United States
Environmental Protection
Agency
Air

Office of Air Quality
Planning and Standards
Research Triangle Park, NC 27711

EPA-454/R-99-003
June 1999

VISIBILITY MONITORING GUIDANCE

VISIBILITY MONITORING GUIDANCE DOCUMENT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Emissions Monitoring and Analysis Division
Monitoring and Quality Assurance Group
MD-14
Research Triangle Park, NC 27711

PREFACE

This EPA Visibility Monitoring Guidance Document was prepared to provide assistance to those organizations responsible for collecting visibility and particulate matter data for regulatory and planning purposes. This document contains EPA policy and, therefore, does not establish or affect legal rights or obligations. It does not establish a binding norm and is not finally determinative of the issues addressed. In applying this policy in any particular case, the EPA will consider its applicability to the specific facts of that case, the underlying validity of the interpretations set forth in this document, and any other relevant considerations, including any that may be required under applicable law and regulations.

EPA has cited examples of and references to existing instruments and protocols that are currently being used in operational visibility monitoring programs in this document. These examples and references to specific instrument models or manufacturers are not intended to constitute an EPA endorsement or recommendation for use.

ACKNOWLEDGMENTS

The Draft Visibility Monitoring Guidance Document was originally compiled by Air Resource Specialists, Inc. for the Environmental Protection Agency - Air Quality Strategies and Standards Division (Order No. 6D0418NASA). Many individuals were involved in the preparation and review of this final document including:

Rich Damberg
Joe Delwiche
Dave Dietrich
Bob Eldred
Dan Ely
Neil Frank
Tom Moore
Marc Pitchford
Bruce Polkowsky
Kristie Savig
Marc Scruggs
IMPROVE Steering Committee Members

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this Visibility Monitoring Guidance Document is to provide a written reference for organizations conducting monitoring of visibility and particulate matter for regulatory, planning, or research purposes. Possible users include the government sector (Federal, State, regional, local, and Tribal air quality agencies), industry, consulting firms, academia, or nonprofit organizations. The information in this document includes:

- Background on the visibility protection requirements of the Clean Air Act and related regulations.

- A summary of visibility monitoring goals and objectives set forth in the Clean Air Act and related EPA regulations.

- Considerations and recommendations for developing effective visibility monitoring sites and networks, particularly for implementation of the monitoring requirements for the PM-2.5 and regional haze regulatory programs. These considerations and recommendations address visibility definitions and theory, monitoring goals and objectives, data quality objectives, monitoring methods, data archive and data applications, and network design.

- Descriptions of current visibility measurement methods and monitoring protocols, particularly those used under the Interagency Monitoring of Protected Visual Environments (IMPROVE) program[1].

It is assumed that the reader of this document is generally familiar with aerometric monitoring principles and has the responsibility to design and operate a monitoring program to characterize visibility and/or particulate matter. This document is not meant to dictate EPA monitoring requirements or to define policy, standards, or data interpretation methods, but to provide a strategic framework that can be used by those with a need to monitor visibility for planning or regulatory purposes. The guidance is intended to assist monitoring organizations in developing effective, consistent, visibility monitoring sites and networks that use state-of-the-art methods to best meet individually defined objectives. The document does not address specific research monitoring requirements, and it does not address methods to evaluate the human perception of visual air quality.

This document focuses on instruments and analytical methods that are currently in use and are considered by EPA and the IMPROVE Program to be best suited for use at this time. Like any monitoring approach, visibility monitoring instrumentation and analytical methods are continually evolving in order to minimize uncertainty and improve quality assurance.

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[1] The IMPROVE Committee consists of representatives from the six cooperating federal agencies: National Park Service (NPS), EPA, National Oceanic and Atmospheric Administration (NOAA) , United States Forest Service (USFS), Bureau of Land Management (BLM), and United States Fish and Wildlife Service (USFWS); and four state consortiums: State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials (STAPPA/ALAPCO, Western States Air Resources Council (WESTAR), Northeast States for Coordinated Air Use Management (NESCAUM) and Mid-Atlantic Regional Air Management Association (MARAMA).

References made to specific instrument models or manufacturers are not intended to constitute an EPA endorsement. It should be recognized that this document may be updated periodically to reflect new and improved instruments and monitoring methods as they become available and are proven reliable.

1.2 DOCUMENT ORGANIZATION

This Visibility Monitoring Guidance Document is comprised of seven primary sections. Each section is described below:

Section 1.0 Introduction

Presents the purpose of the document, the document organization, and a summary of legislative and regulatory requirements that provide the basis for visibility protection and visibility monitoring.

Section 2.0 Monitoring Program Considerations and Requirements

Presents visibility definitions and theory, outlines visibility protection goals and monitoring objectives, how to design a site or network, and how to select and apply appropriate monitoring, data handling, and analytical methods.

Section 3.0 Aerosol Monitoring

Provides detailed examples of standard operating procedures for aerosol monitoring, including monitoring of PM-10 and PM-2.5 (including chemical composition analysis for sulfates, nitrates, organic and elemental carbon, and primary PM).

Section 4.0 Optical Monitoring

Provides detailed examples of optical monitoring protocols, including transmissometer and nephelometer monitoring systems.

Section 5.0 Scene Monitoring

Provides detailed examples of scene monitoring protocols, including 35mm and time-lapse camera monitoring systems.

Section 6.0 References

Section 7.0 Glossary of Terms and Abbreviations

1.3 BACKGROUND

Visibility impairment is probably the most easily recognizable effect of air pollution in the atmosphere. It is caused by the scattering and absorption of light by particles and gases in the air. Under the Clean Air Act (Act), Congress recognized that good visibility is a resource to be valued and preserved, now and for future generations. In section 169A of the Act, Congress set forth a national goal that calls for "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas[2] which impairment results from manmade air pollution." EPA is responsible for establishing regulations ensuring that "reasonable progress" toward the national goal is achieved in the 156 mandatory class I Federal areas (primarily national parks and wilderness areas) identified under the Act.

Visibility is also protected under section 109 (relating to the National Ambient Air Quality Standards, or NAAQS) and section 165 (requirements for new or reconstructed sources) of the Act. Section 109 calls for EPA to establish primary and secondary NAAQS in order to protect the public health and public welfare, respectively. For many years, visibility has been recognized as a "welfare effect" of particulate matter. In July 1997, EPA established new air quality standards for PM-2.5. The annual PM-2.5 standard, to be averaged over a period of 3 years, is 15 micrograms per cubic meter. The 24-hour standard is 65 micrograms per cubic meter. In this action, EPA also set secondary standards for PM-2.5, equivalent to the suite of primary standards. In addition, EPA noted that promulgation of a regional haze program under section 169A would address the welfare effects of particulate matter in class I areas.

The PM-2.5 monitoring regulations at 40 CFR Part 58 recognize the importance of monitoring for protection of secondary National Ambient Air Quality Standards and also allow the use of the IMPROVE protocol for the purpose of characterizing background or transported levels of PM-2.5. The PM-2.5 and IMPROVE programs are closely related through this provision. It will be important to understand the regional nature of PM-2.5 levels in order to improve the accuracy of regional PM models and ultimately to develop effective control strategies. Monitoring of visibility in non-class I areas (such as urban and suburban areas) can also provide important information for State or local governments in developing a local visibility standard (such as exists in Denver), as well as useful data for future EPA reviews of the secondary standards for particulate matter.

Section 165 of the Act provides for preconstruction review of the air quality impacts associated with new or modified major sources. The prevention of significant deterioration (PSD) program protects class I areas by allowing only a small increment of air quality deterioration in these areas and by providing for assessment of the potential impacts on the air quality related values (AQRVs) of class I areas. AQRV's include visibility and other fundamental purposes for which these lands have been established.

A number of federal, state, tribal, and local visibility monitoring sites and monitoring programs have been established to date, some dating back to the 1970's. In order to support implementation of the PM2.5 standards and the regional haze program, EPA is providing for a significant expansion of the IMPROVE visibility monitoring network in 1999. EPA recognizes the need to provide visibility monitoring guidance to ensure that the methodologies used to collect

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[2] See Table 1-1 for the list of mandatory Class I Federal areas.

and analyze aerosol and visibility data are consistent and applicable for tracking progress toward visibility goals in the future.

1.4 STATUTORY AND REGULATORY REQUIREMENTS

1.4.1 1970 Clean Air Act

The 1970 Clean Air Act was the first national legislation to address air quality throughout the United States. The Act included requirements for protecting visibility from adverse effects of air pollution. Visibility was identified as a welfare effect of concern for EPA to consider in setting primary and secondary national ambient air quality standards. The total suspended particulate (TSP) standard established by the EPA in 1971 provided a minimal amount of visibility protection, since visibility impairment is predominantly caused by fine particulate matter.

1.4.2 1977 Clean Air Act Amendments: Section 169A

The Clean Air Act was amended in August 1977, and included a new section 169A for the protection of visibility in areas of great scenic importance, such as national parks and wilderness areas. Congress adopted these provisions to protect the "intrinsic beauty and historical and archaeological treasures" of certain federal lands, noting that "areas such as the Grand Canyon and Yellowstone Park are areas of breathtaking panorama; millions of tourists each year are attracted to enjoy the scenic vistas."[3] In section 169A, Congress established the following national goal for visibility protection:

> *"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 federal areas are national parks greater than 6,000 acres in size, wilderness areas greater than 5,000 acres in size, and international parks that were in existence on August 7, 1977. The list of 156 mandatory Class I areas is provided in Table 1-1. Section 169A required the EPA to promulgate regulations requiring states to adopt measures into their State Implementation Plans (SIPs) that would protect visibility in these areas. EPA promulgated the first of these regulations on December 2, 1980.[4] These regulations addressed visibility impairment that is "reasonably attributable" to a source or group of sources.

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[3] H.R. Rep. No. 294, 95th Congress, 1st Session, 203-204 (1977).

[4] See 45 Federal Register 80084 (December 2, 1980) and 40 CFR 51.300-307.

Table 1-1

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
Alabama			
Sipsey Wild.	12,646	93-622	USDA-FS
Alaska			
Bering Sea Wild.	41,113	91-622	USDI-FWS
Mount McKinley NP	1,949,493	64-353	USDI-NPS
Simeonof Wild.	25,141	94-557	USDI-FWS
Tuxedni Wild.	6,402	91-504	USDI-FWS
Arizona			
Chiricahua National Monument Wild.	9,440	94-567	USDI-NPS
Chiricahua Wild.	18,000	88-577	USDA-FS
Galiuro Wild.	52,717	88-577	USDA-FS
Grand Canyon NP	1,176,913	65-277	USDI-NPS
Mazatzal Wild.	205,137	88-577	USDA-FS
Mount Baldy Wild.	6,975	91-504	USDA-FS
Petrified Forest NP	93,493	85-358	USDI-NPS
Pine Mountain Wild.	20,061	92-230	USDA-FS
Saguaro Wild.	71,400	94-567	USDI-FS
Sierra Ancha Wild.	20,850	88-577	USDA-FS
Superstition Wild.	124,117	88-577	USDA-FS
Sycamore Canyon Wild.	47,757	92-241	USDA-FS
Arkansas			
Caney Creek Wild.	14,344	93-622	USDA-FS
Upper Buffalo Wild.	9,912	93-622	USDA-FS
California			
Agua Tibia Wild.	15,934	93-632	USDA-FS
Caribou Wild.	19,080	88-577	USDA-FS
Cucamonga Wild.	9,022	88-577	USDA-FS
Desolation Wild.	63,469	91-82	USDA-FS
Dome Land Wild.	62,206	88-577	USDA-FS
Emigrant Wild.	104,311	93-632	USDA-FS
Hoover Wild.	47,916	88-577	USDA-FS
John Muir Wild.	484,673	8-577	USDA-FS
Joshua Tree Wild.	429,690	94-567	USDI-NPS
Kaiser Wild.	22,500	94-577	USDA-FS
Kings Canyon NP	459,994	76-424	USDI-NPS
Lassen Volcanic NP	105,800	64-184	USDI-NPS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
California (cont.)			
Lava Beds Wild.	28,640	92-493	USDI-NPS
Marble Mountain Wild.	213,743	88-577	USDA-FS
Minarets Wild.	109,484	88-577	USDA-FS
Mokelumme Wild.	50,400	88-577	USDA-FS
Pinnacles Wild.	12,952	94-567	USDI-NPS
Point Reyes Wild.	25,370	94-544, 94-567	USDI-NPS
Redwood NP	27,792	90-545	USDI-NPS
San Gabriel Wild.	36,137	90-318	USDA-FS
San Gorgonio Wild.	34,644	88-577	USDA-FS
San Jacinto Wild.	20,564	88-577	USDA-FS
San Rafael Wild.	142,722	90-271	USDA-FS
Sequoia NP	386,642	26 Stat. 478 (51st Cong.)	USDI-NPS
South Warner Wild.	68,507	88-577	USDA-FS
Thousand Lakes Wild.	15,695	88-577	USDA-FS
Ventana Wild.	95,152	91-58	USDA-FS
Yolla-Bolly-Middle-Eel Wild.	109,091	88-577	USDA-FS
Yosemite NP	759,172	58-49	USDI-NPS
Colorado			
Black Canyon of the Gunnison Wild.	11,180	94-567	USDI-NPS
Eagles Nest Wild.	133,910	94-352	USDA-FS
Flat Tops Wild.	235,230	94-146	USDA-FS
Great Sand Dunes Wild.	33,450	94-567	USDI-NPS
La Garita Wild.	48,486	88-577	USDA-FS
Maroon Bells-Snowmass Wild.	71,060	88-577	USDA-FS
Mesa Verde NP	51,488	59-353	USDI-NPS
Mount Zirkel Wild.	72,472	88-577	USDA-FS
Rawah Wild.	26,674	88-577	USDA-FS
Rocky Mountain NP	263,138	63-238	USDI-NPS
Weminuche Wild.	400,907	93-632	USDA-FS
West Elk Wild.	61,412	88-577	USDA-FS
Florida			
Chassahowitzka Wild.	23,360	94-557	USDI-FWS
Everglades NP	1,397,429	73-267	USDI-NPS
St. Marks Wild.	17,745	93-632	USDI-FWS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
Georgia			
Cohotta Wild.	33,776	93-622	USDA-FS
Okefenokee Wild.	343,850	93-429	USDI-FWS
Wolf Island Wild.	5,126	93-632	USDI-FWS
Hawaii			
Haleakala NP	27,208	87-744	USDI-NPS
Hawaii Volcanoes	217,029	64-171	USDI-NPS
Idaho			
Craters of the Moon Wild.	43,243	91-504	USDI-NPS
Hells Canyon Wild.	83,800	94-199	USDA-FS
Hells Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon and 83,800 acres are in Idaho.			
Sawtooth Wild.	216,383	92-400	USDA-FS
Selway-Bitterroot Wild.	988,770	88-577	USDA-FS
Selway Bitterroot Wilderness, 1,240,700 acres overall, of which 988,700 acres are in Idaho and 251,930 acres are in Montana.			
Yellowstone NP	31,488	17 Stat. 32 (42nd Cong.)	USDI-NPS
Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.			
Kentucky			
Mammoth Cave NP	51,303	69-283	USDI-NPS
Louisiana			
Breton Wild.	5,000+	93-632	USDI-FWS
Maine			
Acadia NP	37,503	65-278	USDI-NPS
Moosehorn Wild.	7,501		USDI-FWS
(Edmunds Unit)	(2,782)	91-504	
(Baring Unit)	(4,719)	93-632	
Michigan			
Isle Royale NP	542,428	71-835	USDI-NPS
Seney Wild.	25,150	91-504	USDI-FWS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
Minnesota			
Boundary Waters Canoe Area Wild.	747,840	99-577	USDA-FS
Voyageurs NP	114,964	99-261	USDI-NPS
Missouri			
Hercules-Glades Wild.	12,315	94-557	USDA-FS
Mingo Wild.	8,000	94-557	USDI-FWS
Montana			
Anaconda-Pintlar Wild.	157,803	88-577	USDA-FS
Bob Marshall Wild.	950,000	88-577	USDA-FS
Cabinet Mountains Wild.	94,272	88-577	USDA-FS
Gates of the Mtn. Wild.	28,562	88-577	USDA-FS
Glacier NP	1,012,599	61-171	USDI-NPS
Medicine Lake Wild.	11,366	94-557	USDI-FWS
Mission Mountain Wild.	73,877	93-632	USDA-FS
Red Rock Lakes Wild.	32,350	94-557	USDI-FWS
Scapegoat Wild.	239,295	92-395	USDA-FS
Selway-Bitterroot Wild.	251,930	88-577	USDA-FS
Selway-Bitterroot Wilderness, 1,240,700 acres overall, of which 988,770 acres are in Idaho and 251,930 acres are in Montana.			
U. L. Bend Wild.	20,890	94-557	USDI-FWS
Yellowstone NP	167,624	17 Stat. 32 (42nd Cong.)	USDI-NPS
Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.			
Nevada			
Jarbidge Wild.	64,667	88-577	USDA-FS
New Hampshire			
Great Gulf Wild.	5,552	88-577	USDA-FS
Presidential Range-Dry River Wild.	20,000	93-622	USDA-FS
New Jersey			
Brigantine Wild.	6,603	93-632	USDI-FWS
New Mexico			
Bandelier Wild.	23,267	94-567	USDI-NPS
Bosque del Apache Wild.	80,850	93-632	USDI-FWS
Carlsbad Caverns NP	46,435	71-216	USDI-NPS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
New Mexico (cont.)			
Gila Wild.	433,690	88-577	USDA-FS
Pecos Wild.	167,416	88-577	USDA-FS
Salt Creek Wild.	8,500	91-504	USDI-FWS
San Pedro Parks Wild.	41,132	88-577	USDA-FS
Wheeler Peak Wild.	6,027	88-577	USDA-FS
White Mountain Wild.	31,171	88-577	USDA-FS
North Carolina			
Great Smoky Mountains NP	273,551	69-268	USDI-NPS
Great Smoky Mountains National Park, 514,758 acres overall, of which 273,551 acres are in North Carolina, and 241,207 acres are in Tennessee.			
Joyce Kilmer-Slickrock Wild.	10,201	93-622	USDA-FS
Joyce Kilmer-Slickrock Wilderness, 14,033 acres overall, of which 10,201 acres are in North Carolina, and 3,832 acres are in Tennessee.			
Linville Gorge Wild.	7,575	88-577	USDA-FS
Shining Rock Wild.	13,350	88-577	USDA-FS
Swanquarter Wild.	9,000	94-557	USDI-FWS
North Dakota			
Lostwood Wild.	5,557	93-632	USDI-FWS
Theodore Roosevelt NP	69,675	80-38	USDI-NPS
Oklahoma			
Wichita Mountains Wild.	8,900	91-504	USDI-FWS
Oregon			
Crater Lake NP	160,290	57-121	USDA-NPS
Diamond Peak Wild.	36,637	88-577	USDA-FS
Eagle Cap Wild.	293,476	88-577	USDA-FS
Gearhart Mountain Wild.	18,709	88-577	USDA-FS
Hells Canyon Wild.	108,900	94-199	USDA-FS
Hells Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon, and 83,800 acres are in Idaho.			
Kalmiopsis Wild.	76,900	88-577	USDA-FS
Mountain Lakes Wild.	23,071	88-577	USDA-FS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
Oregon (cont.)			
Mount Hood Wild.	14,160	88-577	USDA-FS
Mount Jefferson Wild.	100,208	90-548	USDA-FS
Mount Washington Wild.	46,116	88-577	USDA-FS
Strawberry Mountain Wild.	33,003	88-577	USDA-FS
Three Sisters Wild.	199,902	88-577	USDA-FS
South Carolina			
Cape Romain Wild.	28,000	93-632	USDI-FWS
South Dakota			
Badlands Wild.	64,250	94-567	USDI-NPS
Wind Cave NP	28,060	57-16	USDI-NPS
Tennessee			
Great Smoky Mountains NP	241,207	69-268	USDI-NPS
Great Smoky Mountains National Park, 514,758 acres overall, of which 273,551 acres are in North Carolina, and 241,207 acres are in Tennessee.			
Joyce Kilmer-Slickrock Wild.	3,832	93-622	USDA-FS
Joyce Kilmer Slickrock Wilderness, 14,033 acres overall, of which 10,201 acres are in North Carolina, and 3,832 acres are in Tennessee.			
Texas			
Big Bend NP	708,118	74-157	USDI-NPS
Guadalupe Mountains NP	76,292	89-667	USDI-NPS
Utah			
Arches NP	65,098	92-155	USDI-NPS
Bryce Canyon NP	35,832	68-277	USDI-NPS
Canyonlands NP	337,570	88-590	USDI-NPS
Capitol Reef NP	221,896	92-507	USDI-NPS
Zion NP	142,462	68-83	USDI-NPS
Vermont			
Lye Brook Wild.	12,430	93-622	USDA-FS
Virgin Islands			
Virgin Islands NP	12,295	84-925	USDI-NPS

Table 1-1 (cont.)

List of Mandatory Class I Areas
as of August 7, 1977
(Source: 44 CFR 69124, November 30, 1979)

Area Name	Acreage	Public Law Establishing	Federal Land Manager
Virginia			
James River Face Wild.	8,703	93-622	USDA-FS
Shenandoah NP	190,535	69-268	USDI-NPS
Washington			
Alpine Lakes Wild.	303,508	94-357	USDA-FS
Glacier Peak Wild.	464,258	88-577	USDA-FS
Goat Rocks Wild.	82,680	88-577	USDA-FS
Mount Adams Wild.	32,356	88-577	USDA-FS
Mount Rainer NP	235,239	30 Stat. 993 (55th Cong.)	USDI-NPS
North Cascades NP	503,277	90-554	USDI-NPS
Olympic NP	892,578	75-778	USDI-NPS
Pasayten Wild.	505,524	90-544	USDA-FS
West Virginia			
Dolly Sods Wild.	10,215	93-622	USDA-FS
Otter Creek Wild.	20,000	93-622	USDA-FS
Wyoming			
Bridger Wild.	392,160	88-577	USDA-FS
Fitzpatrick Wild.	191,103	94-567	USDA-FS
Grand Teton NP	305,504	81-787	USDI-NPS
North Absaroka Wild.	351,104	88-577	USDA-FS
Teton Wild.	557,311	88-577	USDA-FS
Washakie Wild.	686,584	92-476	USDA-FS
Yellowstone NP	2,020,625	17 Stat. 32 (42nd Cong.)	USDI-NPS
Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.			

1.4.3 1980 EPA Regulations

The 1980 visibility regulations were designed to address impairment that is "reasonably attributable" to a single source or small group of sources. EPA deferred action addressing "regional haze" until improvements were made in monitoring techniques, in regional scale modeling, and in our understanding of the relationships between specific pollutants and visibility impairment. Regional haze is caused by a multitude of sources, located across a broad geographic area, which emit fine particles and their precursors into the atmosphere. The 1980 regulations consisted of a number of requirements to be addressed by the States, including:

- A long-term strategy to make reasonable progress toward the national visibility goal, with progress reviews every 3 years and SIP revisions as necessary.

- The review of certain existing major sources and the determination of best available retrofit technology (BART) for any such source that emits any air pollutant which may reasonably be anticipated to cause or contribute to visibility impairment in any class I area where that impairment is reasonably attributable to that source.

- Requirements to perform preconstruction review of the potential visibility impacts due to new or modified sources, and procedures for federal land manager notification and consultation.

- A monitoring plan to assess visibility in Class I areas and to track trends over time.

1.4.4 State and Federal Implementation Plans

The 1980 EPA regulations required certain states covered by the regulations to revise its SIP to address visibility. Only seven SIPs with visibility provisions were approved between 1980 and 1985.

In 1985, the settlement of a lawsuit brought by the Environmental Defense Fund (EDF) against the EPA required the EPA to establish Federal Implementation Plans (FIPs) for the remaining states without approved visibility provisions in their SIPS. As part of the FIPs, EPA regulations called for the establishment of a cooperative visibility monitoring effort between the EPA, the National Oceanic and Atmospheric Administration (NOAA) and primary federal land management agencies: the National Park Service (NPS), the United States Fish and Wildlife Service (USFWS), the Bureau of Land Management (BLM), and the United States Forest Service (USFS). This cooperative visibility monitoring effort became a reality in the mid-1980s and was named IMPROVE (Interagency Monitoring of Protected Visual Environments). In 1991, several additional organizations joined the effort: State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials (STAPPA/ALAPCO), Western States Air Resources Council (WESTAR), and Northeast States for Coordinated Air Use Management (NESCAUM). The Mid-Atlantic Regional Air Management Association (MARAMA) was added in 1998 for broader participation of State agencies. The IMPROVE program has been collecting data since 1988, and continues to collect and analyze visibility data from Class I area monitoring sites throughout the United States. The objectives of IMPROVE are to provide data needed to assess the impacts of new emission sources, to identify existing man-made visibility impairment, and to assess progress toward the national visibility goals that define protection of 156 Class I areas.

1.4.5 1990 Clean Air Act Amendments

As part of the development of the Clean Air Act Amendments of 1990, Congress reviewed EPA's progress in protecting visibility in Class I areas. Recognizing that greater emphasis was needed on the role of regional transport of pollutants responsible for visibility impairment, Congress established a new section 169B. Section 169B provides for the following:

1) Expanded research on air quality monitoring, modeling, atmospheric chemistry and physics, and sources of impairment and factors leading to good visibility, including the concept of clean air corridors.

2) A Report to Congress by EPA on visibility improvement that is expected from the implementation of the 1990 Amendments, and periodic reviews every 5 years on actual progress made in class I areas.

3) Establishment of interstate visibility transport commissions for class I areas experiencing visibility impairment. Section 169B required the establishment of the Grand Canyon Visibility Transport Commission (GCVTC).[5] EPA can establish commissions on its own initiative, or by a petition from two or more States. Any visibility transport commission is to assess the nature of adverse impacts on visibility due to potential or projected growth of emissions, and to provide recommendations to EPA within 4 years. These recommendations must address measures to remedy such adverse impacts, including the promulgation of regulations under section 169A.

4) Within 18 months of receiving recommendations from any visibility transport commission, the EPA is required to "carry out the Administrator's regulatory responsibilities under section 169A, including criteria for measuring "reasonable progress" toward the national goal."[6]

5) Section 169B also requires States to revise their visibility SIPs under section 110 of the Act to include emission limits, schedules of compliance, and other measures as may be necessary to carry out the new EPA regional haze regulations.

