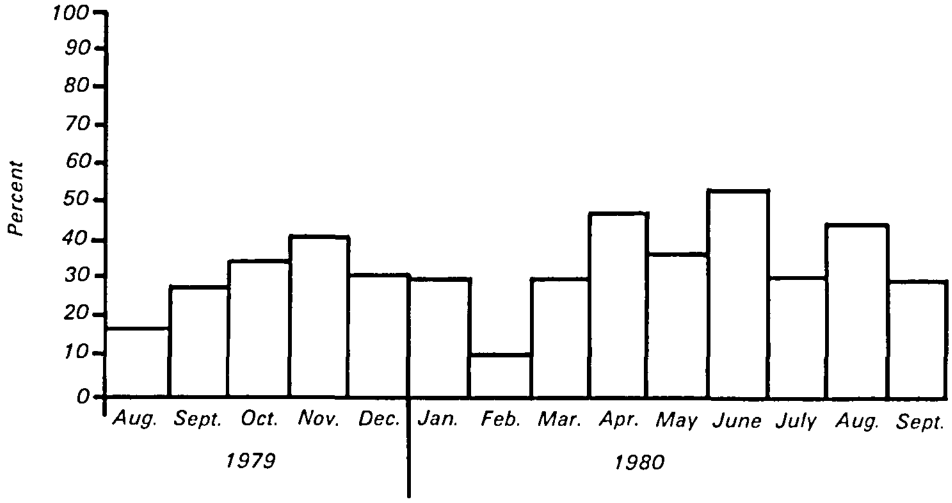
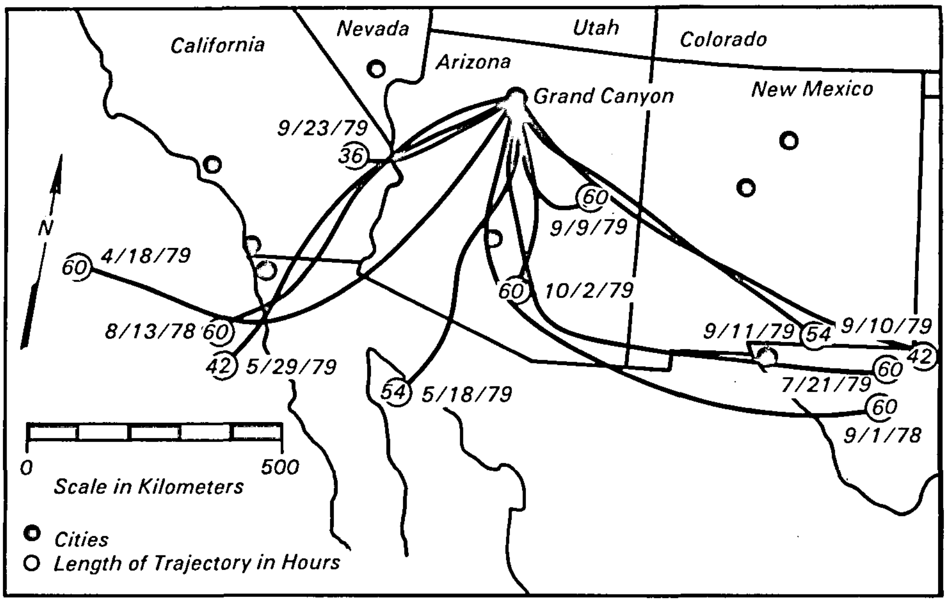


Figure 8. Monthly percent contribution to particle extinction coefficient by coarse particles for Grand Canyon National Park.[7]

*USGPO: 1984-759-102-10655



igure 9. Wind trajectories back in time for days of low visual air quality at Grand Canyon National Park.[9]

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This Project Summary covers the following two reports:

"Western Regional Visibility Monitoring: Teleradiometer and Camera Network" authored by staff of John Muir Institute for Environmental Studies, Inc., 743 Wilson Street, Napa, CA 94558," (Order No. PB 84-211 192; Cost: $13.00, subject to change).

"Western Particulate Characterization Study" authored by T. A. Cahill, R. G. Flocchini, R. A. Eldred, and P. J. Feeney who are with Crocker Nuclear Laboratory, University of California, Davis, CA 95616 (Order No. PB 84-211 200; Cost: $13.00, subject to change).

The above reports will be available only from:

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