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[5] The Commission as created focused on 16 Class I areas of the Colorado Plateau, including: Grand Canyon, Bryce Canyon, Zion, Canyonlands, Mesa Verde, Capitol Reef, Arches, and Petrified Forest National Parks. The GCVTC was comprised of the Governors of eight western States (Arizona, California, Colorado, Nevada, New Mexico, Oregon, Utah, and Wyoming), the leaders of five Indian tribes (Navajo, Hopi, Hualapai, Acoma Pueblo, and the Columbia River Intertribal Fish Commission), and non-voting federal representatives, including EPA and several land management agencies. The GCVTC submitted to EPA its *Recommendations for Improving Western Vistas* in June 1996. The Commission's work involved more than four years of technical assessment and discussion, and it included participation by a wide range of stakeholders.

[6] See Clean Air Act, section 169B(e)(1).

1.4.6 EPA Regional Haze Regulation

In July 1997, EPA proposed revisions to the existing 1980 visibility regulations. These revisions would require States to revise their SIPs to address visibility impairment in the form of regional haze. The regional haze regulations would also serve as a vital component of EPA's overall approach to protect the public welfare from visibility impairment effects associated with particulate matter. The regional haze regulation includes requirements for establishing baseline and current conditions based on monitoring data, and for tracking visibility changes over time. States also are required to submit a monitoring strategy within the time frame specified in the regional haze rule.

To support implementation of the regional haze rule, EPA has funded the deployment of the PM-2.5 monitoring network and the expansion of the IMPROVE network. During 1999, approximately 78 new IMPROVE aerosol monitors will be sited in the vicinity of Class I areas. EPA is working closely with the States and Federal land managers through the IMPROVE Steering Committee on implementing this expansion during FY99. The new $PM_{2.5}$ network will also include IMPROVE samplers which may be used at background or transport sites required under the $PM_{2.5}$ monitoring regulations. This network has a variety of monitors useful for visibility assessments. These include nephelometers and other continuous analyzers as well as aerosol samplers capable of assessing chemical speciation of particulate matter.

2.0 MONITORING PROGRAM CONSIDERATIONS

2.1 VISIBILITY DEFINITIONS AND THEORY

A simple definition of visibility is "the appearance of scenic features when viewed from a distance." The most popular term to characterize visibility is observer visual range which is the greatest distance at which a large black object can just be seen against the horizon sky. Most in the technical community prefer to use the term extinction coefficient (b_{ext}), which is the loss of image-forming light per unit distance due to scattering and absorption by particles and gases in the atmosphere. The extinction coefficient is the sum of the scattering coefficient (b_{scat}) and absorption coefficient (b_{aba}), which are similarly defined as the loss of light per unit distance by scattering and absorption mechanisms respectively.

The extinction coefficient can be represented mathematically as:

$$b_{ext} = b_{sg} + b_{ag} + b_{sp} + b_{ap} = b_{scat} + b_{abs} \quad (2\text{-}1)$$

where s, a, g, and p refer to scattering and absorption by gases and particles, respectively.

Figure 2-1 illustrates how these properties affect the transmission of light from a scenic feature to an observer. A pristine, particle free atmosphere where the only affect on light transmission is caused by the scattering of light by atmospheric gases is called a Rayleigh atmosphere. The only gas normally found in the atmosphere that absorbs light is nitrogen dioxide. The extinction coefficient increases as particles and gases are added to the atmosphere. Therefore, visibility is reduced due to increased particle scattering and absorption.

Figure 2-2 illustrates the size ranges of atmospheric particles that affect visibility. Particle sizes are generally separated into three modes:

- Nuclei mode - 0.005 μm to 0.1 μm
- Accumulation mode - 0.1 μm to 1 - 3 μm
- Coarse mode - 1 - 3 μm to 50 - 100 μm

Fine particles less than 2.5 μm affect light scattering more than particles greater than 2.5 μm. The most efficient light scattering particles are within the size range of the wavelength of visible light; 0.4 μm to 0.7 μm.

A simple model allows the observer visual range to be estimated from the extinction coefficient by dividing a constant by the extinction coefficient. The magnitude of the constant depends on the units used and assumptions concerning the minimal contrast detectable by the observer. Visual range (V_r) is the common name given to the resulting estimate. To compare visibility data from different sites, visual range estimates can be normalized to a Rayleigh scattering coefficient of 10 Mm^{-1} (particle-free atmosphere conditions at an altitude of 1.524 km or 5000 feet). This normalized estimate is called the standard visual range (SVR) and can be expressed as:

$$SVR = 3912 \;/\; (b_{ext} - Ray + 10) \quad (2\text{-}2)$$

where the units for SVR are kilometers (km), b_{ext} is the extinction coefficient expressed in inverse megameters (Mm^{-1}), Ray is the site specific Rayleigh value (elevation dependent) in inverse megameters (Mm^{-1}), 10 is the Rayleigh coefficient used to normalize visual range, and 3912 is a constant derived assuming a 2% contrast detection threshold.

Visual air quality is a term which describes the air pollution aspects of visibility. Visual air quality is what must be monitored and preserved, not the overall visibility which is influenced by non-pollution factors (i.e., clouds, snow cover, sun angle, etc.). The atmospheric extinction coefficient and parameters derived from the extinction coefficient describe visual air quality.

The distribution and extent of pollutants in the atmosphere relative to the observer's sight path has a large effect on the appearance of visibility impairment. If the pollutants are uniformly distributed both horizontally and vertically from the ground to a height well above the highest terrain, it is known as a uniform haze. If the top edge of the pollution layer is visible, as is often

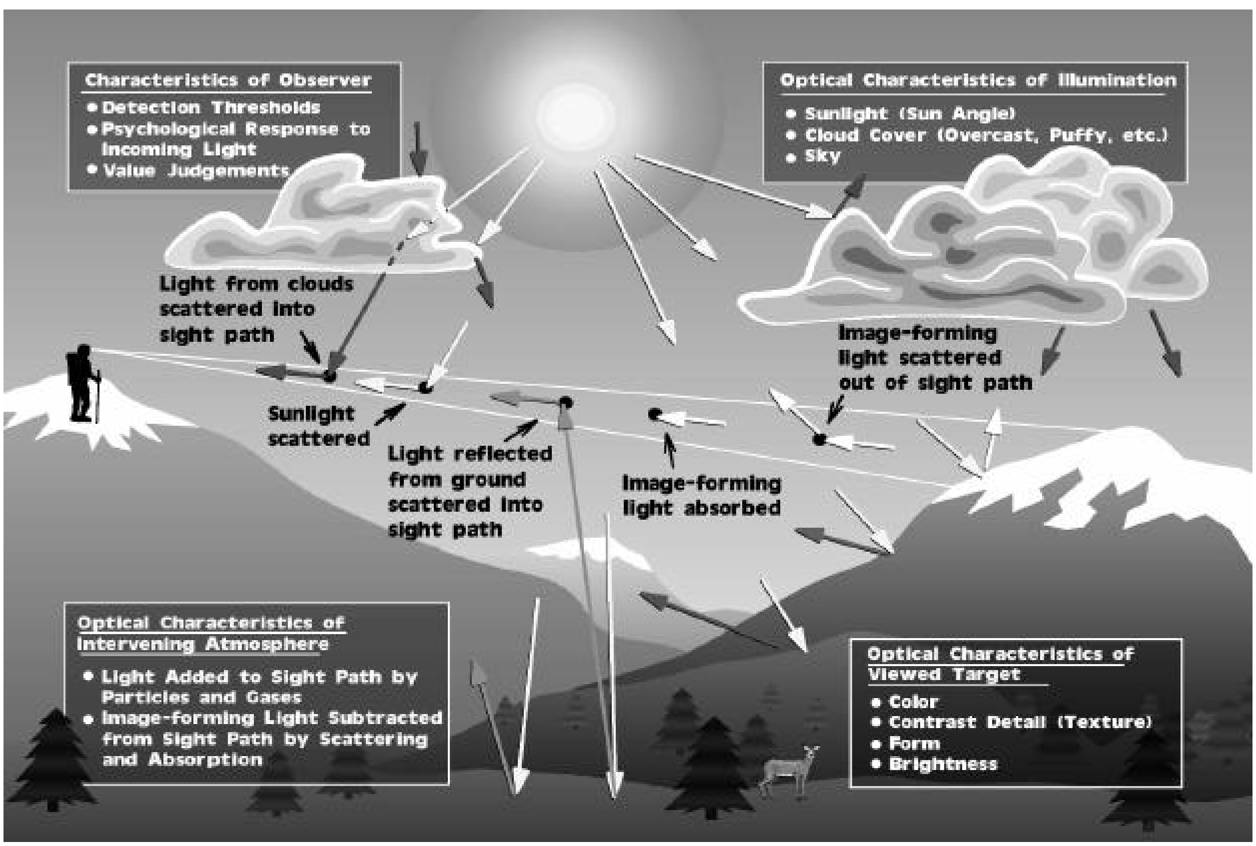

Figure 2-1. Properties of the Atmosphere that Affect the Transmission of Light from a Scenic Feature to a Human Observer.

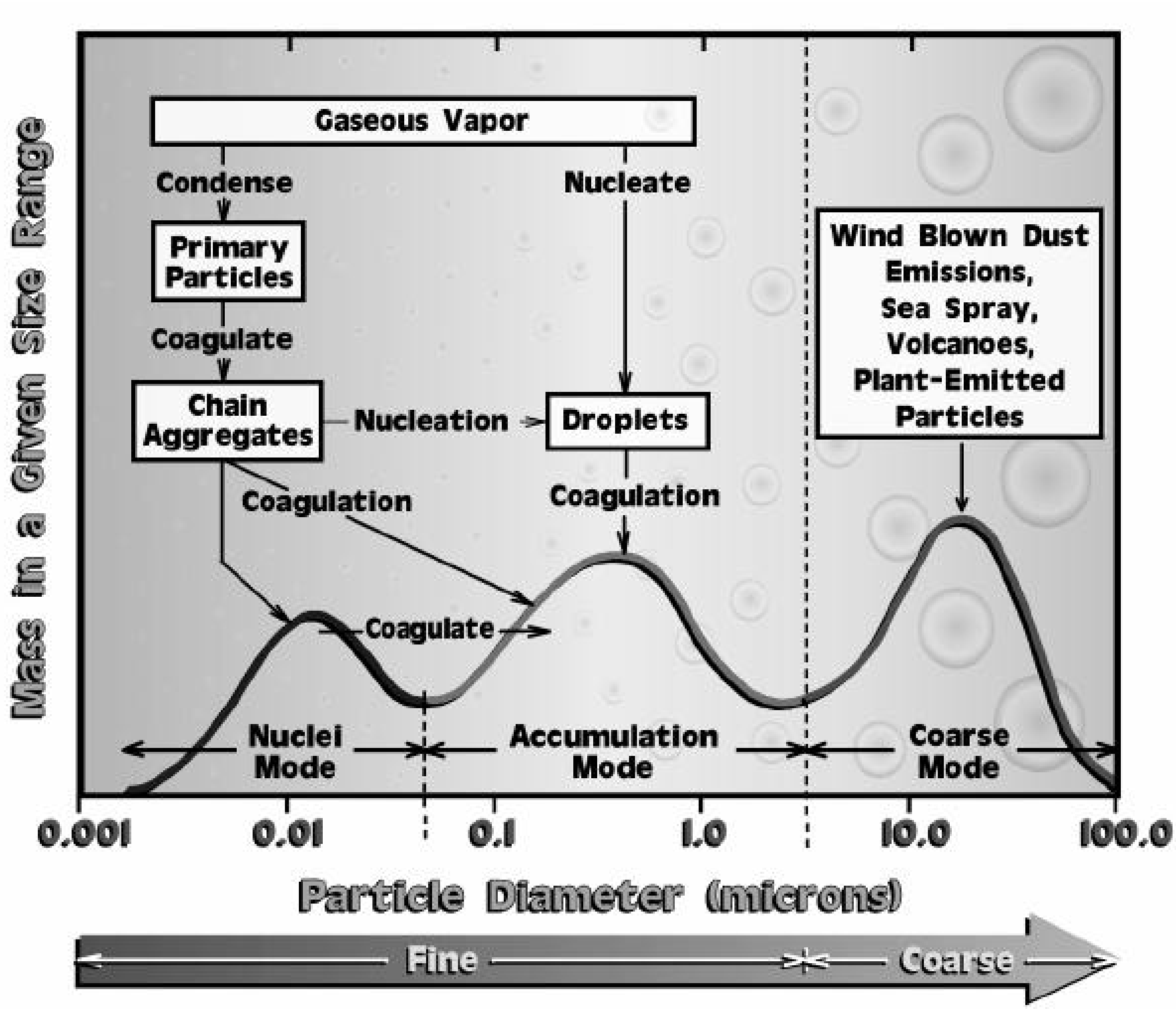

Figure 2-2. Size Distribution and Sources of Atmospheric Particles.

the case when a pollution layer is trapped below an inversion, then it is called a surface layer. A pollution distribution that is not in contact with the ground is an elevated layer. Plumes can be thought of as a special case of an elevated layer, though from many vantage points it may not be possible to distinguish a plume from an elevated layer. It is possible to have combinations of pollutant distributions such as multiple elevated layers superimposed upon a uniform haze.

Uniform haze and surface layered haze can be monitored by a variety of methods on the ground. Elevated layers must be either remotely monitored from the ground or by instruments carried aloft.

Visibility-related measurements can be partitioned into three (3) groups that describe and define the visual characteristics of the air.

Aerosol The physical properties of the ambient atmospheric particles (particle origin, size, shape, chemical composition, concentration, temporal and spatial distribution, and other physical properties) through which a scene is viewed.

Optical The ability of the atmosphere to scatter or absorb light passing through it. The physical properties of the atmosphere are described by extinction, scattering, and absorption coefficients, plus an angular dependence of the scattering known as the normalized scattering phase function. Optical characteristics integrate the effects of atmospheric aerosols and gases.

Scene The appearance of a scene viewed through the atmosphere. Scene characteristics are more nearly in line with the simple definition of visibility than aerosol or optical characteristics. Scene characteristics include observer visual range, scene contrast, color, texture, clarity, and other descriptive terms. Scene characteristics change with illumination and atmospheric composition.

Aerosol and optical characteristics depend only on the properties of the atmosphere through which light passes and therefore can be used to describe visual air quality. However, scene characteristics are also dependent on scene and lighting conditions.

2.1.1 Characterizing Visibility Impairment

Visibility has historically been characterized either by visual range or by the light extinction coefficient. These two measures of visibility are inversely related; visual range decreases as the extinction coefficient increases. Visual range is presented in common units such as miles or kilometers and is commonly used in military operations and transportation safety by providing information to determine the minimum distance required to land an aircraft, the distance to the first appearance of a military target or an enemy aircraft or ship, and safe maneuvering distances under impaired visibility conditions. Because of the use of familiar distance units, the simple definition, and the ability of any sighted person to characterize visual conditions with this parameter without instruments, visual range is likely to remain a popular method of describing atmospheric visibility. However, extreme caution must be applied when interpreting visual range data from historical sources where human observations were the source of the data (e.g., airport observations). The varying methods and procedures used by observers, the quality of the observer measurements, and the availability of adequate visibility targets all can have a dramatic effect on historical, observer-based data.

Extinction coefficient is used most by scientists concerned with the causes of reduced visibility. Direct relationships between concentrations of atmospheric constituents and their contribution to the extinction coefficient exist. Apportioning the extinction coefficient to atmospheric constituents provides a method to estimate the change in visibility caused by a change in constituent concentrations. This methodology, known as extinction budget analysis, is important for assessing the visibility consequences of proposed pollutant emission sources, or for determining the extent of pollution control required to meet a desired visibility condition. Interest in the causes of visibility impairment is expected to continue and the extinction coefficient will remain important in visibility research and assessment.

Neither visual range nor extinction coefficient measurements are linear with respect to the human perception of visual scene changes caused by uniform haze. For example, a given change in visual range or extinction coefficient can result in a scene change that is either unnoticeably small or very apparent depending on the baseline visibility conditions. Presentation of visibility measurement data or model results in terms of visual range or extinction coefficient can lead to misinterpretation by those who are not aware of the nonlinear relationship.

To rigorously determine the perceived visual effect of a change in extinction coefficient requires the use of radiative transfer modeling and psychophysical modeling. Radiative transfer modeling is used to determine the changes in light transmission from the field of view arriving at the observer location. Psychophysical modeling is used to determine the response to the light by the eye-brain system. Results are dependent not only on the baseline and changes to atmospheric optical conditions, but also on the characteristics of the scene and its lighting. The complexity of employing such a procedure and the dependence of the results on non-atmospheric factors complicate its widespread use to characterize perceived visibility changes resulting from changes in air quality.

Parametric analysis methods have been used to suggest that a constant fractional change in extinction coefficient or visual range produces a similar perceptual change for a scene regardless of baseline conditions. Simplifying assumptions eliminates the need to consider the visibility effects of scene and lighting conditions. Using the relationship of a constant fractional change in extinction coefficient to perceived visual change, a new visibility index called deciview (dv) was developed, and is defined as:

$$dv = 10 \ln(b_{ext} / 10Mm^{-1}) \quad (2\text{-}3)$$

where extinction coefficient is expressed in Mm^{-1} (Pitchford and Malm, 1993). One (1) dv change is approximately a 10% change in extinction coefficient, which is a small, but perceptible scenic change under many circumstances. The deciview scale is near zero (0) for a pristine atmosphere (dv = 0 for a Rayleigh condition at about 1.5 km elevation) and increases as visibility is degraded. Like the decibel scale for sound, equal changes in deciview are equally perceptible. Because the deciview metric expresses visual scene changes that are linear with respect to human perception, EPA supports the use of the deciview metric in characterizing visibility changes for regulatory purposes.

2.1.2 Relationship Between Light Extinction and Aerosol Concentrations

The light extinction coefficient (b_{ext}) is the sum of the light scattering coefficient (b_{scat}) and the light absorption coefficient (b_{abs}). Light scattering is the sum of the scattering caused by gases (b_{sg}) and the scattering caused by suspended particles (b_{sp}) in the atmosphere (aerosols). However, natural Rayleigh scatter (b_{Ray}) from air molecules (which causes the sky to appear blue) dominates the gas scattering component. Particle scatter (b_{sp}) can be caused by natural aerosol (e.g., wind-blown dust and fog) or by man-made aerosols (e.g., sulfates, nitrates, organics, and other fine and coarse particles). Light absorption results from gases (b_{ag}) and particles (b_{ap}). Nitrogen dioxide (NO_2) is the only major light absorbing gas in the lower atmosphere; its strong wavelength-dependent scatter causes yellow-brown discoloration if present in sufficient quantities. Soot (elemental carbon) is the dominant light absorbing particle in the atmosphere. Thus, the total light extinction is the sum of its components:

$$b_{ext} = b_{scat} + b_{abs} = b_{Ray} + b_{sp} + b_{ag} + b_{ap} \quad (2\text{-}4)$$

Suspended particles in the atmosphere (i.e., collectively known as aerosols) usually account for the dominant part of light extinction except under extremely clean conditions, when natural Rayleigh gas scattering predominates. Thus, understanding visibility requires understanding the basic concepts of aerosol air quality.

The first concept concerns the origins of atmospheric particles. Particle origins can be either anthropogenic (man-made) or natural. Another origin classification is primary versus secondary. Primary particles are those that are directly emitted into the atmosphere as particles, such as organic and soot particles in smoke plumes or soil dust particles. Secondary particles are those that are formed from gas-to-particle conversion in the atmosphere, such as sulfates (from SO_2), nitrates (from NO_x), and secondary organics (from gaseous hydrocarbons).

Two other aerosol concepts with respect to visibility are size distribution and chemical composition. For visibility purposes, it is critical to distinguish fine particles ($\leq 2.5\ \mu m$) from coarse particles ($> 2.5\ \mu m$), because fine particles are much more efficient at scattering light than larger particles. The major constituents of ambient fine particulate matter consist of five species (and their compounds): sulfates, nitrates, organic carbon, elemental carbon, and soil dust. In addition to these chemical species, the effect of water associated with sulfate, nitrate, and some organics needs to be considered for assessment of visual air quality(see Section 2.1.3 below). Significant differences exist among each of these species, in sources, atmospheric behavior, size distributions, and visibility effects. The coarse fraction of PM_{10} (particles with diameters between 2.5 μm and 10 μm) and other suspended particles (those with diameters greater than 10 μm) can be considered separately and are generally not subdivided into separate species.

The relationship between atmospheric aerosols and the light extinction coefficient can usually be approximated as the sum of the products of the concentrations of individual species and their respective light extinction efficiencies, better known as reconstructed light extinction. Reconstructed extinction is expressed as:

$$b_{ext} = b_{Ray} + \sum \beta_i C_i \qquad (2\text{-}5)$$

where β_i is the light extinction efficiency (m^2/g) of species i, C_i is the atmospheric concentration of species i ($\mu g/m^3$), and the summation is over all light-interacting species (i.e., sulfate, nitrate, organic carbon, elemental carbon, other fine particles, coarse particles, other suspended particles, and NO_2). The above units, when multiplied, yield units for b_{ext} of 10^{-6} m^{-1} or $(10^6\ m)^{-1}$, or as typically labeled, inverse megameters (Mm^{-1}).

An equation used by the IMPROVE program to estimate reconstructed aerosol extinction is:

$$b_{ext} = b_{ray} + (3)f(RH)\,[\text{Sulfate}] + (3)f(RH)\,[\text{Nitrate}] + (4)\,[\text{Organic Mass Carbon}] + (1)\,[\text{Soil}] + (0.6)\,[\text{Coarse Mass}] + b_{abs} \qquad (2\text{-}6)$$

Alternatively, b_{abs} can be replaced by 10 times elemental carbon mass. Sisler and Malm (1999) discuss this issue. In the above formula, all the terms in square brackets refer to the mass associated with those entities.

Note that this aerosol/light extinction relationship is derived from externally mixed particles and does not account for all of the complex interactions possible in the atmosphere. However, the relationship is a good approximation.

2.1.3 Importance of Relative Humidity on Light Scattering

Because some aerosols including sulfates, nitrates, and some organics are hygroscopic (have an affinity for water), their scattering properties can change as a function of relative humidity (RH). As the relative humidity increases these hygroscopic aerosols can grow to become more efficient light scatterers. The aerosol growth curve is particularly significant for relative humidities greater than 70%. Figure 2-3 illustrates the relationship between RH and scattering efficiency for ammonium sulfate aerosols

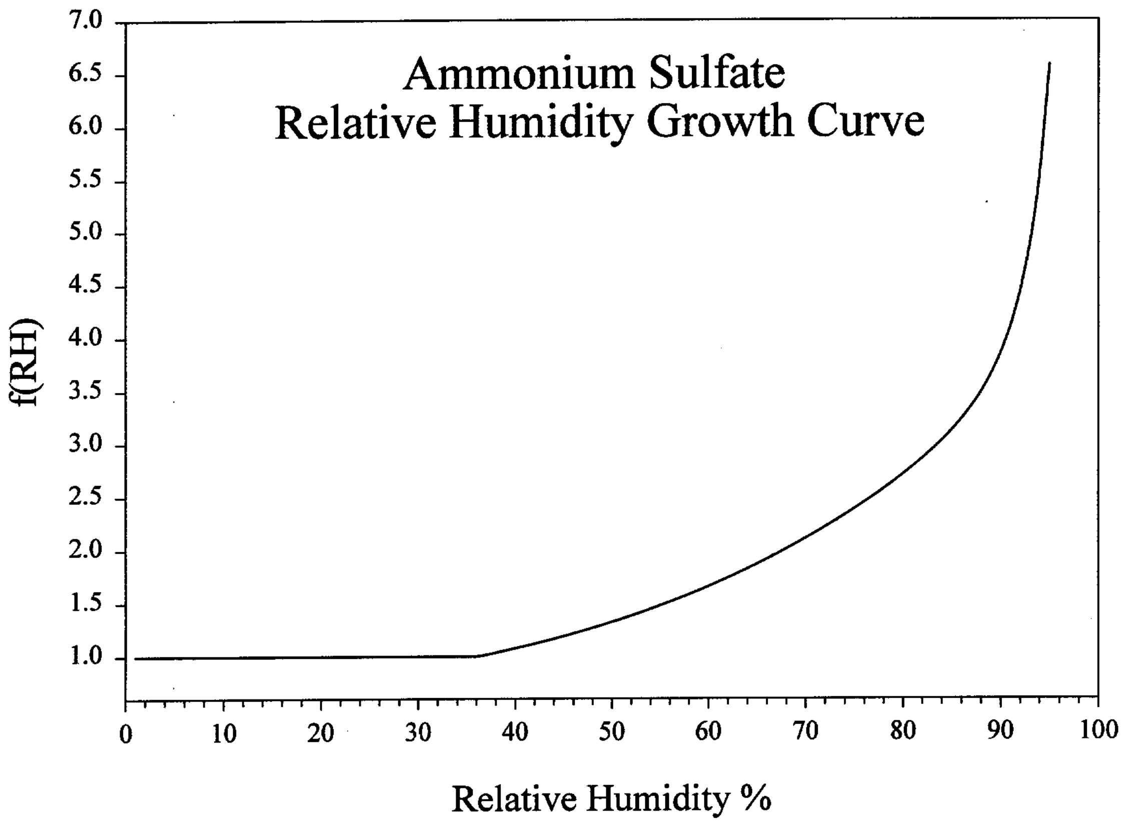

Figure 2-3. The Relationship between the Scattering Efficiency of Ammonium Sulfate Aerosols and Relative Humidity (Malm et al., 1996).

with a mass mean diameter of 0.3 μm and a geometric size distribution of 1.5 μm (Malm et al., 1996). The function of RH, *f*(RH), illustrated in Figure 2-3 is:

$$f(RH) = b_{scat}(RH) \; / \; b_{scat}(0\%) \tag{2-7}$$

where b_{scat} (0%) and b_{scat} (RH) are the dry and wet scattering, respectively. This function describes the scattering efficiencies for ammonium sulfate and ammonium nitrate.

Various functions for the humidity-related scattering efficiencies of organics have been proposed. These functions must consider the solubility of individual organic species and fractions of various organic species in the atmosphere. The types and concentrations of organics can vary geographically and the associated RH functions can change. White (1990) discusses this issue.

To perform reconstructed particle scattering estimates, the scattering efficiencies (in m^2/g) of atmospheric species as a function of relative humidity and the concentration of the species must be considered. Malm et al. (1996) explores the analytical consideration required to reconstruct particle scattering using the Grand Canyon as an example. Ideally, relative humidity would be measured continuously at each site in order to better understand its effect on day-to-day variations and annual changes in visual air quality. If on-site meteorological data are not available, however, humidity can be estimated from climatological databases for appropriate nearby locations to represent the humidity characteristics of the Class I area. In either case, analysis of visibility trends in accordance with the tracking requirements of the regional haze rule should utilize long-term average *f*(RH) factors which are representative of best and worst visibility conditions. This approach will provide measures of visual air quality which are more directly related to the changes in the pollutants that cause visibility impairment, and are less affected by day-to-day or year-to-year changes in humidity.

2.2 VISIBILITY GOALS AND MONITORING OBJECTIVES

The purpose of visibility monitoring is to collect high quality, consistent data that can be used in analyses to assess whether progress is being made toward meeting visibility goals, and to understand the types of emissions sources contributing to visibility impairment. The Clean Air Act and related EPA regulations define the nation's visibility protection goals. Monitoring objectives outline the types of monitoring required for specific analyses or actions needed to make progress toward these goals. These visibility goals and monitoring objectives are outlined in Table 2-1 and discussed in the following subsections.

2.2.1 Visibility Goals

The primary visibility-related goals found in the Act and EPA regulations are summarized below and in Table 2-1:

Section 169A of the Clean Air Act provides two primary goals:

- "...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."
- State implementation plans must ensure "reasonable progress" toward the national visibility goal.

Section 109 of the Act:

- Any national secondary NAAQS should specify a level of air quality that is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air.

Section 172 of the Act (re: NAAQS):

- The attainment of any primary NAAQS should be achieved as expeditiously as practicable, but no later than 5 years after nonattainment designation. Areas with more severe problems can be considered for an additional 5-year extension.

- The attainment of any secondary NAAQS should be achieved "as expeditiously as practicable."

Section 165(d)(2) of the Clean Air Act charged federal land managers (FLM) with the following visibility-related goal:

- FLMs have an affirmative responsibility to "protect the air quality related values (AQRVs) of any mandatory Class I federal area."

The visibility regulations in 40 CFR 51.300-309

- States are required to "assess the impacts of existing and proposed new sources of Class I area visibility impairment." Specifically, this requirement includes provisions related to new source review in 307, to BART in 302 and 308, and to progress goals in 308.

Table 2-1

Visibility Goals and Monitoring Objectives

Visibility Goals	
1 National Visibility 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...." Ensure reasonable progress toward the National Goal.	5 Ensure that SIPs contain: 1) a long-term strategy, BART, and other measures necessary to make "reasonable progress" toward the national visibility goal, 2) visibility analysis in preconstruction review process, 3) monitoring program.
2 NAAQS: The protection of public health and welfare through attainment of NAAQS as expeditiously as practicable.	
3 The FLM has an affirmative responsibility to "protect the air quality related values (AQRVs) of any mandatory Class I federal area."	
4 The FLM has the responsibility to "assess existing and proposed sources of Class I area visibility impairment."	
9 Measuring reasonable progress as specified in the Regional Haze Rule	

Visibility Monitoring Objectives	
1 Adopt monitoring protocols to ensure that high quality, nationally consistent, comparable data are collected by all monitoring organizations.	4 Document long-term trends and track progress toward visibility improvement goals.
2 Establish current visual air quality conditions that for each site are representative of a fairly broad geographic region, based on ! Aerosol characteristics, and when possible for ! Optical characteristics ! Surface and elevated haze characteristics	5 Provide data for the new source review permitting process.
3 Identify sources through source attribution analysis that are "reasonably anticipated to cause or contribute" to visibility impairment in any class I area.	6 Provide data for the prevention of significant deterioration permitting process.

EPA's 1980 visibility regulations address reasonably attributable visibility impairment. The primary regulatory agency and FLM goals presented in these regulations are to:

- Ensure that SIPs contain a long-term strategy, measures addressing best available retrofit technology for certain sources, and other measures as necessary to make "reasonable progress" toward the national visibility 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").

- Establish programs providing for preconstruction visibility impact analyses by new source permit applicants and appropriate review by States and Federal land managers

- Establish a monitoring program to assess current conditions, track progress toward the national goal, and identify the sources contributing to visibility impairment.

When a number of states failed develop SIPs, the Environmental Defense Fund sued the EPA to enforce the 1980 regulations. The lawsuit settlement required the EPA to develop new source review and visibility monitoring provisions for those states in the form of Federal Implementation Plans (FIPs).

- As part of the FIPs, EPA regulations called for the establishment of a cooperative visibility monitoring effort between the EPA, principle federal land management agencies, the states, and state organizations. The first formal cooperative visibility monitoring effort became a reality in the mid-1980s and was named IMPROVE (Interagency Monitoring of Protected Visual Environments).

The 1990 amendments to the Clean Air Act included a new section 169B emphasizing regional visibility impairment issues. Section 169B outlines four specific goals for future visibility protection:

- To expand scientific knowledge and technical tools on visibility.

- To assess how implementation of various CAA programs may result in improvement in visibility in Class I areas; and

- To provide for establishment of the Grand Canyon Visibility Transport Commission and to allow for the establishment of other Visibility Transport Commissions.

- To require EPA to develop regional haze regulations, including "criteria for measuring reasonable progress toward the national goal."

As part of the IMPROVE monitoring program, the EPA, federal land managers, state agencies, and local governments have developed individual goals and objectives in response to visibility regulations set forth in the CAA and EPA regulations. Primary objectives, seen by the EPA as essential when establishing a visibility-related monitoring network, follow in Section 2.2.2, Monitoring Purpose and Objectives. Additional programs and applications which benefit from the information obtained by visibility monitoring are defined in Section 2.4.2, Data Uses.

2.2.2 Monitoring Objectives

The purpose of visibility monitoring is to collect high quality data that can be used in analyses to assess whether or not progress is being made toward meeting the visibility goals. Without measurements there is no quantifiable method of tracking progress. The monitoring objectives listed in Table 2-1 and discussed below outline the types of data required to perform goal oriented analyses.

The monitoring objectives address the visibility protection regulations for mandatory Class I areas and other areas of concern. The mandatory Class I areas were designated by Congress and are listed in Table 1-1 of this document. Other natural areas of concern include non-mandatory Class I areas and Class II areas of particular interest to the land management agency, state, tribe, or other responsible organization. For example, the U.S. Fish and Wildlife Service may define its affirmative responsibility to protect visibility to include selected resource areas, or a state may decide to protect a region of special interest. These non-mandatory areas do not fall under EPA's jurisdiction but could be included in the monitoring objectives of responsible agencies.

The principle objectives for visibility monitoring are as follows:

1) Ensure that high quality, nationally consistent, comparable data are collected by all monitoring organizations through adoption of standard monitoring protocols.

2) Establish present visual air quality conditions.

3) Identify sources of existing man-made visibility impairment.

4) Document long-term spatial and temporal trends to track progress towards meeting the long-term goal of no man-made impairment of protected areas.

5) Provide data for New Source Review (NSR) analyses.

6) Provide data for Prevention of Significant Deterioration (PSD) analyses.

2.2.2.1 Ensure that High Quality, Comparable Data are Collected by All Monitoring Organizations Through Adoption of Standard Monitoring Protocols.

It is essential that data be collected in a technically sound, quality-assured manner by all monitoring organizations. It also must be regionally and nationally comparable, consistent over time and capable of supporting the visibility goals of the Act and EPA regulations. In order to satisfy the visibility monitoring objectives described above, the regional haze rule does not specify a Federal reference method for visibility monitoring. Instead, this document constitutes official EPA guidance on visibility monitoring. The protocols contained herein generally follow those established under the IMPROVE Program, have been peer-reviewed and are widely accepted.

These IMPROVE protocols include Standard Operating Procedures (SOPs) and Technical Instructions (TIs) that define the monitoring methods, laboratory methods, data reduction and validation procedures, quality assurance requirements, and archive formats for aerosol, optical and scenic monitoring. Federal land management agencies and a number of state and municipal organizations have adopted these protocols. These protocols are more fully described in Sections 3.0 through 5.0 of this document.

The guideline protocols may be implemented by individual organizations or cooperative monitoring programs. A county or state agency, an industrial source, a federal land manager, Indian tribe, or a combination of public and private organizations can design and implement a monitoring site or network.

Cooperative monitoring programs have advantages that include: reducing duplication of effort, sharing resources allowing economy of scale, involving more participants, and providing a consistent, comprehensive database. Most cooperative programs are based on a memorandum of understanding between cooperators that clearly defines the program's goals and objectives. The activities of most cooperative programs are defined by a steering committee, composed of representatives from the cooperating organizations, and generally functions like a board of directors. The steering committee generally designates an operating agent (most often one of the committee members agencies) to manage the day-to-day monitoring functions including fiscal and contract management.

The primary example of a long-term, effective cooperative effort to monitor visibility for regulatory, planning, and research purposes is the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. IMPROVE is a cooperative visibility monitoring effort among the EPA, NOAA, FLMs (NPS, USFS, USFWS), and state air agencies (STAPPA/ALAPCO, WESTAR, NESCAUM and MARAMA). Established in 1985, IMPROVE supports routine visibility monitoring in Class I areas nationwide and also conducts research on visibility issues. The broad spatial scale of the IMPROVE Program allows for regional and national scale assessment of visibility. The IMPROVE Program has also established operational visibility monitoring protocols that are used by many other projects.

Other cooperative efforts have been formulated to address specific visibility issues. Examples of public and private partnerships to assess specific visibility impacts on Class I areas include Project MOHAVE (Measurement Of Haze And Visual Effects) and the Mount Zirkel reasonable Attribution Study. An example of recent research programs that included visibility components are SEAVS (South Eastern Aerosol and Visibility Study) and NFRAQS (Northern Front Range Air Quality Study).

Because visibility issues generally include an important regional component, cooperative efforts that cross protected area and state boundaries are an effective way to design and implement visibility monitoring programs.

2.2.2.2 Establish Current Visual Air Quality Conditions

This objective is necessary for two reasons:

1) Visibility levels monitored in or near a specific Class I area, when compared to surrounding area visibility or area estimates of natural levels, may be sufficient to indicate man-made impairment.

2) Knowledge of existing visibility conditions is required to model the anticipated visibility effects of proposed emission sources, or of proposed emissions reductions.

3) A baseline level of visibility impairment is needed in order to judge reasonable progress in accordance with the requirements of the Regional Haze rule.

Establishing present visibility levels requires routine monitoring that documents the frequency, duration, and intensity of both surface and elevated hazes. Aerosol, optical, and scene monitoring methods are appropriate for surface haze monitoring, while scene monitoring is the only practical way to routinely monitor elevated layers.

Visibility varies with time. Diurnal, weekly, seasonal, and inter-annual variations occur. In accordance with the Regional haze rule, five years of data should be used in establishing a baseline of seasonal and annual average conditions to reduce the normal year-to-year fluctuations due to meteorology.

The magnitude of visible effects from a modeled increment of additional air pollution depends on the aerosols already in the atmosphere. For example, 1 microgram per cubic meter of additional fine particles is visible when added to ambient concentrations of 5 micrograms per cubic meter, but may not be perceptible when added to 30 micrograms per cubic meter. Without adequate knowledge of existing visibility levels, the potential impact of new source emissions on the protected resource will be difficult to determine.

2.2.2.3 Identify Sources of Impairment

In order to make progress toward the national goal of no manmade impairment in mandatory Class I areas, as called for by Congress, the States and EPA need to conduct monitoring to identify the sources responsible for the impairment. Regional haze attribution refers to the identification of average contributions by different aerosol species, source categories, or specific sources. Distinguishing man-made from natural impairment, which is fundamental to the congressional goals, requires information derived from monitoring data. Regional haze characterization identifies the time distribution of visibility levels (e.g., diurnal patterns, frequency, intensity, and duration). Monitoring is the principle means of gathering information needed to identify the contribution by emission sources to overall impairment levels and to time distributions of impairment as well.

Scene and aerosol monitoring methods are primarily used to identify emission sources. Photography of a plume emanating from a source and impacting a Class I area is sufficient to indicate impairment. A series of photographs can be evaluated to characterize the intensity, frequency, and duration of the visible plume. Unfortunately, most visibility impairment does not lend itself to this simple type of source attribution. Sources are often not visible from the Class I area, or their plumes disperse and are transformed into a uniform haze before reaching the area. In addition, visibility impacts are often caused by secondary aerosols formed over time from gaseous pollutants. Understanding the characteristics of the aerosols in a haze can help identify the type of sources that contributed to the haze. It is possible to statistically estimate what portion of a haze is caused by each aerosol type. This approach, known as an extinction budget analysis, can narrow the list of possible sources responsible for visibility impacts. For example, if sulfate is shown to be responsible for 75% of the extinction coefficient, the major sources responsible for the haze must emit sulfur dioxide.

Another related approach for source identification using aerosol data is known as receptor modeling. Instead of using only the major aerosol components that are directly responsible for the impairment, receptor models use relative concentrations of trace components which can more

specifically identify the influence of individual sources (or source types). For example, the presence of arsenic may be a good indicator of copper smelter emissions.

2.2.2.4 Document Long-Term Trends

With the establishment of a long-term goal of no man-made visibility impairment in protected areas, Congress imposed the responsibility to show progress towards meeting that goal. Long-term consistent monitoring and trends analysis is an ideal approach for tracking the visibility conditions of Class I and other areas of concern.

The same monitoring methods used to establish present visibility levels will provide the data required to determine long-term visibility trends. To determine the individual effectiveness of several concurrent emission reduction programs, it will be necessary to conduct aerosol monitoring to support extinction budget analysis as described above.

Determining the specific visibility strategy for any area of concern requires an understanding of the effect that man-made aerosols have on the existing conditions, and projecting what the visibility would be like if the man-made aerosols were changed. This type of analysis can range from simple to complex for specific areas. In areas where man-made aerosols exist, the long-term goal is to improve upon existing conditions. The concept of continual improvement toward no man-made impairment is significant. It is not enough to maintain existing conditions in areas where man-made pollution exists when improvement is the goal. The EPA and/or regulatory agencies must define what continual improvement means, but monitoring of ambient air quality will likely be a principle method for tracking and verifying whether improvement occurs.

2.2.2.5 Provide Data for the New Source Review and Prevention of Significant Deterioration Permitting Programs

The New Source Review (NSR) permitting program applies to new major stationary sources and major modifications locating in areas designated as nonattainment for the NAAQS. The Prevention of Significant Deterioration (PSD) permitting program applies to new major stationary sources and major modifications locating in areas designated as attainment or unclassifiable for the NAAQS.

These programs generally require the permit applicant to conduct a source impact analysis. For the NSR program, the impact analysis must demonstrate that the new or modified source will not cause or contribute to a violation of state or national air quality standards (NAAQS) or cause an adverse impact to visibility in any Federal class I area.[7]

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[7] Section 51.307 of EPA's visibility regulations requires any new or modified source locating within a nonattainment, attainment, or unclassifiable area for a NAAQS to evaluate the potential adverse impact of the proposed source on visibility in the relevant Class I area(s).

The PSD program, in addition to providing protection of the NAAQS, is generally designed to provide a more comprehensive source impact analysis than the NSR program. Included in this impact analysis is the protection of Federal lands (national parks, wilderness areas, etc.) which have been designated as Class I areas for PSD purposes. A special feature of the protection of air quality in Class I areas is the responsibility to assure that air pollution will not adversely affect air quality related values (including visibility) that have been identified for these areas.

The company or other entity proposing to build a new stationary source or major modification may be required to apply air quality models to carry out the source impact analysis. The air quality data used to provide existing conditions for these models most often come from routine monitoring sites. State and/or national monitoring networks (e.g., IMPROVE) generally provide the aerosol, optical, and/or scene information necessary to understand existing visibility conditions in Class I areas, represented as the annual frequency distribution of the extinction coefficient and/or standard visual range. Understanding the existing conditions is important in determining whether a new or modified source's emissions may have an adverse impact on visibility. If a potential for visibility impairment exists, the source emissions are generally mitigated (or offset) during the permit process to significantly lower the probability of impacts.

In some cases, if visibility-related monitoring does not exist which represents a Class I area or other area of concern, the implementation plan must define a method to determine how representative data from existing monitoring sites can be used to evaluate potential impacts to Class I areas. To evaluate whether an existing monitoring site is representative of other sensitive areas requires an analysis which must consider several factors, including the geography, topography, meteorological patterns, and potentially contributing sources.

Using monitoring to help evaluate representativeness may only require that a selected methodology, such as a single filter aerosol monitor (e.g., mass and elements only) or an optical monitor (e.g., nephelometer), be placed at the area of interest for comparison to a nearby primary site. Additional considerations to determine local and/or regional representative conditions are described in Section 2.6.1.1.

Under some circumstances, when the uncertainty of modeled results is high, a permit may require pre- and/or post-construction monitoring to better define local existing conditions (if nearby monitoring data are not available) and to verify that no impacts occur. The type of monitoring required is generally defined in the permit and may be limited to a few critical parameters. Most resulting monitoring efforts are local to the proposed source. The basis for visibility monitoring under a permit requirement is often a negotiated process among the state, federal land management agency, and the source. The monitoring techniques applied in this type of program for specific visibility parameters will generally parallel those required for routine monitoring, however, the temporal frequency or local spatial distributions may be enhanced as compared to the more regional monitoring networks so that more information can be gathered over a shorter time period to support timely mitigation decisions.

2.3 VISIBILITY DATA QUALITY OBJECTIVES

To meet the established objectives of a visibility monitoring program, data quality objectives must be adopted or established by the monitoring organization. These data quality objectives must be an integral part of the monitoring program and address: primary parameters, network design, and quality assurance. Recommendations and considerations for defining data quality objectives are outlined below and further discussed throughout this document.

2.3.1 Primary Parameters

Monitoring of the primary visibility parameters can be separated into three categories: aerosol, optical, and scene. The data quality recommendations in each category are summarized below. Detailed descriptions and examples of each monitoring method are provided in Section 2.4.

2.3.1.1 Aerosol

Aerosol monitoring obtains concentration and composition measurements of atmospheric constituents that contribute to visibility impairment. Recommended aerosol monitoring quality objectives are:

- Collect 24-hour filter samples of $PM_{2.5}$ and PM_{10} particulates at least every third day.

- Determine the 24-hour average $PM_{2.5}$ (fine), PM_{10} and PM_{10} minus $PM_{2.5}$ (coarse) mass concentration of the filter samples with an overall accuracy of 10%.

- Analyze $PM_{2.5}$ filters to determine 24-hour mass concentrations (with an overall accuracy of 10%) of the following individual visibility impairing particulate constituents that either contribute to visibility impairment or serve as indicators of the sources of $PM_{2.5}$ particles:

  - Major contributors to visibility impairment (large contributors to mass and important for reconstructed extinction)
    - Sulfates
    - Nitrates
    - Organic carbon
    - Elemental carbon (light absorbing carbon)
    - Chlorides
    - Earth crustal elements
    - Light absorption (optical parameter from filter light transmission measurement)
  - Elements and compounds that further serve as indicators of sources of visibility-related particles
    - Trace elements
    - Ions

- Derive the liquid water associated with hygroscopic species from associated RH measurements and species growth curves.

- Determine additional particulate characteristics that may be useful in source attribution analysis. For example, certain trace elements may be used in Chemical Mass Balance (CMB) to estimate specific source contributions of interest (e.g., vanadium and nickel as indicators of oil refining).

2.3.1.2 Optical

Optical monitoring measures the light scattering and absorbing properties of the atmosphere, independent of physical scene characteristics or illumination conditions. Optical monitoring recommendations are the following:

- Determine the hourly average ambient atmospheric light extinction coefficient with an overall accuracy of 10%. The total extinction can be measured directly or derived from measurements of the light scattering and absorbing components of extinction.

- Air temperature and relative humidity measurements should be collected simultaneously with optical measurements. These readings provide the information required to assess weather interferences and humidity related visibility affects. The overall accuracy of temperature and relative humidity measurements should be ± 0.5°C and ± 2% RH respectively. The meteorological parameters should be measured in accordance with EPA guidance.

2.3.1.3 Scene

Scene monitoring refers to the use of still and/or time-lapse photography (including digital imagery) to provide a qualitative representation of visual air quality. Scene monitoring data quality objective recommendations are to document the appearance of scenes of interest under a variety of air quality and illumination conditions at different times of day and different seasons. The quality (resolution) of the data collection media is important. Photographs should be obtained using 35 mm color slide film. Color video or digital images should be S-VHS format or better.

2.3.2 Network Design

A visibility monitoring program to characterize a Class I area or other area of concern could consist of one site or a network of sites. Detailed site and network design considerations and example network configurations are provided in Section 2.6. However, the principle considerations in network design are the following:

- Each site must be selected to represent visual air quality within the air mass of interest. For example, the visual air quality of a Class I area should be monitored at an elevation typical of the Class I area, and within the area or as close as possible to the Class I area boundary.

- The spatial and temporal aspects of a monitoring network must be designed to meet the monitoring goals and objectives of the network. For example, long-term trend monitoring of a remote area may only require one well placed site that will operate in perpetuity. A specific source attribution study may require a network of many sites placed upwind and downwind of a suspected source region, but may only operate for a short period of time (several months to a year or more).

- “Representative” sites should be determined on a case-by-case basis. Important considerations should include common elevation, common source region of emissions, and similar location relative to major topographic features. (See additional discussion in section 2.6.)

- Year-round monitoring may not be practical at certain mandatory class I sites due certain geographic or safety limitations, such as the extremely remote location of a class I area. The IMPROVE Steering Committee and relevant States should address such situations on a case-by-case basis.

- Visibility site and network designs may vary due to cost, logistical, or historical data considerations, but an ideal site design would include the full complement of aerosol, optical, and scene monitoring. The relevant monitoring organization should fully document the reasons for any site or network monitoring design decisions.

General visibility network design guidelines are the following:

- Aerosol, optical, and scene information is desired for each site.

- At a minimum, aerosols should be monitored at one or more sites representative of an area of concern. These measurements should include $PM_{2.5}$ mass, PM_{10} mass, and the mass concentrations of aerosol species that include sulfates, nitrates, organic carbon, inorganic carbon, earth crustal components, ions, and other major and trace elements. Without aerosol monitoring the causes of visibility impairment can not be quantified. Initially, all aerosol constituents must be addressed. An individual constituent may be eliminated if historical data indicate the constituent is minor or below detection limits. However, this decision should be revisited periodically to ascertain if underlying conditions have changes. In situations where optical monitoring is not possible due to cost considerations, aerosol monitoring alone can be used to calculate reconstructed light extinction using known or assumed extinction efficiencies for principal aerosol components.

- Continuous optical monitoring is recommended at all sites. Continuous optical monitoring by nephelometer or transmissometer (hourly averages) provides an understanding of the temporal dynamics of visibility. When an optical monitor is collocated with an aerosol sampler, the optical data provides a valuable cross-check for reconstructed extinction analyses.

- Scene monitoring (35 mm photography, time-lapse video) documents the visual appearance of uniform haze, ground-based layered haze, elevated layered haze, and the overall characteristics of the scene. Scene monitoring is the only ground-based way to observe and characterize elevated layers or plumes. Scene monitoring at long-term sites can often be reduced after an extended period of time (i.e., five years) if a sufficient photographic record that covers the broad range of expected conditions has been established.

- The configurations of monitoring sites need to be periodically evaluated to determine if changes are warranted. For example, changes in area-wide emissions may warrant changes in the monitoring strategy applied at a site. Or, a network site could be eliminated or its configuration simplified if it correlates well with another network site that could be considered representative.

- New monitoring and analysis technologies need to be evaluated and implemented where appropriate to enhance the information gained at monitoring sites.

Site and network designs vary depending on monitoring objectives, logistic considerations, and cost considerations. Table 2-2 summarizes appropriate configuration sites designed to meet a number of common monitoring objectives, including: 1) Sites to determine existing conditions, track long-term trends, and source attribution; 2) Monitoring for PSD and NSR where only total light extinction measurements or visual range are required; and 3) Short-term pilot study options for initial evaluations or spatial representativeness tests.

The table highlights several approaches for each common objective. For example, to determine existing conditions, the most scientifically sound configuration would include a comprehensive configuration of aerosol, optical, and scene parameters where a transmissometer would measure b_{ext}. If a transmissometer installation were not possible due to logistic limitations, a nephelometer-based installation would be a viable alternative. If no optical monitoring were possible due to cost limitations, an aerosol-based approach could be used. In fact, if the primary objective is to establish a multi-year baseline, then aerosol monitoring is sufficient to evaluate visual air quality. For an aerosol-based configuration, light extinction would have to be reconstructed from known or assumed b_{ext}/aerosol relationships. Such relationships are already well-established for certain regions of the country. Table 2-2 highlights similar configuration considerations for other objectives. The ultimate site and network design must address both scientific and practical issues.

2.3.3 Quality Assurance

All monitoring programs must operate in accordance with documented quality control and quality assurance procedures that address:

- Standard operating procedures and technical instructions for calibration, monitoring, data collection, data processing, reporting, archive, and audit procedures.

- Data recovery and quality goals. Recommended values are:

  - Data recovery better than 90% (including all weather influences).
  - Precision and accuracy better than 10%.
  - Detection limits for all aerosol species based on the specific analytical technique must be defined and measurements must be evaluated against the detection limits.

- Standard scientifically accepted methods to determine, calculate, and report measurements:

  - Standard visibility variables and units:
    b_{ext}, b_{scat}, b_{abs}, (inverse megameters)
    deciview index (in dv)
    visual range (in km)
  - Standard aerosol mass concentrations units:
    $\mu g/m^3$

- Weather influences on visual air quality. These must be addressed in data analyses.
- Specific precision, accuracy, and /or detection limit references. These should be associated with data values.
- Validity flags and weather effects flags. These should be associated with data values.

Quality assurance, sampling methods, and standard unit considerations are addressed further in Section 2.4.

Table 2-2

A Summary of Appropriate Site Configurations for Common Monitoring Objectives

Common Applications (to meet monitoring objectives)	Monitoring Approach	Aerosol							Optical		Scene		Meteorology	Comments
		$PM_{2.5}$				PM_{10}		b_{ag}	Trans	Neph	Still-Frame	Time-Lapse		
		Mass	Elements	Ions	b_{ap}	Mass	Elements	NO_2 Gas	b_{ext}	b_{scat}	Instantaneous	Dynamic	AT/RH	
Determine existing conditions, track long-term trends, and source attribution	Most scientifically sound - Aerosol, Optical (transmissometer), and Scene	✓	✓	✓	✓	✓	AN	AN	✓		✓		✓	Scene monitoring can be terminated after approx. 5 years if a sufficient visual record is compiled
	Aerosol, Optical (nephelometer), and Scene	✓	✓	✓	✓	✓	AN	AN		✓	✓		✓	Scene monitoring can be terminated after approx. 5 years if a sufficient visual record is compiled
	No optical possible, Aerosol-Based (reconstructed extinction)	✓	✓	✓	✓	✓	AN	AN			✓		✓	Scene monitoring can be terminated after approx. 5 years if a sufficient visual record is compiled
PSD or NSR when only extinction measurements are required	Most scientifically sound - Optical (transmissometer-based)								✓				✓	
	Optical (nephelometer-based)				✓			AN		✓			✓	
	No optical possible - Aerosol-Based (reconstructed extinction)	✓	✓	✓	✓			AN					✓	
	Scene only (elevated layer characterization or visible plume attribution)										✓	AN		
Short-term pilot study options for initial evaluations or spatial representativeness tests	Aerosol-Based	✓	✓		✓									IMPROVE Module A only is commonly applied
	Optical - (nephelometer-based)									✓			✓	
	Scene-Based										✓	AN		Cameras are often a first step to document the presence of ground-based or elevated layers

✓ = Recommended
AN = As Needed

2.4 MONITORING METHODS

Adequate monitoring is an essential element for assessing whether the visibility goals adopted as part of the CAA and EPA regulations are being met. Visibility monitoring consists of three distinct monitoring components that describe and define the visual characteristics of the air: aerosol monitoring, optical monitoring, and scene monitoring.

Aerosol monitoring is used to obtain concentration measurements of atmospheric constituents that contribute to visibility impairment. Primary techniques include filter-based aerosol samplers that collect samples on various substrates in two size ranges, aerodynamic diameters $\leq 2.5\ \mu m$ ($PM_{2.5}$) and aerodynamic diameters $\leq 10\ \mu m$ (PM_{10}). To identify and track the relative visibility impacts caused by various pollution species, a complete aerosol characterization is recommended. This would include $PM_{2.5}$ compositional analysis for all of the major components responsible for visibility impacts, including sulfates, nitrates, organic carbon species, inorganic carbon, earth crustal components, and the chemical constituents of other fine mass. Where wind erosion may be a concern, the coarse particle mass concentration (particle diameter from 2.5 μm to 10 μm) should also be characterized. An understanding of the liquid water associated with hygroscopic particle components is also important. With present technology, the liquid water particle component cannot be directly measured, nor is it possible to determine liquid water content from subsequent analysis of particle samples. Relative humidity data can be used to infer the visibility impacts associated with liquid water. Due to the significance of this component for visibility effects for assessment of daily visibility levels, continuous relative humidity monitoring is a desirable supplement to aerosol monitoring. However, aerosol data together with climatological meteorological parameters can be used to estimate extinction.

Optical monitoring is used to measure the light scattering and absorption properties of the atmosphere, independent of physical scene characteristics or illumination conditions. It requires accurate and precise measurements of the ambient optical properties of the atmosphere. The primary optical parameter is the ambient extinction coefficient (b_{ext}), defined as the fraction of light lost per unit distance as light traverses the atmosphere. It is the sum of scattering and absorption coefficients (b_{scat} and b_{abs}) of atmospheric gases and aerosols. Optical monitoring can be performed using a transmissometer to obtain ambient extinction measurements. Where practical considerations limit the use of a transmissometer, direct measurements of scattering (using a nephelometer) can be combined with collocated aerosol measurements of absorption to estimate extinction. Similar to aerosol monitoring, an understanding of the liquid water associated with the observed b_{ext} measurement is important. Relative humidity data can be used to clarify observed visibility impacts that are associated with liquid water. Due to the significance of this component, continuous relative humidity monitoring should also be a part of optical monitoring.

Scene monitoring refers to still and/or time-lapse photography (including digital imagery) that is used to provide a qualitative representation of the visual air quality in the area of interest. The photographic record documents the appearance of a scene. Scene characteristics include color, texture, contrast, clarity, and observer visual range. Photography is uniquely suited for identifying ground-based or elevated layers or plumes that may impact Class I or protected areas, as well as documenting conditions for interpreting aerosol and optical data.

Since its formation in 1985, researching the most effective and efficient means of monitoring visibility and applying these methods in a national monitoring program have been primary objectives of the IMPROVE Program. IMPROVE protocol defines that, where possible, aerosol, optical, and scene monitoring should be conducted at each site.

Instrumentation used to fulfill IMPROVE protocols include:

- Aerosol - IMPROVE modular aerosol sampler

- Optical - transmissometer or nephelometer (collocated with an air temperature/ relative humidity sensor)

- Scene - automatic camera systems

IMPROVE sampling and instrumentation protocols serve as the basis for NPS, USFS, USFWS, and a number of state and local visibility monitoring programs today.

By implementing full IMPROVE protocols, precise and reliable measurements of b_{ext}, b_{scat}, and b_{abs} can be obtained to characterize the parameters of the atmosphere and allow for the determination of effects due to specific pollution species. Table 2-3 summarizes standard IMPROVE monitoring instrumentation and sampling protocols. Although IMPROVE protocols support a full site configuration of aerosol, optical, and scene monitoring, some visibility related objectives can be met with a subset of the monitoring components. Sites without aerosol monitoring but with optical and scene monitoring can still meet the objectives required for baseline models that require an extinction estimate and for surface haze characterization.

Table 2-3

IMPROVE Visibility Monitoring Protocols
Instrument-Specific Monitoring Considerations

Monitoring Component[1]	Instrument	Monitoring Method/ Measured Parameter	Sampling Frequency (Reporting Interval)	System Accuracy	Instrument Uncertainty (Precision)
Aerosol	IMPROVE Aerosol Filter Sampler: Module / Filter A: $PM_{2.5}$, 25mm Teflon B: $PM_{2.5}$, 25mm Nylon C: $PM_{2.5}$, 25mm Quartz D: PM_{10}, 25mm Teflon	Point measurement of aerosol mass and aerosol species as noted below: $PM_{2.5}$ mass, elements (H, Na-Pb), coefficient of absorption $PM_{2.5}$ nitrate, sulfate, and chloride ions $PM_{2.5}$ organic and elemental carbon PM_{10} mass	Integrated (24-hour samples) IMPROVE protocols state samples are taken every third day. Special studies or short-term monitoring may require alternate sampling schedule(s)	! Filter mass accuracy as measured by electromicrobalance that is calibrated to traceable weight standards ! Sampler flow accuracy calibrated to traceable flow standards	! Collocated samplers required to determine system precision. Normally one set of collocated samplers per study (region) ! Measured in terms of a minimum detectable limit (MDL) for the species ! Uncertainty in a measured concentration is the square root of the sum of the squares of the uncertainties of measured mass (M), volume of air sampled (V), and artificial mass (A) ! Elemental dependant precisions are provided in Section 3.0, Aerosol Monitoring
Optical	Transmissometer	Path measurement Calculated measure of extinction (b_{ext})	Continuous (hourly-average)	! No absolute calibration standard ! Accuracy inferred from comparison to measured b_{scat} + b_{abs} and to reconstructed b_{ext} from aerosol measurements	Path dependent: ±0.003 km^{-1} 10 km working path and 0.010 nominal extinction value or ±3% transmission
	Nephelometer	Point measurement Calculated measure of scattering (b_{scat})	Continuous (hourly average)	! Calculated from regular (usually weekly) zero/span calibrations. Generally ±10% of true value for air near Rayleigh and using two minutes of integration (longer integrations will increase the accuracy i.e., 10 minutes of integration will increase accuracy to ±4.5%)	Collocated samplers required to determine precision tests indicate precision approximately ±5%
Scene	35 mm Camera	Qualitative representation of a scene, haze characterization	3 times per day	N/A	N/A
	Time-Lapse Video Camera (Super 8 mm camera)	Qualitative representation of a scene, haze characterization, and documentation of air flow and visibility/meteorological related dynamics in relation to the scene	Continuous during daylight hours	N/A	N/A
Meteorology	Air Temperature and Relative Humidity	Point measurement (aspirated AT/RH sensor)	Continuous (hourly average)	Temperature ±0.3°C Relative Humidity ±1.5% RH from (0 to 100%)	Precision determined by collocated samplers Repeatability: Temperature ±0.1°C RelativeHumidity ±0.3% RH

1. Goals and objectives addressed by each monitoring type are provided in Table 2-1

Sites without optical monitoring but with aerosol and scene monitoring can be used to determine long-term trends of man-made impairment and surface haze attribution, given a periodic re-evaluation of b_{ext} to aerosol relationships. Scene monitoring by itself can lead to the identification and characterization of elevated layers. (Pitchford, IMPROVE Committee "Discussion of Issues for Monitoring of Visibility-Protected Class I Areas," September 1993.)

The deployment of instrumentation and initiation of operational monitoring often depends on the availability of funds. The financial resources (total budget) and financial tradeoffs (e.g., more sites or fewer sites with more instruments) are real considerations. Site logistics may also restrict the operation of certain instruments at some sites.

Additional monitoring techniques exist and more will be developed that are applicable to visibility monitoring. Listed below are several currently available techniques that are sometimes used to collect visibility-related data for regulatory and planning purposes.

! NO_2 analyzer - b_{ag} (light absorption by NO_2 gas)

! Aethalometer - continuous particle absorption

! Enhanced filter analysis techniques
  - enhanced resolution on organic measurements
  - enhanced tracer techniques and relationships

! Multi-wavelength optical instruments (transmissometer and nephelometer)

These techniques may be appropriate for research monitoring, may have value at specific sites, and may be recommended in the future.

The following subsections describe each visibility monitoring method and the current instrumentation that are considered by the EPA and IMPROVE Committee to be best suited for use. References made to specific instruments or manufacturers are not intended to constitute endorsement or recommendations for use. New or improved instruments and monitoring methods may become available at any time.

2.4.1 Aerosol Monitoring

Aerosol monitoring data are used to determine the gravimetric mass and chemical composition of size differentiated particles. Practical considerations (i.e., budget and logistics) often limit filter-based data collection to a selected number of 24-hour samples per week. The IMPROVE Program has historically collected two 24-hour samples per week (Wednesday and Saturday). Starting in December 1999, the sampling protocol changes to once every third day for increased sample collection and consistency with the $PM_{2.5}$ program. IMPROVE protocols for aerosol monitoring employ four (4) independent sampling modules at each site. As described below, three of the four samplers collect fine particles with aerodynamic diameters $\leq 2.5\ \mu m$:

! A Teflon filter is used to measure fine mass, sulfur, soil elements, organic mass, absorption, and trace elements (H and those elements with atomic weights from Na to Pb).
! A nylon filter is used to measure nitrate, sulfate, and chloride ions.

- ! A quartz filter is used to measure organic and elemental carbon.

Fine particles with diameters less than 2.5 microns are especially efficient at scattering light.

The fourth sampler collects PM_{10} particles with aerodynamic diameters up to 10 μm, using a Teflon filter. Particles >2.5 μm are less efficient light scatterers than $PM_{2.5}$ particles. By subtracting collocated $PM_{2.5}$ from PM_{10} mass concentrations, an estimate of coarse particles (2.5 μm <10 μm) can be made.

Analysis of IMPROVE filters for mass concentrations of separate aerosol species is a key to aerosol-based reconstructed extinction (b_{ext}) techniques. The measured mass concentration of the species that contribute to visibility degradation multiplied by their extinction efficiencies can yield an estimate of the extinction coefficient. The relationship of relative humidity and hygroscopic aerosols is also an important component in this analysis; therefore, it is strongly recommended that temperature and relative humidity sensors be collocated with aerosol monitors when the data are used to assess current, short-term visibility conditions.

Using the IMPROVE monitoring protocols as the example, a complete description of aerosol monitoring criteria, instrumentation, installation and site documentation, system performance and maintenance, sample handling and data collection, filter analysis and data reduction, validation, reporting, and archive, supplemental analysis including composite variables, quality assurance, and analysis and interpretation are provided in Section 3.0 of this Visibility Monitoring Guidance Document.

2.4.2 <u>Optical Monitoring</u>

Optical monitoring provides a quantitative measure of ambient light extinction (light attenuation per unit distance) or its components to represent visibility conditions. IMPROVE protocols provide continuous measures of b_{ext} and/or b_{scat} using ambient long-path transmissometers and/or nephelometers respectively. Water vapor in the air can affect the growth of hygroscopic aerosols and thus affect visibility; therefore, it is strongly recommended that temperature and relative humidity sensors be collocated with the chosen optical instrument.

Transmissometers measure the amount of light transmitted through the atmosphere over a known distance (generally between 0.5 km and 10.0 km) between a light source of known intensity (transmitter) and a light measurement device (receiver). The transmission measurements are electronically converted to hourly averaged light extinction (b_{ext}). If practical constraints make it impossible to operate a transmissometer at a particular area, ambient scattering (b_{scat}) can be measured with an ambient-temperature nephelometer. Ambient nephelometers draw air into a chamber and measure the scattering component of light extinction. On days when aerosol samples are taken, the determined scattering coefficient can be combined with the absorption coefficient, estimated from aerosol monitoring filters, to estimate the average total light extinction (b_{ext}) for the period.

Using the IMPROVE Program as the example, a complete description of optical monitoring criteria, instrumentation, installation and site documentation, routine operations, data collection, data reduction and reporting, quality assurance, and analysis and interpretation are provided in Section 4.0 of this Visibility Monitoring Guidance Document.

2.4.3 Scene Monitoring

Scene monitoring documents the visual condition observed at a monitoring site.

IMPROVE protocols recommend that color photographs (i.e., 35 mm slides or digital images) be taken several times a day. The data collection schedule can be tailored to capture the periods when visibility impairment is most likely at specific sites. For example, photographs during stable periods may yield more information in areas susceptible to ground-based or elevated layered hazes. Time-lapse movies (generally time-lapse video or super 8 mm film) have also been used at selected monitoring sites and during special studies to document the visual dynamics of a scene or source. To the extent possible, the selected scene should be collocated with or include the aerosol and optical monitoring equipment, so that conditions documented by photography can aid in the presentation of these data.

Using the IMPROVE Program as an example, a complete description of scene monitoring criteria, instrumentation, installation and site documentation, system performance and maintenance, data collection, reduction, validation, and reporting, and quality assurance procedures are provided in Section 5.0 of this Visibility Monitoring Guidance Document.

2.4.4 Standard Units

As indicated in the previous sections, visibility monitoring is not well defined by one single method. In turn, many of the indices for characterizing visibility are not directly measurable, but must be calculated from measurements using various assumptions (Section 2.1). Visibility related indexes can also be separated into three groups: aerosol, optical, and scene. Table 2-4 includes some of the most useful indexes for each group. Monitoring methods can similarly be subdivided based upon these measured indexes (Section 2.6.1.4).

Table 2-4 provides the recommended standard reporting units. Tracking, reporting, archive, and database formats should be consistent to promote comparable visibility data nationwide.

One source of confusion concerning visibility related measurements and standard units has been the common practice of converting measurement data to a different index. Such conversions usually require models with assumptions that are not always met. (Known conversions are noted in Sections 2.1, 3.0, 4.0, and 5.0). Direct measurement of the indexes of interest avoids these concerns and is recommended.

Table 2-4

Recognized
Visibility-Related Indexes
and Standard Units[1]

Index	Example	Standard Unit	Secondary Unit/Comments
Mass concentration of particles for size ranges based on aerodynamic diameters	Total suspended particulate matter, particulate matter less than 10 μm, particulate matter less than 2.5 μm	$\mu g/m^3$	ng/m^3
Particle composition	Elemental and ion concentrations	$\mu g/m^3$	ng/m^3
Physical characteristics	Shape, structure, and index of refraction		
Extinction coefficient (b_{ext})	Total loss of light due to absorption and scattering	Mm^{-1}	
Scattering coefficient (b_{scat})	The portion of light loss due to scattering by particles and gases	Mm^{-1}	
Absorption coefficient (b_{abs})	The portion of light loss due absorption by particles and gases	Mm^{-1}	
Scattering phase function	Angular distribution of scattered light		
Rayleigh scattering coefficient (b_{Ray})	The portion of light loss due to natural atmospheric molecules	Mm^{-1}	Varies with atmospheric pressure, altitude. Standard Rayleigh scattering at 5,000 feet is 10 Mm^{-1}
Visual range (VR)	Furthest distance that a suitable object can be seen	km	Standard Visual Range (SVR km), standardized to a Rayleigh atmosphere at 5,000 feet
Deciview	An index representing the loss of light (b_{ext}) with a constant fractional change in relation to visual range	dv	One dv is approximately a 10% change in extinction
Contrast	Contrast between two points, most often the horizon and sky	Unitless ratio	
Apparent radiance of scenic elements	Photograph or video		
Color	Chromaticity or color contrast		
Detail	Scene modulation		

[1] Adapted from Table 24-4 of the NAPAP Report.

2.5 DATA ARCHIVE AND DATA APPLICATIONS

2.5.1 National Visibility Archive

The need for a national archive of collected visibility data continues to increase. Numerous monitoring programs, special studies, and research efforts have been conducted since the Clean Air Act was enacted. In order to adequately protect all Class I areas and address other resource issues, FLMs, states, tribes, and other monitoring entities must share information and evaluate the representativeness of available visibility data. A centrally located database will be coordinated by the EPA for all historical and future aerosol, optical, and scene visibility monitoring information and visibility data. Uniform tracking, reporting, and archive formats will be established to assure that data collected today can be used in future applications and future new source review models. Data exchange will be available in standard ASCII format by FTP or Internet access. Standard file formats currently used for IMPROVE protocol data are presented in Figures 2.4, 2.5, and 2.6. All data will be archived in the standard units noted in Table 2-4. These file formats will be used as the standard for the future National Visibility Archive.

2.5.2 Data Uses

Visibility data are collected and used by air resource managers, scientists, and private organizations to address the visibility goals set forth in Section 169A and Section 169B (See Section 2.2 herein). Environmental policy and actions, as well as organizational goals and objectives, are often a result of or a catalyst to visibility monitoring programs.

Primary considerations when evaluating the representativeness or adequacy of collected data for meeting defined monitoring objectives include: 1) the monitoring location, 2) the type of data, 3) the quality of the data, and 4) the time period of the data. Visibility monitoring information must be generated in a manner consistent with promulgated regulations and this EPA Visibility Monitoring Guidance Document to be acceptable as a primary source of visibility data for mandatory Class I areas, or any area of concern. For example, human observer-based visibility such as airport or fire lookout observations should not be used as a surrogate for measured extinction values (see Section 2.1.1).

Visibility monitoring data are used to address existing and potential data requirements set forth in each of the following applications:

- Visibility Protection Program - Data are used to identify existing conditions and determine long-term trends. Program data are also used to assess progress towards existing national goals.

- PSD Program Requirements - Visibility data that describes existing conditions can be used as input for new source review (NSR) models and to assess a proposed source's potential impact on a particular PSD area. (Ref. EPA CFR 40, Parts 51 & 52) (Ref. EPA-450/4-87-007)

ACAD1	03/20/93	0000	0.00	0.0 BSO4	2070.50	79.00	47.10	NM
ACAD1	03/20/93	0000	0.00	0.0 CL-	65.10	163.40	326.20	NM
ACAD1	03/20/93	0000	0.00	0.0 NO2-	-24.00	0.90	0.30	NM
ACAD1	03/20/93	0000	0.00	0.0 NO3-	2444.50	104.70	22.40	NM

Records of the data files are written in the following format:

Field	Description
1	Site Code
2	Sample Date
3	Start Time
4	Duration
5	Flow Rate
6	Species
7	Amount
8	Error
9	Minimum Detectable Limit
10	Species Status

If the Amount, Error, and Minimum Detectable Limit are all zero there is not valid measurement for that species.

All species amounts, errors, and minimum detectable limits are in values nanograms per cubic meter except for 'BABS.' 'BABS' values are in 10**(-8) inverse meters.

Start times are in military hours.
Sample durations are in decimal hours.
Flow rate is in liters per minute (ambient).

SPECIES STATUS CODES:

NM	=	Normal
QU	=	Questionable; Undetermined
QD	=	Questionable Data
AA	=	Organic Artifact Corrected
AP	=	Possible Organic Artifact (No correction performed)
' '	=	No Analysis Available for this Species

NOTE: From 9/90 through 2/92 we received some Teflon filters with an organic contamination. This artifact influenced only the Hydrogen and Fine Mass measurements in less than 7% of the samples (marked AA). All other measurements of Hydrogen and Fine Mass during this period are marked with a status AP.

SPECIES CODES:

MF	=	Fine Mass (UCD)
MT	=	PM-10 Mass (UCD)
BABS	=	Optical Absorption (UCD)
H	=	Hydrogen (UCD)
BSO4	=	Sulfate on Nylon (RTI, GGC)
NO2-	=	Nitrite (RTI, GGC)
NO3-	=	Nitrate (RTI, GGC)
CL-	=	Chloride (RTI, GGC)
SO2	=	Sulfur Dioxide (DRI)
O1	=	Organic carbon, $\leq$120 °C (DRI)
O2	=	Organic carbon, 120 °C - 250 °C (DRI)
O3	=	Organic carbon, 250 °C - 450 °C (DRI)
O4	=	Organic carbon, 450 °C - 550 °C (DRI)
OP	=	Pyrolized organic, 550 °C, 2% O2, reflectance $\leq$ initial (DRI)
E1	=	Elemental carbon + pyrolized organic, 550 °C, 2% O2 (DRI)
E2	=	Elemental carbon, 550 °C - 700 °C, 2% O2 (DRI)
E3	=	Elemental carbon, 700 °C - 800 °C, 2% O2 (DRI)

All other species are elemental values from UCD Elemental Analysis.

Figure 2-4. Standard ASCII File Format IMPROVE Protocol Aerosol Visibility Data.

Field Number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
GRCA	900702	183	700	12	1	4	0	18	10	300	0	17	1	0	38	3	0	134
GRCA	900702	183	800	-99	-99	0	4	18	10	300	4H	-99	-99	0	-99	-99	0	-99

<u>Field</u>	<u>Description</u>
1	Site abbreviation
2	Date in year/month/day format
3	Julian Date
4	Time using a 24-hour clock in hour/minute format
5	b_{ext} (Mm^{-1})
6	b_{ext} uncertainty (Mm^{-1})
7	Number of readings in average
8	Number of readings not in average due to weather
9	Uncertainty threshold (Mm^{-1})
10	Δ threshold (Mm^{-1})
11	Maximum threshold (Mm^{-1})
12	b_{ext} validity code [1]
13	Temperature (°C)
14	Temperature uncertainty (°C)
15	Temperature validity code [2]
16	Relative humidity (%)
17	Relative humidity uncertainty (%)
18	Relative humidity validity code [2]
19	Haziness (dv x 10)

[1] b_{ext} validity codes:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from alternate logger
4x	=	Weather:	a letter code representing specific conditions as noted below:

Condition	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > 90%	x		x		x		x		x		x		x		x
b_{ext} > maximum threshold		x	x			x	x			x	x			x	x
b_{ext} uncertainty > threshold				x	x	x	x					x	x	x	x
Δ b_{ext} > delta threshold								x	x	x	x	x	x	x	x

(Letter Code)

Z Weather observation between 2 other weather observations.

Threshold values may be different for each site. See Appendix A.

8	=	Missing:	Data acquisition error
9	=	Invalid:	b_{ext} below Rayleigh
A	=	Invalid:	Mis-alignment
L	=	Invalid:	Defective Lamp
S	=	Invalid:	Suspect Data
W	=	Invalid:	Unclean optics

[2] Meteorology validity codes:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from alternate logger
5	=	Invalid:	Data > maximum or < minimum
8	=	Missing:	Data acquisition error

A -99 in any data field indicates missing or invalid data.

Figure 2-5. Standard ASCII File Format IMPROVE Protocol Transmissometer Visibility Data.

```
NGN_PULL  V1.91:2/15/94  02-15-1994  14:12:39-------------------------------------------------------------------------------------------------------------------------------------------------------
LEVEL-0: NGN_SEAS 1.3 3/2/94 03-02-1994 15:01:19----------------------------------------------------------------------------------------------------------------------------------------------------
LEVEL-1: NGN_SEAS 1.3 3/2/94 03-02-1994 17:43:10----------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

SITE YYMMDD  JD HHMM INS  BSCAT  PREC    VA  RAW-M   RAW-SD  #  N/A   SD/M  DEL   MAX     RH 0123456789MPM0T  YINTER   SLOPE     AT  AT-SD  #  AT-PR     CT  CT-SD  #   CT-PR    RH  RH-SD  #   RH-PR N/A
LOPE 931130 334 1900 014    57   0.000   XL  122.68  25.49  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0450 0.00083  -0.97  0.20  12   1.00   0.22   0.20 12   1.00  88.01   1.18 12   2.00XXXX
LOPE 931130 334 2000 014    80   0.000   V   151.25   8.71  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0457 0.00083  -1.47  0.11  12   1.00  -0.25   0.10 12   1.00  90.46   0.88 12   2.00XXXX
LOPE 931130 334 2100 014    87   0.000   V   160.71   8.58  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0465 0.00083  -1.78  0.28  12   1.00  -0.44   0.19 12   1.00  90.71   0.96 12   2.00XXXX
LOPE 931130 334 2200 014    72   0.000   XD  143.10  22.18  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0472 0.00083  -2.65  0.21  12   1.00  -1.16   0.19 12   1.00  92.16   0.32 12   2.00XXXX
LOPE 931130 334 2300 014    70   0.000   XD  142.32  21.74  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0479 0.00083  -3.17  0.15  12   1.00  -1.65   0.11 12   1.00  91.63   0.51 12   2.00XXXX
```

Column Number

```
         1         2         3         4         5         6         7         8         9        10        11        12        13        14        15        16        17        18        19        20
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
1
```

Column	Data
1-4	Site Abbreviation
6-7	Year
8-9	Month
10-11	Day
13-15	Julian Day
17-18	Hour
19-20	Minute
22-24	Nephelometer Serial Number
26-32	b_{scat} (Mm^{-1})
34-40	b_{scat} Estimated Precision (%/100)
42-43	b_{scat} Validity/Interference Code
45-51	Raw Nephelometer Hourly Average (Counts)
53-59	Standard Deviation of Raw Nephelometer Average (Counts)
61-62	Number of Data Points in Hourly Nephelometer Average
64-68	(Not Used)
70-74	Standard Deviation/Mean Interference Threshold
76-81	b_{scat} Rate of Change Interference Threshold
83-88	Maximum b_{scat} Interference Threshold
90-92	Relative Humidity Interference Threshold
94-108	Composite Nephelometer Code Summary
110-116	Y-intercept of Calibration Line Used to Calculate b_{scat}
118-124	Slope of Calibration Line Used to Calculate b_{scat}
126-131	Average Ambient Temperature (°C)
133-138	Standard Deviation of Hourly AT Average
140-141	Number of Data Points in Hourly AT Average
143-148	Estimated Precision of Ambient Temperature
150-155	Average Nephelometer Chamber Temperature (°C)
157-162	Standard Deviation of Hourly CT Average
164-165	Number of Data Points in Hourly CT Average
167-172	Estimated Precision of Chamber Temperature
174-179	Average Relative Humidity (%)
181-186	Standard Deviation of Hourly RH Average
188-189	Number of Data Points in Hourly RH Average
191-196	Estimated Precision of Relative Humidity
197-200	(Not Used)

b_{scat} Validity/Interference Code (columns 42-43):

V = Valid
I = Invalid
< = b_{scat} less than Rayleigh scattering
XZ = Data point immediately preceded and followed by interference
X? = Interference of type ?

Type (?) of Interference	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > max. threshold	x		x		x		x		x		x		x		x
b_{scat} > max. threshold	x	x			x	x			x	x				x	x
St. Dev./Mean>threshold			x	x	x	x						x	x	x	x
b_{scat} rate of change > threshold								x	x	x	x	x	x	x	x

Composite Nephelometer Code Summary (columns 94-108):

Column	Data
94-103	Nephelometer diagnostic code (internal use)
104	Number of missing data points
105	Number of power failure codes
106	Number of manual QA invalidation codes
107	Number of Level-0 invalidated data points
108	Number of times non-serial data were used

Note: The first 10 lines are for data reduction information.

Figure 2-6. Standard ASCII File Format IMPROVE Protocol Integrating Nephelometer Visibility Data.

- State Implementation Plans (SIPs), Federal Implementation Plans (FIPs), and Tribal Implementation Plans (TIPs) - Visibility data can be used to quantify existing conditions, support trend analysis, and support impairment designation policies in SIPs, FIPs, and TIPs. Monitoring programs in turn, enable the enforcement of emission limitations and other air quality related control measures.

- Federal Documents, (e.g. regional assessments, management plans, Environmental Impact Statements, etc.) - Visibility data that describe existing conditions are often referenced in federal documents to denote resource conditions (i.e., AQRVs) prior to land management changes. Data presentations can also be used in political forums to aid in the understanding of existing conditions and need for future air quality related policy and/or regulations.

- Acid Rain Program - The links between acid rain and visibility degradation, although indirect are quite strong. Of particular importance is the relationship of visibility to the air pollutants associated with acid deposition - i.e., the relationship of visibility to nitrogen dioxide, nitrate aerosols, and (especially) sulfate aerosols.

- Fire Emissions Inventories - Natural and prescribed fire emissions often impact visibility in Class I and other protected natural areas. With the development of increased fire programs, existing and future visibility data can be used to evaluate the visibility impacts of fire emissions.

- Fine Particulate Standards - Existing visibility-related $PM_{2.5}$ and PM_{10} data may be used to supplement Federal Reference Method measurements (e.g. to estimate regional background concentrations) in association with new fine particulate standards.

- Other Uses for Non-Class I Area Management - Document the frequency, dynamics, intensity, and causes of urban hazes, establish visual air quality acceptance criteria and evaluate daily air quality indexes.

2.6 NETWORK DESIGN

To address the visibility protection provisions of the CAA and EPA regulations, states and appropriate federal agencies must have access to high quality visibility data representative of the Class I or other areas of concern. Ideally, long-term routine monitoring would be conducted in every area of concern and every site would have a full aerosol, optical, and scene configuration. In some of the larger Class I areas or areas with dramatic differences in elevation, monitoring should be conducted at more than one location. State, urban, and tribal monitoring is often designed in association with existing ambient (i.e., SLAMS, NAMS) air quality monitoring programs. Funding and logistic realities, however, often limit the number of visibility monitoring sites and the configuration of the sites used to define a network.

Visibility monitoring objectives must be clearly defined prior to the design and implementation of any visibility monitoring network or individual site. Background information from historical and existing aerometric monitoring programs, climatological summaries, and local geographical resources need to be obtained. Visibility protection goals, monitoring objectives, EPA regulations, background information, data quality objectives, spatial, temporal, logistic, and economic considerations must be evaluated by all supporting proponents. A thorough review will ensure the design of an effective monitoring program that meets common objectives, and that data collected can be interpreted and applied, in accordance with the law, for regulatory and planning purposes.

Visibility monitoring information generated in a manner consistent with this EPA Visibility Monitoring Guidance Document will be acceptable as a primary source of visibility data for mandatory Class I areas, or any area of concern. IMPROVE Program monitoring sites that measure aerosol, optical, and scene components and those following IMPROVE protocol configurations are consistent with the methods described in this guideline. Data from individual IMPROVE sites can be used to represent the visual air quality of nearby Class I areas if the nearby areas are generally affected by the same air mass (Section 2.6.1.1). Collecting a single aerosol or optical parameter at these nearby sites can provide a quantitative link to the IMPROVE data from a fully configured site. Documenting the scenic qualities at these nearby sites can provide an additional qualitative link to the quantitative IMPROVE data.

Design of a special visibility study network is often more locally oriented and more intensive than routine network designs. Special studies include site-specific pre- and post-operation monitoring related to a proposed PSD source, pollution attribution analyses to define the causes of existing impairment, or other research programs. Pre- and post-operation monitoring for a PSD source can often be coordinated with and even funded by the proposed source. Visibility monitoring using routine monitoring techniques in conjunction with standard ambient PSD measurements can define and help to mitigate the specific impacts of a PSD source. As provided for under the 1980 EPA visibility regulations, an attribution analysis may be required for a Class I area where one or more pollution emission sources are thought to contribute substantially to visibility impairment. Often, routine data will not be sufficient for attribution analysis. In such circumstances, special studies may be required to supplement the routine monitoring information. Monitoring and other sources of information (e.g., emissions characterization, model outputs, etc.) must allow the identification of substantial visibility impairment source(s) and the assessment of the frequency, duration, and intensity of impairment from the identified sources(s). Other research programs could include studies of aerosol conversion, aerosol growth, optical parameters, scenic parameters, instrument trials, and other research topics. These studies are usually designed to address scientific theses and include traditional and research instrumentation and analytical techniques.

2.6.1 Assessment Criteria

Based on established overall program monitoring objectives a series of spatial, temporal, logistical, legal, and economic issues must be assessed prior to the implementation of a visibility monitoring site or network. Table 2-5 identifies a series of criteria that are considered in the network design phase of visibility monitoring. Each set of criteria parameters are independent, however they should be evaluated in association with other selected criteria. The following subsections further define these considerations and summarize the benefits and tradeoffs of each.

Table 2-5

Assessment Criteria
Related to Designing a Visibility Monitoring Program

Criteria to Consider						
Identify: Purpose of Data Collection	Define: the Spatial Extent of the Program	Define: the Temporal Extent of the Program	Determine: How Data from Existing Monitoring Programs Could be Integrated	Determine: Parameters to be Monitored	Develop: Cost Guideline and Budgeting Limits	Identify: Possible Data Applications
Assessment Consideration(s)						
What is the network or site-specific objective(s)?	What is the physical extent of land that needs to be monitored to meet the objective?	How often and how long must monitoring continue to obtain an accurate assessment of visibility conditions for the objective?	Does any additional monitoring need to occur?	What data/information will be necessary to form conclusions or support hypothesis (objectives)?	What are the economical and logistical tradeoffs that will need to be considered prior to implementation?	Are there associated programs or research efforts that could benefit from the data collected
Assessment Criteria						
1. Reasonably attributed impairment 2. Existing conditions, document for future protection. Trend analysis 3. New source review, pre- and post- construction monitoring 4. Regional haze assessment 5. Research	1. Local 2. Regional 3. National 4. International 5. Site-specific objectives 6. Network-specific objectives	1. Long-term - decades of routine monitoring 2. Short-term - several years of specialized monitoring 3. Special study - simple - complex	1. Representativeness 2. Historical review of ambient AQ trends 3. Cooperative monitoring efforts 4. Meteorological records 5. Other programs - PM_{10}, NAMS, SLAMS, other studies	1. Aerosol point measure - $PM_{2.5}$, PM_{10} 2. Optical -b_{ext} path measurement - b_{ext} point measurement 3. Scene - 35 mm still - time-lapse film or video	1. Capital costs 2. Operational costs 3. Access, personnel, logistics	1. PSD 2. New Source Review (NSR) 3. Attributable impairment 4. Regional Assessments (AQRVs) 5. Acid Rain, Fire Emission Inventories
Other Considerations						
	Consider scenic sensitivity	Consider anticipated visibility changes				

2.6.1.1 Spatial Considerations

Spatial considerations consist of a set of general criteria that identify candidate monitoring locations in terms of the physical characteristics which most closely match a specific monitoring objective or set of objectives. The goal is to correctly match the spatial scale represented by the visibility monitoring data collected with the spatial scale most appropriate for the given monitoring objective(s). The spatial scale of representativeness is described in terms of the physical dimensions of the regional or local air mass in which pollutant concentrations and visibility are expected to be reasonably similar.

The scales of representativeness of most interest for visibility monitoring are:

Definition	Example Monitoring Objectives
Local/Urban This scale defines conditions within an area that has relatively uniform land use and common geographical and climate features. The dimensions of a local or urban area can range from 4 to 50 kilometers square. Broader ranges will usually require more than one site for definition.	Existing conditions, source attribution, daily index
Regional This usually defines a rural area of reasonably homogeneous geography and air quality and extends from tens to hundreds of kilometers square. Care must be taken to ensure that both vertical and horizontal air quality characteristics are considered at this scale.	Existing conditions, long-term trends
National and Global These measurement scales represent concentrations characterizing the nation and/or global conditions as a whole.	National data for policy analyses/trends and for reporting to the public

Unlike site-specific objectives, which can be met at isolated individual locations without reference to measurements made elsewhere, network-specific objectives often require simultaneous monitoring at several sites. In other words, these objectives require comparison among different sites. Class I and non-Class I local and regional representative considerations are described below. Temporal resolution, data sources, and data comparability issues associated with meeting network-specific data objectives are described in the following subsections.

Local Representative Considerations

To demonstrate that data collected at one location are representative of one or more nearby Class I area(s) requires an analysis of existing conditions that includes consideration of common meteorology, a similar degree and frequency of exposure to visibility influencing pollution sources, and similar terrain. Representative Class I areas should share the same air basin or geographic province (e.g., not be on opposite sides of a major mountain range). They should be closer to each other than the average distance to any major stationary point source of visibility reducing emissions. They should roughly share the same average elevation (e.g., mountain tops are not representative of valley floors). Representative analyses should be shared with and approved by state agencies, the EPA, and cooperating federal land managers.

To evaluate the adequacy of individual network monitoring sites, it is necessary to examine individual site objectives and determine each site's spatial scale of representativeness. This will do more than ensure compatibility of stations with the same purpose. It will also provide a physical basis for the interpretation and application of the data.

Several criteria should be considered when selecting a monitoring site among several Class I areas that are likely to be mutually representative:

- If a proposed emission source or any other development is anticipated that could change the visibility impacts in the candidate areas, then the area with the greatest estimated change in visibility should be chosen.

- Similarly, higher priority should be given to areas with more visually sensitive vistas (e.g., longer views).

- If existing impairment from man-made sources is known to impact one of the areas more often or with greater intensity than the others, then the area of greater impact should be chosen for a monitoring location.

If none of the above criteria are applicable, then the most desirable location would be the one that best represents the group of Class I areas. This could be the one nearest the center of a group of visibility protected areas.

Practical considerations such as the availability of power, security, year-round access, and on-site personnel should also be considered when selecting the location of a monitoring site. Such considerations, however, should be treated as secondary unless it can be demonstrated that practical constraints would substantially jeopardize the data quality or data recovery. Ideally, a pilot study could be conducted that would include some level of monitoring, for at least a short period of time, at all of the Class I areas within a "representative area." A pilot study could provide specific data to evaluate representative monitoring decisions. Pilot studies are encouraged; however, budget, time, and logistic considerations often restrict their application.

Representative considerations for non-Class I areas of scenic importance generally parallel those of Class I areas. Representative areas should share common meteorology, geographic features, and exposure to visibility influencing pollution sources. Monitoring objectives and monitoring data collected must be compatible to provide a common basis for the interpretation and application of the data.

Regional Representative Conditions

Regional areas can cover a broad geographic area. Generally, a number of sites will be required to effectively characterize a regional area. The Colorado Plateau would be an example of a regional area that includes the "Golden Circle" of national parks. The climate patterns throughout the region are similar and, therefore, the air mass influences throughout the region are similar.

Monitoring visibility in only one Class I area in the region may provide a qualitative understanding of the existing conditions, dynamics, and trends that could generally affect the region, but the quantitative data collected at one site may not be representative of another site in the region. For example, one site in the region may record a significant visibility event at noon and a site further downwind may record the same event but with less magnitude later in the day. The same air mass influenced both regional sites, the visibility reducing species were the same, but the magnitude and timing of the event were different. One site was not purely representative of the next, but data from both can lead to a better understanding of how an air mass from the same source area influences a geographic region.

The methods used to define regions can vary, but generally each method used differentiates one region from another in a similar fashion. The parameters used to characterize and define regions include:

- Weather and climate
- Elevation
- Terrain
- Vegetation and dominant ecosystem types
- Dominant land use
- Geology
- Air pollution source types
- Air pollution chemistry

As an example, the IMPROVE Program has defined twenty-one regions by which to summarize spatial distribution data in their historical summary reports (Sisler, et al., 1996). A list of these regions is provided as Table 2-6. Sites should be located to document the range of conditions that occur in the region. All data collected in the region should be analyzed and compared to identify regional patterns and trends. These patterns and trends can then be compared to other regions.

Table 2-6

IMPROVE and IMPROVE Protocol Sites According to Region (Sisler, et al., 1996)

Alaska (AKA) ! Denali NP (DENA) **Appalachian Mountains (APP)** ! Great Smoky Mountains NP (GRSM) ! Shenandoah NP (SHEN) ! Dolly Sods WA (DOSO) **Boundary Waters (BWA)** ! Boundary Waters Canoe Area (BOWA) **Cascade Mountains (CAS)** ! Mount Rainier NP (MORA) **Central Rocky Mountains (CRK)** ! Bridger WA (BRID) ! Great Sand Dunes NM (GRSA) ! Rocky Mountain NP (ROMO) ! Weminuche WA (WEMI) ! Yellowstone NP (YELL) **Coastal Mountains (CST)** ! Pinnacles NM (PINN) ! Point Reyes NS (PORE) ! Redwood NP (REDW) **Colorado Plateau (CPL)** ! Bandelier NM (BAND) ! Bryce Canyon NP (BRCA) ! Canyonlands NP (CANY) ! Grand Canyon NP (GRCA) ! Mesa Verde NP (MEVE) ! Petrified Forest NP (PEFO) **Florida (FLA)** ! Chassahowitzka NWR (CHAS) ! Okefenokee NWR (OKEF) **Great Basin (GBA)** ! Jarbidge WA (JARB) ! Great Basin NP (GRBA)	**Lake Tahoe (LTA)** ! D.L. Bliss State Park (BLISS) ! South Lake Tahoe (SOLA) **Mid Atlantic (MAT)** ! Edmond B. Forsythe NWR (EBFO) **Mid South (MDS)** ! Upper Buffalo WA (UPBU) ! Sipsey WA (SIPS) ! Mammoth Cave NP (MACA) **Northeast (NEA)** ! Acadia NP (ACAD) ! Lye Brook WA (LYBR) **Northern Great Plains (NGP)** ! Badlands NM (BADL) **Northern Rocky Mountains (NRK)** ! Glacier NP (GLAC) **Sierra Nevada (SRA)** ! Yosemite NP (YOSE) **Sierra-Humboldt (SRH)** ! Crater Lake NP (CRLA) ! Lassen Volcanoes NP (LAVO) **Sonoran Desert (SON)** ! Chiricahua NM (CHIR) ! Tonto NM (TONT) **Southern California (SCA)** ! San Gorgonio WA (SAGO) **Washington, D.C. (WDC)** ! Washington, D.C. (WASH) **West Texas (WTX)** ! Big Bend NP (BIBE) ! Guadalupe Mountains NP (GUMO)

NP = National Park
NM = National Monument
WA = Wilderness Area
NWR = National Wildlife Refuge
NS = National Seashore

The IMPROVE network expansion from 30 to 108 sites during 1999 and 2000 is an example of how a regional scale network with specific goals can be planned. The goal of the expansion is to provide data needed to represent regional haze conditions for all 156 visibility-protected Class I areas where monitoring is feasible. The IMPROVE Steering Committee devised a plan for the expansion that involved several stages. In a scoping stage, two criteria were applied to assess the feasibility of individual monitoring platforms to be applicable to more than one Class I area. The criteria required that monitoring must be within 100km of the protected area and that the monitoring site elevation be within 100 feet or 10% of the elevation range of the protected area. These criteria were first applied to the 30 then current IMPROVE monitoring sites to identify other Class I areas that would be covered by these criteria. Then the criteria were used to identify the locations and elevations that would be required for the smallest number of monitoring sites that could represent the remaining protected Class I areas. Wherever the location requirements by these criteria could be met by an existing IMPROVE protocol site (i.e. a site using IMPROVE methods but not operated by the Steering Committee) it was identified as a possible candidate site.

The names and location of existing and required additional monitoring sites generated in the scoping stage of the planning were displayed on a map and in a table. These were widely circulated for review including to the federal land manager, EPA staff, and State and local air quality agencies to ask for comments. The Steering Committee asked for suggested changes that reflected more detailed knowledge of additional regional siting criteria such as nearness to large sources or source areas, local meteorology, and topography. Reviewers were also asked to comment on the feasibility of monitoring at any of the sites. One of the Class I areas (Bering Sea, an island over 200km off the coast of Alaska) was indicated as infeasible due to its remoteness, lack of power and an operator. Comments received by the Steering Committee were incorporated as modifications to the tables and maps that indicated where additional monitoring was needed. The final stage in the network design involves visiting potential sites to determine their suitability for siting the monitoring equipment. Again all organizations with an interest in the monitoring were invited to participate in the final site selection visits.

2.6.1.2 Temporal Considerations

Temporal considerations consist of a set of criteria that specify the type, frequency, and duration of data required to accurately assess visibility conditions.

Monitoring Period Criteria/Duration

Long-term monitoring sites provide valuable information about the existing conditions and long-term trends of visibility. Data from long-term sites can be used to track progress toward the national visibility goals, to support permit applications, and to support a range of resource-related research projects. It is recommended that long-term sites established and supported to evaluate trends or track progress should continue taking data for decades. Periodic evaluation of long-term sites is necessary to ensure their benefit (historical or future) to overall network goals and objectives. A network monitoring plan should define the frequency of periodic reviews. In cooperation with state agencies and the EPA, data from long-term trend sites can be adopted as regionally representative of a series of nearby Class I areas for permit review purposes.

Short-term monitoring sites are established to address specific visibility concerns. Examples of short-term monitoring include pre- and post-construction source-specific monitoring sites, source attribution study sites, and/or specialized research. Short-term sites can also be established as a precursor to long-term sites. Collected data are often evaluated in association with the nearby long-term monitoring sites to determine the representativeness of the monitored region. Sites may also be classified "short-term" due to abbreviated/seasonal monitoring periods. Many Class I area monitoring sites are in remote locations and at certain sites monitoring is limited to the warm season (e.g., June through September) due to weather, accessibility, and/or available servicing personnel. Short-term sites will generally operate from a single season to several years.

Special studies, unlike routine monitoring, often do not lend themselves to standard design recommendations. The design is tailored to:

- The nature of the impairment (e.g., ground-based or elevated, short-term intermittent or long-term frequent, etc.).

- The characteristics of the source(s) (e.g., continuous or intermittent, point or area, primary particle or gas, or precursor gas for secondary particle, etc.).

- Existing information deficiencies.

Special studies range from simple to sophisticated. In the case of a plume or layer from a large nearby point source of primary particles, deployment of additional cameras to document the impairment may suffice (time-lapse photography may be particularly appropriate). To document the contribution of a more distant source of gaseous precursors for secondary particles, a substantial effort may be required which could include a supplemental monitoring network, instrumented aircraft, and stack release and ambient monitoring of unique tracer materials.

To increase the likelihood of the success of a special study, it should be designed in conjunction with those who are responsible for conducting the attribution analysis and with the involved industry. In some circumstances, a special study may be better accomplished in several phases, where data from the earlier phase(s) are used to help design the later phases.

Data Collection Criteria

Instrument or parameter-specific temporal resolution criteria include instrument limitations, instrument detection limits, and data reporting methods. Continuous data collection should be summarized hourly to be consistent with other aerometric monitoring methods. Filter-based data generally require collection periods from several hours to 24 hours depending on the ambient concentrations and analyses techniques. Most particulate samples in long-term programs are generally taken for 24 hours (midnight to midnight). This approach is also consistent with filter monitoring by SLAMS. IMPROVE protocol sites collect 24-hour filter samples twice per week. In remote areas tested by IMPROVE, no statistical difference in seasonal averages were observed in aerosol data collected daily versus bi-weekly. Filter data collected in urban areas may or may not yield similar statistical results.

Similar to spatial representativeness, site objectives and temporal parameters must be shown to be representative of nearby monitoring areas to ensure network compatibility and provide a physical basis for the interpretation and application of the data.

Temporal considerations must be evaluated repeatedly throughout the design, implementation, and analysis phase of visibility monitoring. Meteorological conditions, fire emissions, regional haze, and industrial processes can vary substantially from day to day and year to year. The selected period of data collection must be qualified as representative of average visibility conditions for the site. This requires an assessment of historical climate and visibility conditions and comparison of historical conditions with the conditions for the period of data collection.

2.6.1.3 Historical and Existing Monitoring Program Considerations

Program considerations involve taking a closer look at past and present visibility monitoring programs and other monitoring data that can be used to support defined objectives and proposed data applications. It is possible that one or more representative sites' data could satisfy the majority of objectives defined.

A review should be conducted of historical and existing data from all visibility, meteorological, ambient, and PM monitoring sites within the representative boundaries of the site to be monitored. Do the data provide a record of average aerometric conditions that represent the spatial and temporal objectives defined above? Given the data are representative of the proposed monitoring location, existing monitoring data can often be used to define existing meteorology and/or visibility conditions, support trend analysis, or support regional haze assessment research.

Many economic and logistic benefits can be obtained by establishing cooperative monitoring efforts between representative air monitoring sites and programs. Capital equipment, land use fees, and routine monitoring site operator resources can be shared between associated FLMs and state agencies. Data collected can also be used to support other monitoring programs, research, or future trend analysis.

2.6.1.4 Monitoring Parameter Considerations

In the process of network design, what visibility parameters will be necessary to base conclusions, support hypotheses (objectives), or address defined legal standards? What parameter considerations regarding measurement accuracy and precision, temporal resolution, spatial resolution, and comparability need to be evaluated given site-specific or network-specific objectives? A number of these monitoring issues were addressed by Marc Pitchford for the IMPROVE Network (September 1993). Excerpts of his recommendations to IMPROVE Committee members are provided in the following subsections. Table 2-7 provides a tabular listing of the data sources, associated temporal resolution and spatial representativeness, and data comparability for each visibility monitoring parameter. Example parameter and instrument specifications based on the IMPROVE Program are provided in Sections 3.0, 4.0, and 5.0. These monitoring methods and instruments are currently considered by the EPA and IMPROVE Committee to be best suited for use (field tested, known precision and accuracy, widely used). References made to manufacturers or trade names are not intended to constitute endorsement or recommendations for use. New or improved instruments, instrument upgrades, and methods of monitoring are being developed each year. This guidance document will be revised over time to reflect the ongoing changes of the science and monitoring instruments most appropriate (researched, tested, and recommended) for use.

Aerosol Parameter Considerations

The primary objective of visibility-related aerosol monitoring is to gather information required to establish the relative contributions of various species to visibility impairment. The most popular approach for particle monitoring uses any of a variety of samplers which size selectively separate the particles from the gases by filtration, inertial impaction, and denuding. The size selective particle samples are subsequently analyzed for mass and elemental composition.

This combination of particle sizing with elemental composition analyses is important for visibility monitoring because:

- Scattering is highly dependent on particle size. Collecting particles in visibility-sensitive size ranges allows aerosol concentrations to be better correlated to extinction.

- Elemental composition provides information about the chemical and physical properties of aerosols and about probable sources and source types. For example, identifying a sulfate aerosol would indicate a hygroscopic aerosol that can grow in high relative humidities to be an efficient light scatterer and that the probable source of the aerosol is sulfur rich fossil fuel combustion. Specific elements may also be used as source indicators. For example, the presence of arsenic may be a good indicator of copper smelter emissions.

- Particle sizing provides further information about sources or source types. For example, a given element from separate sources may be differentiated by particle size.

Table 2-7

Monitoring Parameter Considerations

Parameter	Spatial Representativeness	Data Sources	Temporal Resolution	Data Comparability
Aerosol				
Aerosol components: $PM_{2.5}$ Fine Mass Elemental Analysis (H, Na-Pb) Coefficient of absorption (b_{abs}) Nitrate, Sulfate, and Chloride ions Organic and elemental carbon PM_{10}	Point Measurement	Multiple filter* system	Commonly 24-hour samples at least twice per week	Best available method for source attribution. Temporal sampling limitations minimize analysis comparisons to at best seasonal averages. In the absence of optical data, aerosol data can be used to estimate visibility levels by using generally accepted models. (MIE scattering theory or literature values for extinction efficiencies to determine reconstructed extinction).
Optical				
Light Extinction (b_{ext})	Path Measurement	Transmissometry*	Continuous sampling, commonly summarized as 1-hour, 4-hour, or 24-hour averages	Most direct measure of absorption and scattering properties. Does not define the source of impairment.
Light Extinction Components:				
Scattering (b_{scat})	Point Measurement	Nephelometry*	Continuous sampling, commonly summarized as 1-hour, 4-hour, or 24-hour averages	Data can be combined with collocated absorption (b_{abs}) measurements to estimate total light extinction (b_{ext}). Does not define the source of impairment.
Particle Absorption (b_{ap})	Point Measurement	Filter-based particle absorption measurements	Continuous sampling (e.g., aethalometer)	Data can be combined with collocated scattering (b_{scat}) measurements to estimate total light extinction (b_{ext}). Does not define the source of impairment.
			Intermittent sampling (e.g., integrating plate, integrating sphere analysis method)	Data can be combined with collocated scattering (b_{scat}) measurements to estimate total light extinction (b_{ext}). Does not define the source of impairment.

* Monitoring methods and instruments considered by the EPA and IMPROVE Committee to be well suited (field tested, high precision and accuracy, widely used) for use.

Table 2-7 (Continued)

Monitoring Parameter Considerations

Parameter	Spatial Representativeness	Data Sources	Temporal Resolution	Data Comparability
Optical (Cont.)				
Gas Absorption (b_{ag})	Point Measurement	NO_2 gas analyzer	Continuous sampling commonly summarized as 1-hour averages	NO_2 is the only common atmospheric gas that is important to light absorption.
Air Temperature and Relative Humidity	Point Measurement	Aspirated AT/RH sensor*	Continuous sampling commonly summarized as 1-hour, 4-hour, or 24-hour averages	Used to screen weather effects from optical data. Used to determine humidity-related hygroscopic aerosol growth functions applicable to reconstructed extinction estimates.
Scene				
Haze Characterization	Qualitative representation of a scene	Still photography*	Commonly 3 photographs or more per day (e.g., 0900, 1200, 1500)	Often used to document source impacts for public presentation or to aid in the interpretation or quantitative data.
Visual Dynamics	Qualitative representation of a scene	Time-lapse or video photography	Commonly set to photograph in 1-minute or less intervals during daylight hours	Often used to document the visual dynamics of a scene in relation to source impacts and local meteorology.

* Monitoring methods and instruments considered by the EPA and IMPROVE Committee to be well suited (field tested, high precision and accuracy, widely used) for use.

Aerosol samplers used in visibility monitoring programs most commonly collect aerodynamic diameters in two size ranges; $PM_{2.5}$ and PM_{10}. Numerous sampler designs exist (Chow, 1995). As examples, several of these samplers are included in Table 2-8 along with their general specifications. Table 2-8 is not intended to be a comprehensive list.

Both monitoring and analytical considerations need to be evaluated when establishing an aerosol monitoring site. The sample frequency, particle size, filter substrate, flow rate, and analytical methods are all important considerations when measuring major aerosol components and trace element constituents.

Aerosol monitoring for visibility should include at a minimum $PM_{2.5}$ mass concentration and elemental analyses at least twice a week. However, in order to identify and track visibility impacts caused by various pollutant species, a more complete aerosol characterization is strongly recommended. This more complete approach should include both $PM_{2.5}$ and PM_{10} sampling. $PM_{2.5}$ filter samples should generally be analyzed for mass, optical absorption, elements, sulfates, nitrates, chlorides, organic carbon, and elemental carbon. PM_{10} filters should be analyzed for mass and elements. With this information it is possible to use analytical techniques to estimate the extinction coefficient from these aerosol constituents. This method of reconstructing extinction from aerosol species is an important evaluation and quality assurance tool. Knowing the relative contribution of visibility reducing aerosol species allows an agency to focus on the source types responsible for impairment and to develop mitigation strategies.

Samplers such as the IMPROVE Modular Aerosol Sampler provide the flexibility to collect all or part of the recommended samples. Each module uses an appropriate filter substrate to support specific laboratory analyses. As an example, IMPROVE aerosol monitoring methods are further discussed in Section 3.0 of this document. Other samplers would also be applicable as long as the entire system including the selected sampler, sizing devices, flow rate, filter substrate, and analytical techniques were all integrated to meet the visibility-related size selection, mass, and speciation recommendations.

Optical Parameter Considerations

The primary objective of optical monitoring is to measure the atmospheric extinction coefficient (b_{ext}) and/or the absorption and/or scattering components of b_{ext} independent of physical scene characteristics or illumination conditions. Optical measurements, however, do not define the source of impairment.

Light Extinction

Transmissometers measure the combined effects of light absorption and scattering over a known site path ($b_{abs} + b_{scat} = b_{ext}$). The useful measurement range for a transmissometer is related to its precision and the path length over which it is operated. Longer path lengths are required for accurate measurements in cleaner air (e.g., 10 km paths in remote western locations of the United States), while shorter paths are used in more polluted situations (e.g., paths of approximately one kilometer in eastern regions). Short-path transmissometers (on the order of several hundred meters) have been used for years at many airports. These have a useful range of measurements only up to a few kilometers visual range. Though useful for airport safety in fog or other severe conditions, such measurements are of little value for routine visibility monitoring. Long-path transmissometers are required for visibility monitoring.

Table 2-8
Example Particle Samplers (Chow, 1995)

Filter-based Research Particle Sampling Systems							
Sampling System	Particle Size (μm)	Sizing Device	Flow Rate (L/min)	Sampling Surfaces	Filter Holders	Filter Media	Features
Western Region Air Quality Study (WRAQS) Sampler	PM_{15}	Aluminum high-volume impactor	113 out of 1,130	Aluminum and copper	Nuclepore polycarbonate in-line	47 mm Teflon-membrane 47 mm quartz-fiber	
Western Region Air Quality Study (WRAQS) Sampler	$PM_{2.5}$	Steel medium-volume cyclone	113	Aluminum and copper	Nuclepore polycarbonate in-line	47 mm Teflon-membrane 47 mm quartz-fiber	
Size Classifying Isokinetic Sequential Aerosol (SCISAS) Sampler	PM_{15}	Aluminum high-volume impactor	113 out of 1,130	Aluminum and polyvinyl chloride	Nuclepore polycarbonate open-face	47 mm Teflon-membrane 47 mm quartz-fiber	Sequential sampling.
Size Classifying Isokinetic Sequential Aerosol (SCISAS) Sampler	$PM_{2.5}$	Steel medium-volume cyclone	113 out of 1,130	Stainless steel and aluminum	Nuclepore polycarbonate open-face	47 mm Teflon-membrane 47 mm quartz-fiber	
Southern California Air Quality Study (SCAQS) Sampler	PM_{10}	Aluminum medium-volume impactor	35 out of 113	Stainless steel and aluminum	Gelman stainless steel in-line	47 mm Teflon-membrane 47 mm quartz-fiber	Option to add 20 cm length flow homogenizer.
Southern California Air Quality Study (SCAQS) Sampler	$PM_{2.5}$	Bendix 240 cyclone	35 out of 113	Teflon-coated aluminum	Gelman stainless steel in-line	47 mm Teflon-membrane 47 mm quartz-fiber 47 mm impregnated quartz-fiber	Option to add 20 cm length flow homogenizer.
Southern California Air Quality Study (SCAQS) Sampler	$PM_{2.5}$	Bendix 240 cyclone	35 out of 113	Teflon	Savillex PFA Teflon in-line	47 mm nylon-membrane 47 mm etched poly-carbonate	
Sequential Filter Sampler (SFS)	PM_{10}	Aluminum medium-volume impactor	20 out of 113	Aluminum	Nuclepore polycarbonate open-face	47 mm Teflon-membrane 47 mm quartz-fiber	Option to add nitric acid denuders in the sampling stream. Sequential sampling.
Sequential Filter Sampler (SFS)	$PM_{2.5}$	Aluminum medium-volume cyclone	20 out of 113	Teflon-coated aluminum	Nuclepore polycarbonate open-face	47 mm Teflon-membrane 47 mm quartz-fiber 47 mm nylon-membrane 47 mm impregnated cellulose-fiber	
California Acid Deposition Monitoring Program (CADMP) Dry Deposition Sampler	PM_{10}	Aluminum medium-volume impactor	20 of 113	Aluminum	Savillex open-face	47 mm Teflon-membrane 47 mm impregnated cellulose-fiber	Includes nitric acid denuders. Sequential sampling.
California Acid Deposition Monitoring Program (CADMP) Dry Deposition Sampler	$PM_{2.5}$	Teflon-coated steel medium-volume cyclone	20 of 113	PFA Teflon-coated aluminum	Savillex PFA Teflon open-face	47 mm Teflon-membrane 47 mm nylon-membrane	

Table 2-8 (cont.)

Example Particle Sampling Systems (Chow, 1995)

Filter-based Research Particle Sampling Systems							
Sampling System	Particle Size (μm)	Sizing Device	Flow Rate (L/min)	Sampling Surfaces	Filter Holders	Filter Media	Features
Versatile Ambient Pollutant Sampler (VAPS)	PM_{10}, $PM_{2.5}$	Teflon-coated aluminum low-volume elutriator and Teflon-coated aluminum low-volume virtual impactor	33	Teflon-coated aluminum	University Research Glassware glass filter pack (Model 2000-30F)	47 mm Teflon-membrane 47 mm etched polycarbonate membrane 47 mm quartz-fiber	Includes annular denuders to capture nitric acid, nitrous acid, and sulfur dioxide: and polyurethane foam (PUF) to collect organic compounds.
California Institute of Technology Sampler	PM_{10}	Aluminum low-volume impactor	16.7	Stainless steel and aluminum	Gelman stainless steel in-line	47 mm Teflon-membrane 47 mm quartz-fiber	
	$PM_{2.5}$	Aluminum low-volume cyclone	22	Teflon-coated aluminum and glass	Gelman stainless steel in-line	47 mm Teflon-membrane 47 mm quartz fiber 47 mm nylon-membrane	
Interagency Monitoring of Protected Visual Environments (IMPROVE) Sampler	PM_{10}	Aluminum low-volume cyclone	19	Aluminum	Nuclepore polycarbonate open-face	25 mm Teflon-membrane	Uses Wedding Beta Gauge PM_{10} inlet.
	$PM_{2.5}$	Aluminum low-volume cyclone	22.7	Aluminum	Nuclepore polycarbonate open-face	25 mm Teflon-membrane 25 mm quartz fiber 25 mm nylon-membrane	Nitric acid denuders ahead of nylon filter.
Stacked Filter Unit (SFU)	$PM_{2.5}$	Large-pore etched polycarbonate filters	10	Polycarbonate	Nuclepore polycarbonate open-face	25 mm Teflon-membrane	Uses large-pore etched polycarbonate filter as $PM_{2.5}$ sizing device.
BYU Organic Sampling System (BOSS)	$PM_{2.5}$	Teflon-coated aluminum medium-volume cyclone	140 L/min through inlet and 35 L/min per channel	Teflon-coated stainless steel	University Research Glassware glass filter pack (Model 2000-30F)	47 mm quartz-fiber 47 mm activated-charcoal impregnated filter (CIF)	A multichannel diffusion denuder sampler to determine semi-volatile organic compounds.
BYU Organic Sampling System (BOSS)	$PM_{2.5}$, $PM_{0.8}$, $PM_{0.4}$	Aluminum high-volume virtual impactor	1,130 L/min through inlet, with 11, 60, 93, and 200 L/min per channel	Teflon-coated stainless steel	University Research Glassware glass filter pack (Model 2000-30F)	47 mm quartz-fiber 47 mm activated-charcoal impregnated filter (CIF) compounds	A multichannel diffusion denuder sampler to determine semi-volatile organic compounds.
Harvard/EPA Annular Denuder System (HEADS)	$PM_{2.5}$	Teflon-coated low-volume glass impactor	10	Glass	Graseby-Andersen open-face ring	37 mm Teflon-membrane 37 mm impregnated quartz-fiber etched polycarbonate membrane	Includes sodium carbonate coated denuders to collect acidic gases (e.g., nitric acid, nitrous acid, sulfur dioxide organic acids) and citric acid coated denuders to collect ammonia.

Table 2-8 (cont.)

Example Particle Sampling Systems (Chow, 1995)

Filter-based Research Particle Sampling Systems							
Sampling System	Particle Size (μm)	Sizing Device	Flow Rate (L/min)	Sampling Surfaces	Filter Holders	Filter Media	Features
New York University Medical Center/Sequential Acid Aerosol Sampling System (NYUMC/SAASS)	$PM_{2.5}$	Teflon-coated glass low-volume impactor	4	Teflon-coated glass	Graseby Andersen open-face ring	37 mm Teflon-membrane 37 mm nylon membrane	Sequential sampling.
Minivol Portable Survey Sampler	PM_{10}, $PM_{2.5}$	Nylon low-volume impactor	5	Polycarbonate	Nuclepore polycarbonate open-face	47 mm Teflon-membrane 47 mm quartz-fiber	Battery-powered sampler weighs 18 pounds.

Filter-based Systems Designated by U.S. EPA as Reference or Equivalent Methods for PM_{10}						
Sampling System	Particle Size (μm)	Sizing Device	Flow Rate (L/min)	Filter Media	Reference/Equivalent Method Designation Number)	Federal Register Citation (Notice Date)
Wedding & Associates PM_{10} Critical Flow High-Volume Sampler	PM_{10}	Cyclone-type inlet	1,130	20.3 cm x 25.4 cm filters	Reference method (RFPS-1087-062)	Vol. 52, 37366 (10/06/87)
Sierra-Andersen (SA) or General Metal Works (GMW) Model 1200 PM_{10} High-Volume Air Sampler System	PM_{10}	Impaction-type size-selective inlet (SA or GMW-1200)	1,130	20.3 cm x 25.4 cm filters	Reference method (RFPS-1287-063)	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
Sierra-Andersen (SA) or General Metal Works (GMW) Model 321 B PM_{10} High-Volume Air Sampler System	PM_{10}	Impaction-type size-selective inlet (SA or GMW-321 B)	1,130	20.3 cm x 25.4 cm filters	Reference method (RFPS-1287-064)	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
Sierra-Andersen (SA) or General Metal Works (GMW) Model 321 C PM_{10} High-Volume Air Sampler System	PM_{10}	Impaction-type size-selective inlet (SA or GMW-321 C)	1,130	20.3 cm x 25.4 cm filters	Reference method (RFPS-1287-065)	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
Oregon DEQ Medium-Volume Sequential Filter Sampler for PM_{10}	PM_{10}	SA 254 impaction-type inlet		47 mm Teflon-membrane 47 mm Quartz-fiber	Reference method (RFPS-0389-071)	Vol. 54, 12273 (03/24/89)

Table 2-8 (cont.)

Example Particle Sampling Systems (Chow, 1995)

Filter-based Systems Designated by U.S. EPA as Reference or Equivalent Methods for PM_{10}						
Sampling System	Particle Size (μm)	Sizing Device	Flow Rate (L/min)	Filter Media	Reference/Equivalent Method Designation Number)	Federal Register Citation (Notice Date)
Sierra-Andersen Models SA 241 and SA 241M, or General Metal Works Models G 241 and GA 241M PM_{10} Low Volume Dichotomous Samplers	PM_{10}, $PM_{2.5}$	SA 246 B or G 246 impaction-type inlet, 2.5 um virtual impactor assembly	Total: 16.7 for PM_{10} Coarse: 1.67 Fine: 15.03 for $PM_{2.5}$ and less	37 mm $PM_{2.5}$ 37 mm coarse [PM_{10} minus $PM_{2.5}$]	Reference method (RFPS-0389-073)	Vol. 54, 31247 (07/27/89)
Andersen Instruments Model FH621-N PM_{10} Beta Attenuation Monitor	PM_{10}	SA 246 B impaction-type inlet	16.7	40 mm filter tape	Equivalent method (EQPM-0990-076)	Vol. 55, 38387 (09/18/90)
Rupprecht & Patashnik TEOM Series 1400 and 1400a PM_{10} Monitor	PM_{10}	Impaction-type inlet	3.00 out of 16.7	12.7 mm diameter filter	Equivalent method (EQPM-1090-079)	Vol. 55, 43406 (10/29/90)
Wedding & Associates PM_{10} Beta Gauge Automated Particle Sampler	PM_{10}	Cyclone-type inlet	18.9	32 mm filter tape	Equivalent method (EQPM-0391-081)	Vol. 56, 9216 (03/05/91)
Rupprecht & Patashnik Partisol Model 2000 Air Sampler	PM_{10}	Impaction-type inlet	16.7	47 mm diameter filter	Equivalent method (EQPM-0694-098)	Vol. 59, 35338 (07/11/94)

Light Extinction Components

A number of instruments measure light scattering (b_{scat}) by particles and gases. These instruments are called nephelometers and are classified according to the scattering angle that is measured: forward scattering, back scattering, integrating, and polar. Forward and back scattering instruments have been evaluated and used on limited basis for transportation safety purposes. Since only a portion of the scattered light is measured, however, and since absorption is completely unaccounted for, these instruments will mis-measure visibility under atypical aerosol conditions. Integrating nephelometers measure scattering over nearly the entire range of angles from 0° to 180°. The integrating nephelometer has been a popular instrument for monitoring the variations of particle concentrations in air pollution studies. Integrating nephelometer measurements can be directly related to the scattering coefficient (b_{scat}). The polar nephelometer measures the light scattered from any chosen angle. While helpful in predicting the effects of aerosols on the appearance of a scene, the polar nephelometer is not easily adapted to routine monitoring and has not been used except in laboratory situations. Since a nephelometer makes a point measurement, direct comparisons to collocated aerosol measurements are practical. In addition, the system can be absolutely calibrated using clean (Rayleigh) air and various dense gases with a known multiple of Rayleigh scattering.

Optical absorption (b_{abs}) has traditionally been measured by evaluating the light absorption characteristics of particles collected on a filter media. This type of analysis can be performed in the laboratory on collected filters. For example, the IMPROVE Program applies a combination of Laser Integrating Plate and Laser Integrating Sphere Methods (LIPM and LISM, respectively) to estimate b_{abs} from Teflon filters. An aethalometer is one instrument that continuously measures particle light absorption on a filter media. Other experimental methods have also been developed. Absorption methods used to estimate the absorption coefficient can be combined with nephelometer scattering measurements to estimate extinction.

Scene Parameter Considerations

The primary objective of scene monitoring is to provide a qualitative representation of the scenic appearance of visual air quality. Commonly used monitoring methods include documentation of the scene by photography, human observations of visual range, and contrast measurements. Scene monitoring data are often converted to optical indexes because of the usefulness of information in that form. Specifically, visual range observations and target contrast data are converted to extinction coefficient values (b_{ext}). Concerns associated with these data transformations, however, have limited their usefulness. One key assumption often violated is that the inherent contrast is known. Target inherent contrast changes as a function of the sun position in the sky (i.e., time of day and day of the year), cloud cover, and target cover. Another source of error is associated with cloud shading of the sight path but not the target. These non-uniform lighting conditions will cause the extinction coefficient to be significantly underestimated. Since the development of alternative optical monitoring instrumentation, IMPROVE protocols use scene monitoring data for qualitative purposes only.

2.6.1.5 Capital and Operational Considerations

Economical and logistical tradeoffs also must be considered prior to establishing a visibility monitoring site or network. Long-term and short-term objectives also must be reviewed with respect to available funding. Capital outlay for instrumentation and installation can often be reduced when cooperative monitoring programs are established between state, federal, tribal, and private participants. As program budgets are enhanced or trimmed, site and network-specific objectives must be further evaluated.

Practical considerations such as the availability of power, security, year-round access, and on-site personnel should also be considered when selecting the location of a monitoring site. Such considerations, however, should be treated as secondary to spatial and temporal criteria, unless it can be demonstrated that practical constraints would substantially jeopardize data quality or data recovery.

2.6.2 Example Network Configurations

Visibility monitoring information must be generated in a manner consistent with CAA, EPA regulations, and this EPA Visibility Monitoring Guidance Document to be acceptable as a primary source of visibility data for regulatory or planning purposes. IMPROVE Protocols, adopted by the IMPROVE Program in 1988, are consistent with these requirements and are reviewed on an ongoing basis by IMPROVE Committee participants. Although additional monitoring protocols are or may be developed that meet CAA and EPA regulations, the remaining sections of this document will focus on IMPROVE Visibility Monitoring Protocols. Examples of three types of monitoring configurations are described below. Each example addresses one or more network-specific/site-specific objectives for Class I or Non-Class I areas.

2.6.2.1 Routine Monitoring Network

IMPROVE is a cooperative visibility monitoring effort between the EPA, federal land management agencies, and state air agencies. Network-specific objectives of the IMPROVE Program are:

- To establish existing visibility conditions in Class I areas.
- To identify chemical species and emission sources responsible for existing man-made visibility impairment.
- To document long-term trends.

The IMPROVE Visibility Monitoring Program was established in 1985. Due to resource and funding limitations it was not practical to place monitoring stations at all 156 mandatory Class I areas where visibility is an important attribute. Instead, the IMPROVE Committee selected a set of sites that were representative of the Class I areas. Thirty-six (36) full-IMPROVE and IMPROVE Protocol sites were originally selected to represent the distribution of visibility and aerosol concentrations over the United States. In 1998, thirty (30) IMPROVE Program sites have various configurations of optical and aerosol monitoring equipment. Additional Class I area monitoring sites that have adopted IMPROVE protocols, but are not part of the IMPROVE Program network, are often called IMPROVE Protocol Sites.

Aerosol monitoring is conducted at all IMPROVE Program sites and is accomplished by a combination of particle sampling and sample analysis. At most sites, the 4-module IMPROVE sampler used has been programmed to collect two 24-hour duration samples per week. Starting in December of 1999, the sampling will be conducted once every three days. The sampler collects four simultaneous samples: three $PM_{2.5}$ samples (Modules A, B, and C) and one PM_{10} sample (module D). Module A uses a Teflon filter that is analyzed for $PM_{2.5}$ mass, elements, and light absorption. Module B uses a nylon filter that is analyzed for sulfates, nitrates, and chloride ions. Module C uses a quartz filter that is analyzed for organic and elemental carbon. Module D uses a Teflon filter to determine total PM_{10} mass. Additional specifications regarding the IMPROVE aerosol sampler are provided in Section 3.0.

Transmissometers are currently employed to measure the optical light-extinction coefficient (b_{ext}) at selected IMPROVE Program sites. Nephelometers are employed at other sites to measure the optical light scattering coefficient (b_{scat}). Absorption measurements (b_{abs}) are made using combined laser integrating plate and laser integrating sphere laboratory methods on the IMPROVE Module A filter. Both a transmissometer and nephelometer are located at Grand Canyon to research existing and future visibility monitoring methods. Relative humidity is measured continuously in association with all optical monitoring sites (transmissometer and nephelometer).

Scene monitoring using 35 mm automatic cameras was initially conducted at all IMPROVE Program sites in association with aerosol and optical monitoring. Most sites, however, discontinue scene monitoring after 5 years of data collection because a sufficient visual record of the range of visibility conditions has been collected. In some cases scene monitoring continues to provide a qualitative record of the appearance of the scene for further interpretation of aerosol and optical data.

The IMPROVE monitoring program objective of documenting long-term trends will require monitoring in perpetuity. IMPROVE encourages FLMs, states, and others that have IMPROVE protocol sites in Class I areas to also make a long-term commitment to monitoring. The IMPROVE Program has also been a leader in visibility research and in the development of visibility monitoring instrumentation. The commitment to these efforts continues.

2.6.2.2 Special Study Monitoring Site (Network)

A series of monitoring studies were conducted in 1987 and 1990 to determine emission impacts and haze sources at Grand Canyon National Park, Arizona. Based on these studies, EPA proposed regulations that would require substantial reduction of sulfur dioxide emissions from the Navajo Generating Station (NGS). While the NGS has been linked to a portion of the haze at Grand Canyon National Park, it is generally recognized that a number of other area and point sources also contribute to the haze. In response to a 1991 congressional mandate to further determine the sources of visibility impairment, the EPA established a short-term special study titled Project MOHAVE (Measurement of Haze and Visual Effects). The primary goal of Project MOHAVE was to determine the contribution of the Mohave Power Project (MPP), a 1580 Megawatt, coal-fired steam electric power plant, to haze at Grand Canyon and other mandatory Class I areas where visibility is an important air quality related value (attribution analysis). Additional goals included:

- Determining the improvement in visibility that would result from the control of MPP emissions.

- ! Identifying other sources that contribute to haze in Grand Canyon National Park, including those sources that are regionally transported.

The Project MOHAVE study plan was developed and evaluated by the Project MOHAVE Steering Committee (composed of government and industry scientists), members of the Haze in National Parks and Wilderness Areas Committee of the National Research Council, National Academy of Sciences participants, and various other individuals. Study plan considerations included an overview of the MPP and Grand Canyon National Park geography, regional transport regimes, regional meteorological conditions, and historical study findings.

The field measurement portion of the study was scheduled to last one year, from September 1991 through August 1992. Intensive monitoring and tracer release periods were scheduled for January 4-31, 1992, and July 15-August 25, 1992. During the intensive periods a tracer was emitted from the MPP stack, and tracer and particulate data were collected continuously at more than 30 sites. Different artificial tracers were released from the Los Angeles Basin and San Joaquin Valley during the summer intensive to gain insight into the transport of emissions from these large source areas. Each site was equipped with a programmable Brookhaven atmospheric tracer sampler. During the non-intensive periods when a tracer was not released, no tracer sampling was conducted, the number of particulate monitoring sites was scaled back considerably, and samples were collected only two days per week. Meteorological, optical, and scene monitoring was conducted continuously throughout the study.

Four classes of sites were established for the MOHAVE study:

- ! <u>Receptor Sites</u> - Four (4) sites were selected within or in very close proximity to Grand Canyon National Park. Most of these sites had some degree of existing or planned monitoring prior to Project MOHAVE. All sites operated during the entire study period. Instrumentation included a full IMPROVE aerosol sampler, transmissometer, nephelometer, 35 mm camera, and surface meteorology at three of the four sites. The fourth site had a DRUM sampler for particle monitoring and a nephelometer.

- ! <u>Other Class I Sites</u> - Six (6) existing Class I sites were selected to represent areas that could be impacted by MPP and/or serve as background sites. Class I sites operated during the entire study period. Instrumentation consisted primarily of full IMPROVE aerosol samplers and cameras. Three of the six sites had additional optical measurements with a transmissometer. Surface meteorological data were collected at two of the transmissometer sites.

- ! <u>Background Sites</u> - Twenty-one (21) background sites were selected to characterize high elevation and low elevation transport into the study area and to show detailed concentration patterns within the study area. Module A of the IMPROVE aerosol sampler and a filter pack for SO_2 were used to collect 24-hour samples (aerosol and tracer) during each day of the intensive periods. No background data were collected during non-intensive periods.

- ! <u>Scene Sites</u> - Camera monitoring sites with broad views and panoramas were selected throughout the study domain. Both 35 mm still-frame and 8 mm time-lapse photography were taken to document the visual air quality throughout the study.

Site selection considerations included the proximity to Grand Canyon National Park, location in respect to possible pollution transport corridors and "clean" (no emissions) corridors, and location with respect to regional air flow, as well as the availability of power and accessibility.

Tracer monitoring data were used to identify the general transport patterns for the MPP plume and to help identify the interaction between MPP and southern California emissions. Tracer data also served as a "check" for transport model predictions. Air quality (particle and optical) data served as input for hybrid and receptor models, to document the regional distribution of particulate and SO_2, and to identify boundary conditions for other pollutants transported into the study area. Camera (scene) monitoring provided documentation of the visual impairment of specific unique vistas under various air quality conditions. Meteorological monitoring characterized the speed, direction, and depth of transport into the region. Upper air and surface data were also used for model initiation and validation.

2.6.2.3 Non-Class I (Urban or Sensitive Area) Monitoring Site

The Tahoe Regional Planning Agency (TRPA) established a visibility monitoring program in the Lake Tahoe Basin in December 1988. The Lake Tahoe Basin, with its nearly pristine lake surrounded by the Sierra Nevada Mountains, is a nationally recognized area of scenic beauty. The basin's visibility has been acknowledged as one of its finest attributes.

Based on data collected during an initial short-term 1981-82 visual air quality study, the Tahoe Regional Planning Agency established regional and sub-regional environmental threshold-carrying capacities for the Tahoe Basin. Regional visibility is defined as the overall prevailing visibility in the Tahoe Basin. Sub-regional visibility is characterized by the layered haze (regional haze with a defined boundary) in the Lake Tahoe urbanized areas. Thresholds were established to achieve visual ranges of given kilometers (miles), as estimated from measured particulate concentrations. Both regional and sub-regional goals also included the desire to reduce wood smoke emissions by 15% from 1981 base values. The TRPA monitoring program was established to confirm standard attainment or non-attainment with the established thresholds and to further understand the causes of visibility degradation in the Basin.

Two monitoring sites were selected for the Lake Tahoe study. The primary site was located on Lake Tahoe Boulevard adjacent to California Air Resource Board (CARB) criteria pollutant and PM_{10} monitors. A full IMPROVE aerosol sampler, integrating (ambient) nephelometer, and an automatic camera system were installed in December 1988 to monitor sub-regional visibility from this location. The camera system viewed across Lake Tahoe to the north. A second monitoring station was established at Bliss State Park to monitor regional air within the Lake Tahoe Basin. A full IMPROVE aerosol sampler, integrating (ambient) nephelometer, and transmissometer were installed in November 1990. The 13.3 km transmissometer sight path extended from the Zephyr Point Fire Tower to the Bliss State Park monitoring location. Meteorological measurements, temperature, relative humidity, wind speed, and wind direction are also continuously measured at both primary monitoring locations. As of this publication all these instruments are still operating. Two additional camera-only monitoring locations were initially proposed for viewing the south shore of Lake Tahoe and north of the Lake Tahoe Basin, but as of this publication, they have not been installed.

Collected data are reviewed annually by the Tahoe Regional Planning Agency and compared to established visibility thresholds. Monitoring is scheduled to continue.

3.0 AEROSOL MONITORING

As an example of an existing visibility-related aerosol monitoring program, this section describes IMPROVE aerosol monitoring and data management techniques. References made to manufacturers or trade names are not intended to constitute EPA endorsement or recommendations for use. New or improved instruments, instrument upgrades, and methods of monitoring are continually being developed.

Aerosol monitoring is used to identify chemical species and obtain concentration measurements of atmospheric constituents that contribute to visibility impairment. Primary techniques include filter-based aerosol samplers that collect samples on various substrates in two size ranges, aerodynamic diameters $\leq$ 2.5 µm ($PM_{2.5}$) and aerodynamic diameters $\leq$ 10 µm (PM_{10}). The particulate monitoring portion of the IMPROVE program measures the concentration of $PM_{2.5}$ particles for mass, optical absorption, major and trace elements, organic and elemental carbon, and sulfate, nitrate, and chloride ions, and the concentration of PM_{10} particles for mass.

An understanding of the liquid water associated with hygroscopic particles is also critical. With present technology, the liquid water particle component cannot be directly measured, nor is it possible to determine liquid water content from subsequent analysis of particle samples. Relative humidity data can be used to infer the visibility impacts associated with liquid water. Due to the significance of this component for visibility effects, continuous relative humidity monitoring is a desirable supplement to aerosol monitoring.

The following subsections describe the monitoring criteria, instrumentation, installation and site documentation, system performance and maintenance, data collection, filter analysis, data reduction, validation, reporting, and archive, supplemental analysis, quality assurance, and analysis and interpretation recommended for aerosol monitoring. Operation manuals and manufacturers specifications are provided in Appendix B.

3.1 MEASUREMENT CRITERIA AND INSTRUMENTATION

Both monitoring and analytical considerations need to be evaluated when establishing an aerosol monitoring site. The sample frequency, particle size, filter substrate, flow rate, and analytical methods are all important considerations when measuring major aerosol components and trace element constituents. For good monitoring statistics, a high recovery rate is essential. The factors here are sampler reliability and the ability to service the sampler (change filters) in all weather conditions.

The standard IMPROVE aerosol sampler, shown in Figure 3-1, consists of one PM_{10} module with Teflon filters, and three $PM_{2.5}$ modules, one with Teflon, one with nylon, and one with quartz filters. Not shown is the separate controller module. The power for the pumps is through a switched outlet with a signal from the controller. Each module is optimized for a specific purpose and matched to its analytical protocols as shown in Table 3-1. The use of this standard setup of four modules is strongly recommended in order to maintain the quality assurance of redundant measurements. All IMPROVE sites the IMPROVE network use this standard setup. Approximately 10% of the sites in mandatory Class I areas have an additional $PM_{2.5}$ module with Teflon filters for quality assurance. The samplers were designed by Crocker Nuclear Laboratory (CNL) at the University of California, Davis

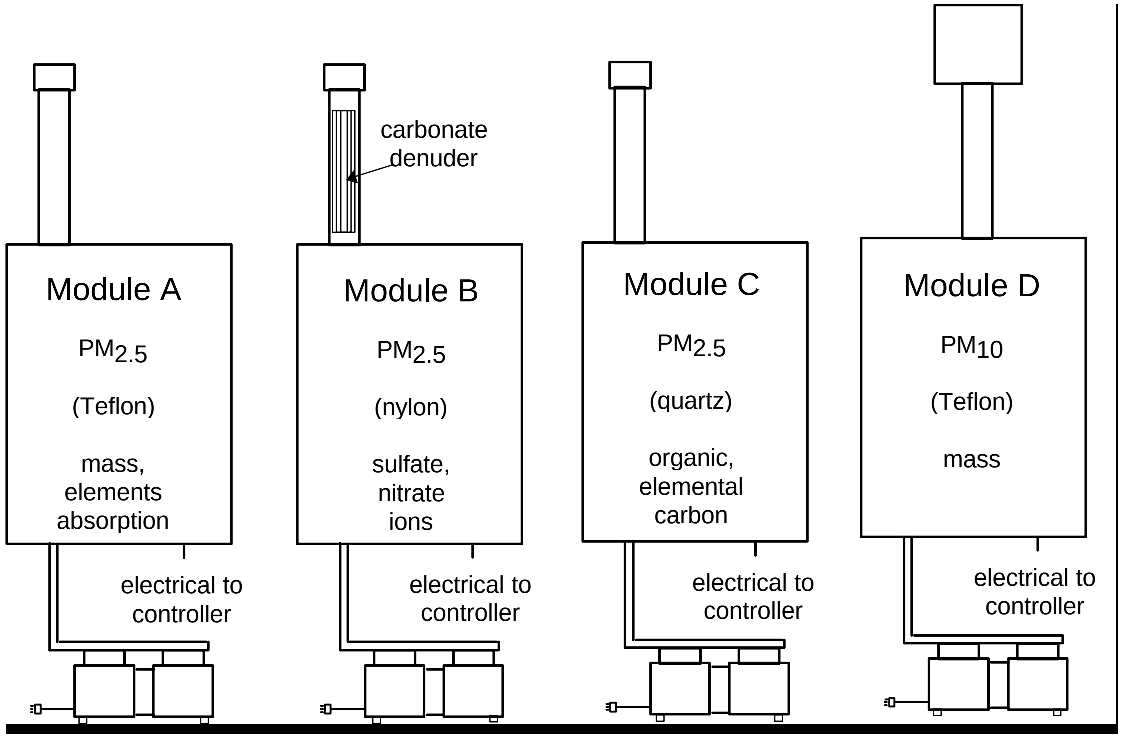


Figure 3-1. Diagram of the IMPROVE Aerosol Sampler.

Table 3-1 Summary of IMPROVE Aerosol Sampler Data Collection Parameters

Module	Particle Size	Filter Type	Analytical Method (Variables)
A	0.0-2.5 µm	Teflon®	• Gravimetric Analysis ($PM_{2.5}$ mass) • Hybrid Integrating Plate/Sphere Method (coefficient of optical absorption) • Particle Induced X-Ray Emission (elements Na-Mn) • X-Ray Fluorescence (elements Fe-Pb) • Proton Elastic Scattering Analysis (H)
B	0.0-2.5 µm	Nylon	• Ion Chromatography (sulfates [$SO_4^{=}$], nitrates [NO_3^-], nitrites [NO_2^-], & chloride [Cl^-])
C	0.0-2.5 µm	Quartz	• Thermal Optical Reflectance Carbon Combustion Analysis (carbon in eight temperature fractions)
D	0.0-10.0 µm	Teflon®	• Gravimetric Analysis (PM_{10} mass)

Each module has an independent air stream with a sizing device, a flow controller, and a pump, plus solenoid valves for exposing two or three filters between weekly sample changes. Figure 3-2 shows schematics for $PM_{2.5}$ modules used before and after 1999, for the PM_{10} module used after 1999 and for the controller module used after 1999. The primary change in the IMROVE sampler in 1999 is the controller module. In the version used from 1998 to 1999, programmable clock controlled the pump and solenoid valve switching for each filter module. A new version of the sampler, installed in 1999, uses a microprocessor to (1) control the pumps and solenoid valves, (2) read and record the flow rate pressure transducers, (3) read and record the temperature at the filter during and after sampling, and (4) optionally read and record the relative humidity. The microprocessor will permit sampling on a 1-day-in-3 schedule. The collection data will be stored on a removable magnetic card that is sent between the central laboratory and the site in the box with the filters. The magnetic card will also have the sampler programs and the site-specific flow rate calibration equations. The operator will read all collection data on the microprocessor screen. With the microprocessor, the readable pressure gauges and elapsed timers in the earlier version of the sampler are unnecessary. The pumps are housed separately.

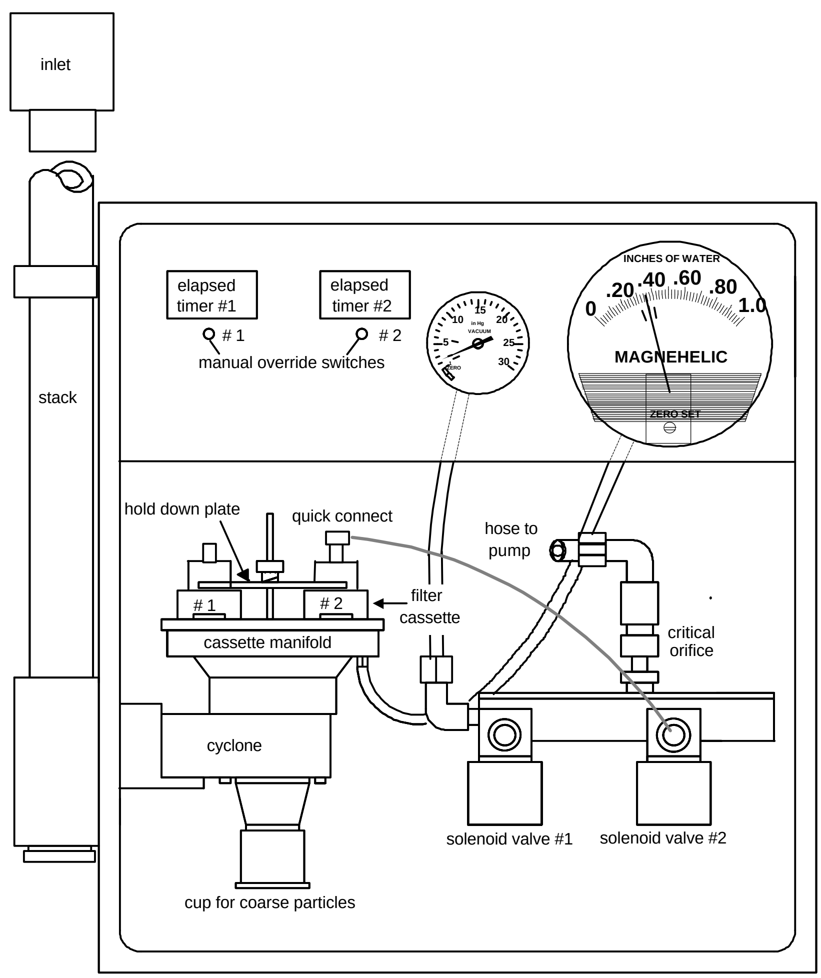
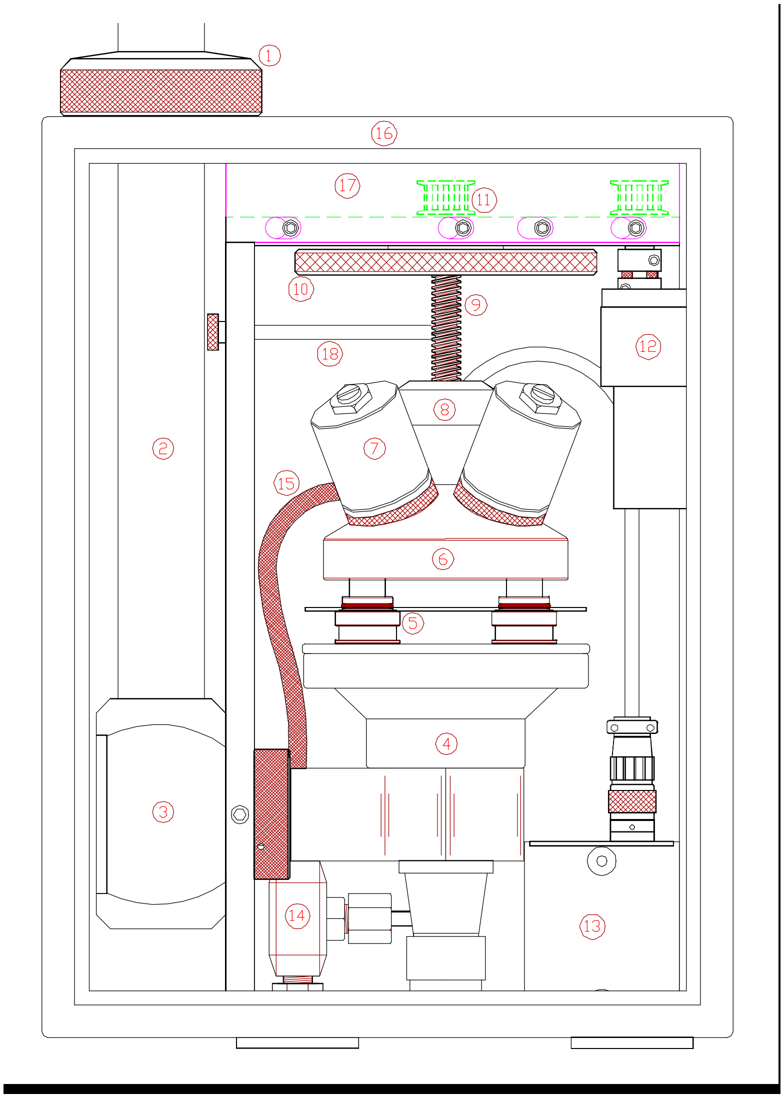


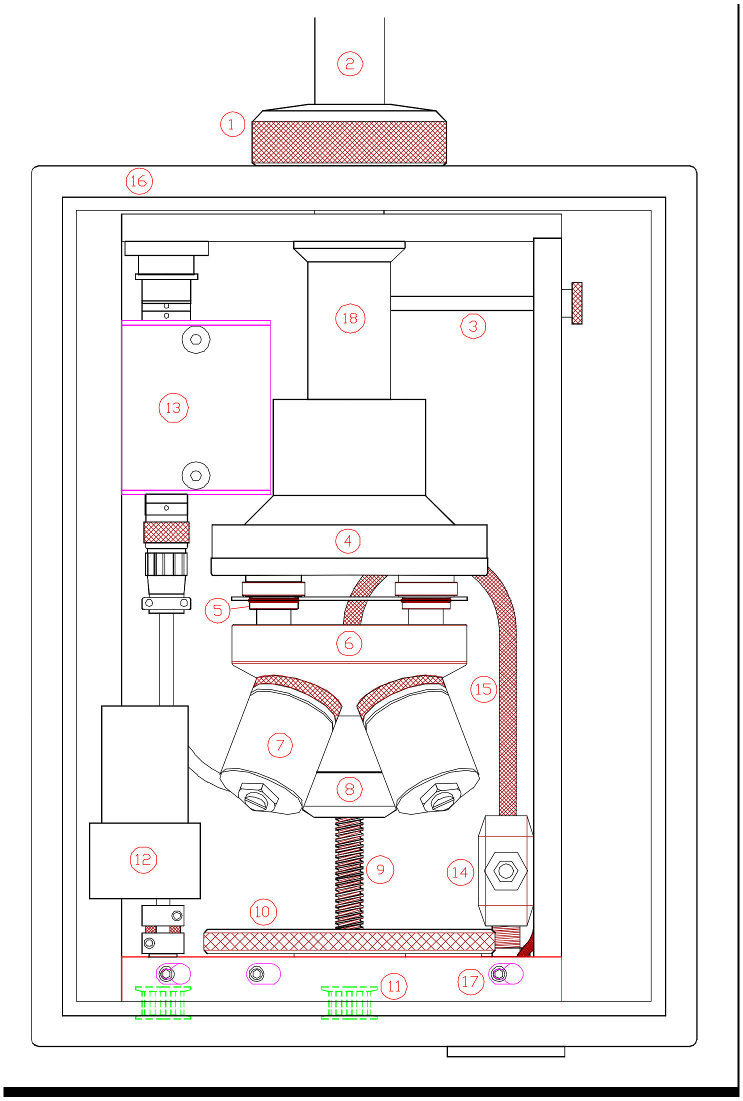
Figure 3-2a. Schematic of the IMPROVE $PM_{2.5}$ module used before 1999.



$PM_{2.5}$ Filter Module

1 stack compression sleeve
2 inlet stack
3 inlet tee
4 cyclone / cassette manifold
5 cartridge with 4 filter cassettes
6 solenoid value assembly
7 solenoid valve (4)
8 manifold nut drive
9 leadscrew
10 handwheel
11 timing pulleys for motor
12 gear motor
13 electronics enclosure
14 critical orifice valve
15 Teflon hose with stainless steel braid
16 enclosure box (outdoor sampler)
17 belt guard
18 sampler retainer pin

Figure 3-2b. Schematic of the IMPROVE $PM_{2.5}$ module used after 1999.



PM_{10} Filter Module

1 stack compression sleeve
2 inlet stack
3 sampler retainer pin
4 PM_{10} cassette manifold
5 cartridge with 4 filter cassettes
6 solenoid value assembly
7 solenoid valve (4)
8 manifold nut drive
9 leadscrew
10 handwheel
11 timing pulleys for motor
12 gear motor
13 electronics enclosure
14 critical orifice valve
15 Teflon hose with stainless steel braid
16 enclosure box (outdoor sampler)
17 belt guard
18 funnel extension

Figure 3-2c. Schematic of the IMPROVE PM_{10} module used after 1999.

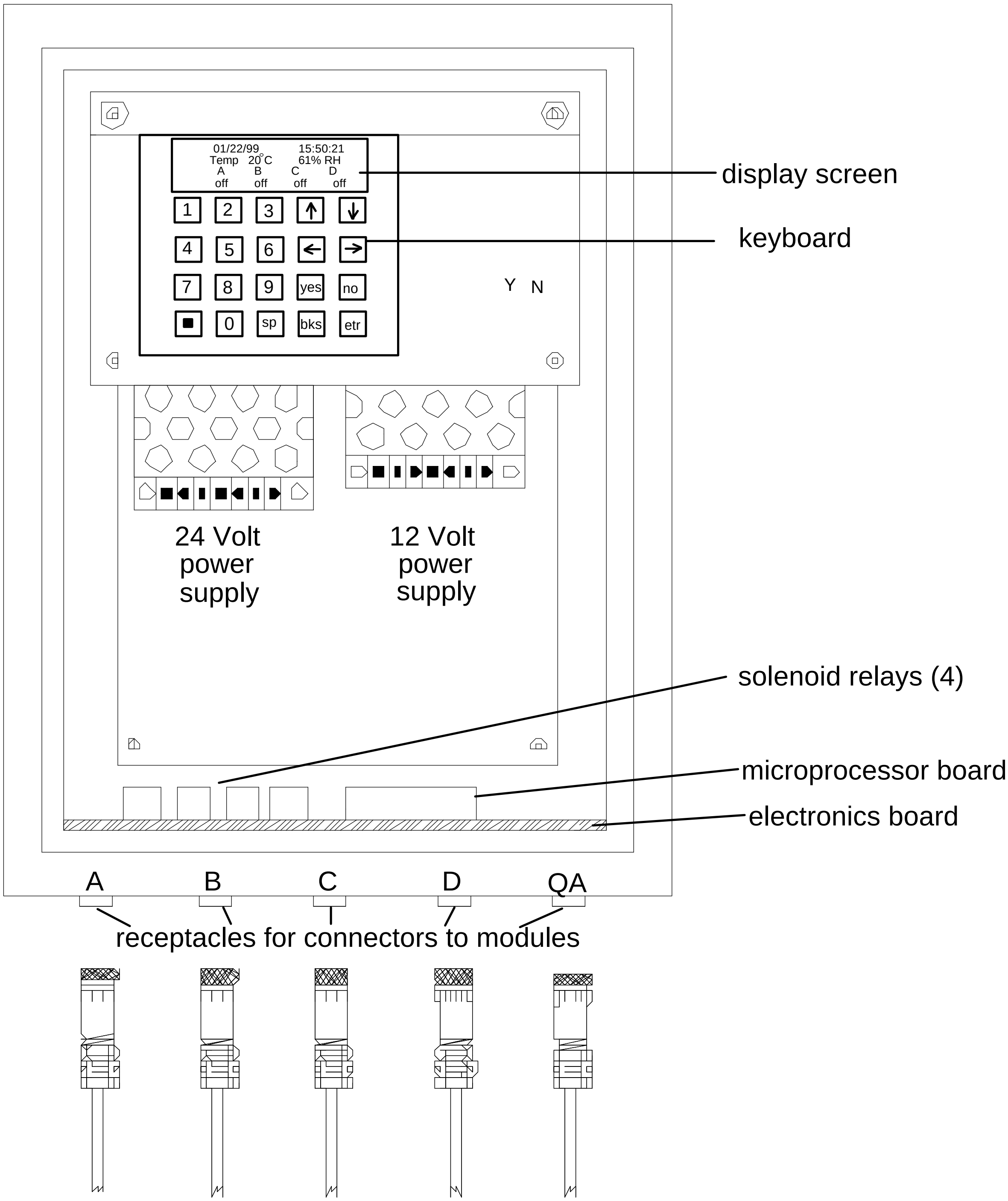


Figure 3-2d. Schematic of the IMPROVE controller module used after 1999.

The particle sizing for $PM_{2.5}$ particles is accomplished with a cyclone operating with an ambient flow rate of 22.8 L/min. Flow control is maintained by a critical orifice between the filter and pump. The flow rate is measured both in front of and behind the filter. The flow rate in front of the filter is determined from the pressure drop across the cyclone, while the flow rate behind the filter is determined from the pressure at the front of the critical orifice. The dual measurements provide a quality assurance check for every sample and shows the operator that the cassettes are properly seated prior to sample collection. The standard deviation of flow rates over a year is typically 2%-3%. Precision tests using collocated samplers typically indicate that the flow rate precision is 3%.

The particle sizing for PM_{10} particles is accomplished with a commercial PM_{10} inlet. Inlets of the Wedding design operate at 19 L/min. Inlets of the Sierra-Anderson design operate at 16.7 L/min. Flow control is also maintained by a critical orifice. The flow rate is measured only behind the filter, using the pressure at the front of the critical orifice.

The filters are transported to the site and loaded into the samplers using a system of cassettes and cartridges. A cartridge is a circular disk holding four cassettes. Clean filters are loaded into two or three cassettes at a central laboratory. Each cartridge is labeled for the desired module and change date, and also identified by color. The cartridges are mailed directly to the site in sealed, insulated shipping containers. During the weekly site visits, the cartridge of clean filters in each module is exchanged for a cartridge of exposed filters. For 1-day-in-3 sampling, the samplers will be operating on the day of sample change once every third week. The cartridge for this change will have only three cassettes and one hole. The operator will suspend sampling, move a specially marked cassette from the exposed cartridge and place it in the hole in the clean cartridge. The operator will resume sampling after the clean cartridges are all in place. The cartridges of exposed filters are returned to the laboratory for processing. The $PM_{2.5}$ Teflon filter deposits are analyzed for the concentrations of deposit mass, hydrogen, elements with atomic weights from sodium to lead, and for an optical parameter, the coefficient of absorption. The nylon filters are analyzed for the concentrations of nitrate, sulfate, and chloride ions, the quartz filters for the concentrations of organic and elemental carbon, and the PM_{10} Teflon filters for the concentration of deposit mass.

There are two factors concerning whether it is better to have samplers in shelters or completely outdoors. The first factor is temperature during sampling and between the end of sampling and the removal of the filters. During sampling it is important to maintain an approximately constant temperature of the air stream to avoid changing the relative humidity and the gas-particle equilibrium. (Changes in relative humidity would effect the particle size of sulfate particles. If the particle diameter is in the region of 2.5 µm, the change would effect the passage through the particle sizing device.) After sampling is completed, it is important to avoid volatilizing particles by excessively heating the sample. The sampler must not be in a shelter that overheats nor in direct sunlight. The second factor in whether to use shelters is protecting the integrity of the samples during sample change and allowing the operator to be able to perform the change in extreme weather conditions. In regions of extreme winter cold and during periods of heavy precipitation and or high winds, it may not be possible to obtain valid samples with an outdoor sampler.

Therefore, in the IMPROVE network, samplers are normally inside a well-ventilated shelter that shades the sampler from direct sunlight and protects the integrity of the sample during sample changing in inclement weather. In regions of high summer temperature and mild winters, the wall opposite the samplers may have only a screen. The shelter in this case protects against direct sunlight, rain, and high wind. One consequence with using a shelter is that the stacks must be longer than in an outdoor site, in order to have a 1 m clearance above the shelter roof. The standard height of inlet stack for IMPROVE samplers is 2 m (when used in a shelter, the height of the inlet can be more than 2 m above the ground). The temperature at the filter is monitored during sampling and between sampling periods. The shelters are not heated or air-conditioned.

The IMPROVE particle sampler has been in use since 1988. In 1998, over 70 IMPROVE sampler sites were operating in various visual air quality monitoring programs in North America, from highly-polluted urban areas to pristine wilderness environments. Of those, approximately 25% of the sites operate with a single $PM_{2.5}$ module. By the end of 1999, over 100 IMPROVE sites will be operating throughout the U.S. Detailed and updated information regarding IMPROVE particle sampler instrumentation or operation can be found *IMPROVE Particulate Monitoring Network Standard Operating*, Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis). This is available as a pdf file on a National Park Service Web site, http://www.nature.nps.gov/ard/vis/sop/index.html. The Sampler Operations Manual is included as a Technical Instruction, TI201A *IMPROVE Aerosol Sampler Operations Manual*.

3.2 SITING CRITERIA

IMPROVE aerosol samplers are generally sited in conjunction with other IMPROVE protocol optical and/or scene monitoring equipment. Therefore aerosol sampler protocols closely resemble siting protocols for transmissometer, nephelometer, and scene monitoring equipment, described in Sections 4.1.2, 4.2.2, and 5.2 respectively.

The primary siting criterion is to ensure that the air mass monitored is representative of the area or region of interest. To assure consistent quality data, aerosol sampling sites are selected to meet most if not all of the following criteria:

- For a mandatory Class I area, it must be within 100 km and have an elevation that is between the minimum and maximum elevations. A given sampling site may represent multiple mandatory Class I areas.

- Have good ventilation. (That is, not be in a valley with meteorological inversions.)

- Be removed from local sources such as diesel, wood smoke, automobile, road dust, construction, etc.

- Be located in an area free from large obstructions, such as trees or buildings, that would hinder sampling of representative aerosols. (Sampler inlets must be located between 2 and 15 meters above the ground.)

- Be representative of the same air mass measured by other optical or scene monitoring.

- Have adequate AC power (a 20 Amp circuit of 110 V, 60 Hz line power for a standard configuration). The primary power should not be provided by electric generators.

- Be secure from potential vandalism.

- Be located in a region with available servicing personnel (operator).

- Be accessible during all months of the year.

3.3 INSTALLATION AND SITE DOCUMENTATION

The standard samplers are installed in a well-ventilated shelter with the inlet stacks and cyclones mounted vertically. Mounting structures must be stable to avoid vibration or shifting, and strong enough to support the weights of all installed samplers. Each IMPROVE module and controller weighs approximately 40 pounds.

After the sampler hardware is installed, the critical orifice in each module is adjusted to give the desired nominal flow rate. The flow rate calibration equations for each sampler are determined by the audit procedures described further in Section 3.4 (System Performance and Maintenance). (The flow rate calibration is audited every six months by either site operators or field technicians from the central laboratory. If necessary the critical orifice is adjusted at these times.)

When the flow rate calibration is complete, cartridges of test filters are placed in the sampler and the operation of the sampler is tested using the system diagnostics magnetic card.

After the system is verified, the installing technician will train all operators, back-up operators, and any other involved or interested on-site personnel. This includes reviewing the sampler manual (Crocker Nuclear Laboratory Technical Instruction TI201A *IMPROVE Aerosol Sampler Operations Manual*). Hard copies of this manual are left with the on-site personnel. Additional copies are obtained as a pdf file on http://www.nature.nps.gov/ard/vis/sop/index.html. The manual provides documentation on sampler operation, repair, and audits, and troubleshooting.

Finally, the installing technician will complete the following:

- A site visit trip report

- Photographic documentation (including photographs of the shelters, all components, shelter supports, local surroundings, sight path, power supply, etc.)

- Instrument and site configuration documentation, including site map and site specifications (latitude, longitude, instrument elevations, elevation angle, sight path distance, etc.)

3.4 SYSTEM PERFORMANCE AND MAINTENANCE

System performance and maintenance includes routine servicing, and instrument calibration and maintenance.

3.4.1 Routine Servicing

Routine servicing is primarily the responsibility of the site operator, although any deviations from expected behavior are reported to and solved in conjunction with the lab manager or field specialist. Repairs are performed by the site operator under the supervision of a field specialist. Similarly, biannual audits are performed by the site operator under the supervision of a field specialist.

During the weekly sample changes, the site operator shall review the field log sheet and verify that the sample collection parameters are within the acceptable ranges specified in the *IMPROVE Aerosol Sampler Manual*. The microprocessor program will make internal checks and note discrepancies on the viewing screen. The site operator should contact the central laboratory when problems occur. The site operator should also inspect the equipment and the shelter to verify cleanliness and identify possible problems. Weekly procedures are further detailed in TI201A *IMPROVE Aerosol Sampler Manual*.

Additional routine servicing, to be performed monthly includes emptying the water bottle on the Module D PM_{10} inlet for sites with Sierra-Anderson inlets, and verifying the integrity of the mounting platform and filter mounting ports.

The purpose of the denuder in Module B (nylon filter) is to remove HNO_3 from the air stream before it reaches the filter. Since 1988, the denuders have been changed annually. Tests indicate that with respect to SO_2, the denuders will saturate during this time at most IMPROVE sites. However, test with old and new denuders indicate that there is no decrease in the efficiency to collect HNO_3 over this period. Tests will be continued to monitor this. If necessary, the frequency of changing the denuders will be increased to quarterly.

For quality control purposes, roughly 2% of the IMPROVE sampler filters are field blanks. Field blanks are collected to determine the amount of material (artifact), picked up by the filter cassettes during the shipping, installation, removal, and laboratory processing procedures. No extra steps are required of the site operators for handling field blanks. All cartridges have four cassettes; normally one or two will have no filters.

3.4.2 Instrument Calibration and Maintenance

Flow rate audits are performed whenever the sampler gauges indicate a potential error in the flow rate and biannually at randomly selected sites. If an audit indicates the calculated flow rates in any module are off more than 5%, a complete four point audit is performed. Flow rate audit devices are delivered through the mail, and the audit is performed by the site operator. Biannual audit procedures consist of nominal flow checks for two clean, newly installed filter cassettes, for two consecutive sampling periods. If the biannual audit indicates the calculated flow rates in any module are off by more than 3%, the sampling module in error must be re-calibrated. Calibration and flow rate audit procedures are described further in the Crocker

Nuclear Laboratory SOP 176, *Calibration, Programming, and Site Documentation* and TI201A *IMPROVE Aerosol Sampler Operations Manual*.

Annual site visits are performed by field specialists. Annual maintenance includes:

- Pre-maintenance inspections and site inventory.
- Cleaning individual cyclones, stacks, and inlets.
- Checking module components and electronics.
- Auditing each module and recording updated annual calibrations.
- Post-calibration verification checks.
- Site operator training.

3.5 SAMPLE HANDLING AND DATA COLLECTION

Sample handling includes pretesting (preliminary validation) of aerosol filters prior to use, processing the clean filters and shipment to the site, routine field procedures used by site operators, and processing the exposed filters in preparation for ionic, carbon, or elemental analysis.

The standard operating procedures used in the handling of IMPROVE aerosol filters are summarized in Figure 3-3.

3.5.1 Procurement and Pretesting of IMPROVE Aerosol Filters

The central laboratory is responsible for:

- Purchasing Teflon and nylon filters from commercial vendors.
- Acceptance testing of the filters.
- Preparing filter collection masks.

The carbon analysis laboratory is responsible for:

- Purchasing quartz filters from commercial vendors.
- Acceptance testing of the filters.
- Prefiring all filters.

Procedures for purchasing, acceptance testing, preparing, and assembling filters and cassettes for the field are fully described in Crocker Nuclear Laboratory SOP 101, *Procurement and Acceptance Testing* and its associated Technical Instructions.

3.5.2 Processing of Clean Aerosol Filters

The standard operating procedures for processing the clean aerosol filters include:

- Measuring the tare masses of the Teflon filters.
- Loading clean filters into cassettes and the cassettes into cartridges.
- Attaching identification tags to the cassettes and color codes and identification tags to the cartridges.
- Leak testing cassettes.
- Sending the cartridges/cassettes with clean filters to the sites in specially designed shipping containers.

Approximately 1500 field blanks are collected each year in the IMPROVE network. These are used to determine the amount of material (artifact), picked up by the filter cassettes during the shipping, installation, removal, and laboratory processing procedures. The determination of when to include a field blank is determined by the sample handling software at the time of loading the clean filters. Normally one or two of the four cassettes in each cartridge will have no filters. When instructed, the laboratory technician will add a field blank in the cassette in position four. This will be processed in the same manner as a normal filter except no air is drawn through. No extra steps are required of the site operators for handling field blanks.

Procedures for processing filters and gravimetric analysis are fully described in Crocker Nuclear Laboratory SOP 251 *Sample Handling.*

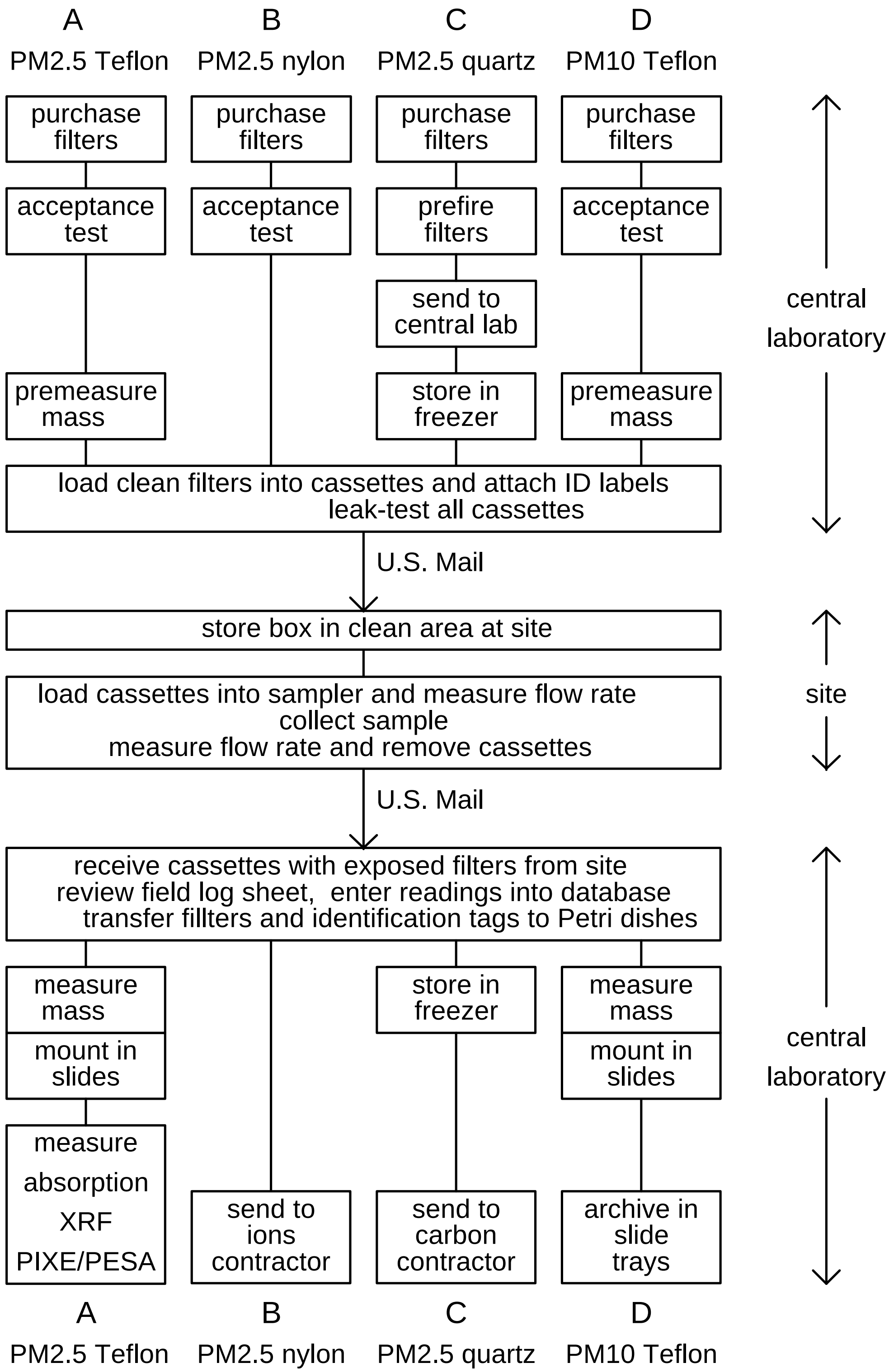


Figure 3.3. Flow diagram of filter handling procedures before, during, and after sample collection. U.C. Davis has been the central laboratory for IMPROVE since 1988.

3.5.3 <u>On-Site Filter Handling</u>

Aerosol filter cassettes are changed weekly by the site operator every Tuesday. The filters are loaded into the samplers using a system of cassettes and cartridges. A cartridge is a circular disk holding four cassettes. Clean filters are loaded into two or three cassettes at a central laboratory. Each cartridge is labeled for the desired module and change date. The desired module is also identified by color. The cartridges are mailed directly to the site in sealed, insulated shipping containers.

During the weekly site visits, the operator first activates the check flow rate program on the microprocessor. For 1-day-in-3 sampling, the samplers will be operating on the day of sample change once every third week. This step will suspend sampling during the sample change. The operator records the information of the screen on the provided log sheet. Next, the operator removes the cartridge of exposed filters in each module and inserts the cartridge of clean filters. If this is a day with current sampling, the cartridge for this change will have only three cassettes and one hole. The operator will move the partially exposed filter from the exposed cartridge and place it in the hole in the clean cartridge. This cassette is clearly labeled by color. The operator will then activate the program to check the initial flow rates of the new filters and record the information from the screen to the log sheet. The microprocessor includes programs to check that the flow rates are within specifications. The operator will be alerted if their are problems. If this is a sampling day, the microprocessor will resume sampling. During this process, the operator never directly touches the filters.

The operator returns the exposed filter cassettes, log sheets, and memory card to the central laboratory by mail. The purpose of the log sheet is to maintain a record of collection data even if the memory card were to be lost or damaged in transit.

3.5.4 <u>Processing Exposed Filters and Preparation for Filter Analysis</u>

Filter cassettes returned from the field are processed and prepared for analysis as follows:

- The data on the memory card are downloaded. The dates are compared to those on the field log. If there is a match, the data are transferred to the tracking/analysis database.
- All log sheet information and written notes are entered into the tracking/analysis database.
- Site operators are contacted if any errors or equipment malfunctions are noted.
- The nylon and quartz filters (Modules B and C) and identification tags are transferred to Petri dishes.
- The Teflon filters (Modules A and D) are weighed and the filters are loaded into slide frames for further analysis. The identification numbers are written of the slide frames.
- All gravimetric mass measurements are entered into the tracking/analysis database.

3.6 FILTER ANALYSES AND DATA REDUCTION AND VALIDATION

The laboratory analysis of the $PM_{2.5}$ Teflon filters (Module A) are performed at the central laboratory. The analysis of the nylon filters (Module B) and quartz filters (Module C) are done by two outside laboratories on separate contracts. The analytical results from these outside laboratories are returned to the central laboratory as mass per filter without artifact correction or sample volumes. At the central laboratory, the laboratory analysis of the Teflon filters, except for gravimetric analysis, is performed quarterly, following the standard season for IMPROVE. The data processing and validation are also done quarterly. The specific procedures are summarized in the following subsections.

3.6.1 Gravimetric Mass

Gravimetric analysis of Module A and Module D IMPROVE Teflon_filters uses the difference method to determine the mass of the collected aerosol. The pre-weight of each filter is measured prior to loading the filter into a cassette. Once exposed and returned to the laboratory, the filter is removed from the cassette, and the post-weight of the filter is measured. Level-1 validation includes determination of the mass of the aerosol by calculating the difference between the pre- and post-weights.

3.6.2 Absorption (b_{abs})

The coefficient of light absorption for fine particles, b_{abs}, is determined from the Module A Teflon filters using a Hybrid Integrating Plate and Sphere (HIPS) method. This involves direct measurement of the absorption of a laser beam by a sample, over the area of the sample, to obtain an ambient b_{abs} value. With the HIPS method, it is not necessary to analyze the clean filter before collection. Currently, the method is being re-evaluated to determine its accuracy in determining the coefficient of absorption in the atmosphere. Until, this evaluation is completed, the coefficient is not being reported.

3.6.3 Analysis of Aerosol Species

Starting December 1999, the standard IMPROVE protocol is to collect 24-hour aerosol data samples once every third day. Prior to December 1999, two samples were collected each week, on Wednesday and Saturday. All major fine aerosol components plus PM_{10} mass are measured, including several redundant measurements for quality assurance.

The IMPROVE aerosol sampler has four (4) separate modules. Three (3) modules (denoted A, B, and C) are fine particle samplers with cyclone systems that operate at a nominal flow rate of 22.8 liters per minute and collect particles up to 2.5 µm in diameter. The fourth module (D) is a PM_{10} sampler operated at nominal flow rates of 19.1 liters per minute (Wedding inlet) and 16.7 liters per minute (Sierra-Anderson inlet) and collect particles up to 10 µm. The measurement and data reduction protocols associated with each module are described below.

Module A

The Module A Teflon filters are analyzed for elements with atomic weights from sodium to manganese by Particle Induced X-ray Emission (PIXE), from iron to lead by X-ray fluorescence (XRF), and simultaneously for hydrogen by Proton Elastic Scattering Analysis (PESA). Both PIXE and PESA subject the collected aerosol sample to a beam of 4.5 MeV protons, in vacuum, at the laboratory cyclotron. In PIXE, each element present in the sample is induced by the proton beam to emit X-rays whose energy is characteristic of the element, and whose number is proportional to the mass of the element. In PESA, the protons in the cyclotron beam, which are elastically scattered through a given angle (30°) by the hydrogen atoms in the sample, are also easily discriminated and counted, to give an accurate measure of the amount of hydrogen. XRF analysis employs a grounded anode diffraction type X-ray tube with a molybdenum anode. The X-rays produced by the tube are collimated and directed onto an aerosol sample. The sample deposit absorbs the Mo X-ray energy and re-emits the energy as X-rays characteristic to the elements present on the sample. The X-rays are detected by high-resolution SiLi detectors with pulsed optical feedback to provide high count rate capabilities.

Module B

The Module B nylon filters are analyzed by Ion Chromatography (IC) for sulfate, nitrate, and chloride ions, from which the sulfate and nitrate compounds are estimated. A sample is prepared for IC analysis by desorption of the collected material in 15 mL water. This solution is applied to strips of filter paper and allowed to dry, and the various ion species are separated in the standard way according to their solubilities, by suspending the strips over a solvent and allowing it to pass up through the paper by capillary action. Ambient gaseous nitric acid (HNO_3) is subject to adsorption by the nylon filter and subsequent transformation to the solid nitrate form, which would bias measurements of the latter. Therefore, a gas denuder, consisting of a set of concentric cylindrical aluminum sheets coated with potassium carbonate (K_2CO_3), is placed in the Module B inlet to remove HNO_3 before collection.

Module C

The Module C quartz filters are analyzed by Thermal Optical Reflectance (TOR) for organic and elemental carbon. A second quartz filter behind the first is used to estimate the artifact due to adsorption of organic gases. TOR involves:

- Heating a sample through a series of temperature increases or steps in a pure helium atmosphere. Oxygen is added in the later stages to enable the volatilization of elemental carbon.

- Converting the carbon evolved at each step into CO_2 using an oxidizer (MnO_2 at 912°C).

- Reducing the CO_2 to methane which is then quantified by passage through a flame ionization detector. Over the mid-range of the TOR heating (between about 130°C and 550°C), charring of the sample occurs due to pyrolysis of organic particles; this is monitored as a decrease in the reflectance from the sample surface. When the reflectance reaches a minimum, 2% oxygen is added to the atmosphere. This allows the elemental carbon in the sample, including the char produced by pyrolysis of organic matter, to oxidize. The reflectance of the sample increases as the char is removed. All carbon measured up to the point where the reflectance reattains its initial value is interpreted as organic carbon. Carbon evolved beyond this point is reported as elemental carbon. Table 3-2 outlines the eight carbon fractions reported as a function of temperature and added oxygen. OP is the portion of elemental carbon before the reflectance returns to the initial value. The total organic carbon (OC) is the sum of the four organic fractions plus the pyrolytic fraction:

$$\text{total organic carbon} = OC = OC1 + OC2 + OC3 + OC4 - OP \quad (3\text{-}1)$$

The total elemental carbon, also known as light-absorbing carbon (LAC), is the sum of the three elemental carbon fraction minus the pyrolytic fraction

$$\text{total elemental carbon} = EC = LAC = EC1 + EC2 + EC3 - OP \quad (3\text{-}2)$$

<u>Module D</u>

The gravimetric mass of all sampled particles up to 10 µm (PM_{10}) is measured as the difference between the weight of the primary Teflon filter before and after sampling, using an electromicrobalance. Coarse mass is estimated by subtracting fine mass $PM_{2.5}$ from total aerosol mass PM_{10}. Except under special circumstances, no further chemical analysis is performed on individual Module D filters. It is assumed that coarse mass consists primarily of insoluble airborne soil particles.

Table 3-2. Carbon Components as a Function of Temperature and Added Oxygen

<table>
<tr><th>Fraction</th><th>Pyrolized Fraction</th><th>Temperature Range</th><th>Atmosphere</th><th>Reflectance vs. Initial</th></tr>
<tr><td>OC1</td><td></td><td>Ambient to 120°C</td><td rowspan="4">100% He</td><td>At Initial</td></tr>
<tr><td>OC2</td><td></td><td>120°C – 250°C</td><td rowspan="4">Under Initial</td></tr>
<tr><td>OC3</td><td></td><td>250°C – 450°C</td></tr>
<tr><td>OC4</td><td></td><td>450°C – 550°C</td></tr>
<tr><td rowspan="2">EC1</td><td>OP</td><td rowspan="2">Remains at 550°C</td><td rowspan="4">98% He
2% O_2</td></tr>
<tr><td></td><td rowspan="3">Over Initial</td></tr>
<tr><td>EC2</td><td></td><td>550°C – 700°C</td></tr>
<tr><td>EC3</td><td></td><td>700°C – 800°C</td></tr>
</table>

IMPROVE sample analysis procedures are fully documented Crocker Nuclear Laboratory SOP 276, *Optical Absorption Analysis*; SOP 301, *X-Ray Fluorescence Analysis*; and SOP 326, *PIXE and PESA Analysis*.

3.6.4 Data Reduction and Validation of Laboratory Analyses

All aerosol data, both measured and calculated, are entered into the project database and validated according to IMPROVE protocols. Procedures for processing and validation of the laboratory analysis data include:

- Calculating concentrations and uncertainties of the measured variables. These calculations use standard IMPROVE equations for determining volume, mass, optical absorption, and concentrations from XRF, PIXE/PESA, IC, and TOR analysis results. Table 3-3 lists the commonly reported measured variables. In addition to these measured variables, composite variables can be derived from the measured variables by applying reasonable assumptions. These composite variables are included in Table 3-4 and discussed in more detail in Section 3.8.

- Entering the measured and composite variables data into the Concentration Database and checking for internal consistency
- Validating the data to identify anomalous variations with time using the following techniques:

  A. Correlation plots between:
     1) Si and Fe
     2) 3[S] (Teflon, PIXE) and $SO_4^{=}$ (Nylon, IC)
     3) Organic mass from carbon and organic mass from hydrogen
     4) Mass and reconstructed mass

  B. Timeline plots of major variables

  C. Statistical comparisons

  D. Examination of individual anomalies and errors transcribing data

Concentration uncertainty and precision estimates are presented in Section 3.8. IMPROVE data processing and validation procedures are fully documented in Crocker Nuclear Laboratory SOP 351, *Data Processing and Quality Assurance*.

Table 3-3. Commonly Reported Measured Variables

MEASURED VARIABLES						
Abbreviation	Atomic No.	Component	Module	Analytical Method	Reporting Units	General Reporting Category
MASS	N/A	$PM_{2.5}$ Fine Mass	A	Gravimetric	ng/m^3	Fine Mass
H	1	Hydrogen	A	PESA	ng/m^3	Major Element
Na	11	Sodium	A	PIXE	ng/m^3	Marine
Mg	12	Magnesium	A	PIXE	ng/m^3	Soil Elements
Al	13	Aluminum	A	PIXE	ng/m^3	Soil Elements
Si	14	Silicon	A	PIXE	ng/m^3	Soil Elements
S	16	Sulfur	A	PIXE	ng/m^3	Major Element
Cl	17	Chlorine	A	PIXE	ng/m^3	Marine
K	19	Potassium	A	PIXE	ng/m^3	Soil Elements
Ca	20	Calcium	A	PIXE	ng/m^3	Soil Elements
Ti	22	Titanium	A	PIXE	ng/m^3	Soil Elements
V	23	Vanadium	A	PIXE	ng/m^3	Metallic Tracer
Mn	25	Manganese	A	PIXE	ng/m^3	Soil Elements
Fe	26	Iron	A	XRF	ng/m^3	Soil Elements
Co	27	Cobalt	A	XRF	ng/m^3	Multiple
Ni	28	Nickel	A	XRF	ng/m^3	Metallic Tracer
Cu	29	Copper	A	XRF	ng/m^3	Metallic Tracer
Zn	30	Zinc	A	XRF	ng/m^3	Metallic Tracer
As	33	Arsenic	A	XRF	ng/m^3	Metallic Tracer
Se	34	Selenium	A	XRF	ng/m^3	Metallic Tracer
Br	35	Bromine	A	XRF	ng/m^3	Metallic Tracer
Pb	82	Lead	A	XRF	ng/m^3	Metallic Tracer
NO_3^-	N/A	Nitrate Ion	B	IC	ng/m^3	Major Ion
NO_2^-	N/A	Nitrite Ion	B	IC	ng/m^3	Major Ion
$SO_4^=$	N/A	Sulfate Ion	B	IC	ng/m^3	Major Ion
Cl^-	N/A	Chloride Ion	B	IC	ng/m^3	Marine
OC1	6	Low Temperature Organic Carbon	C	TOR	ng/m^3	Organic Carbon
OC2	6	High Temperature Organic Carbon	C	TOR	ng/m^3	Organic Carbon
OC3	6	High Temperature Organic Carbon	C	TOR	ng/m^3	Organic Carbon
OC4	6	High Temperature Organic Carbon	C	TOR	ng/m^3	Organic Carbon
EC1	6	Low Temperature Elemental Carbon	C	TOR	ng/m^3	Elemental Carbon
EC2	6	High Temperature Elemental Carbon	C	TOR	ng/m^3	Elemental Carbon
EC3	6	High Temperature Elemental Carbon	C	TOR	ng/m^3	Elemental Carbon
PM_{10}	N/A	PM_{10} Mass	D	Gravimetric	ng/m^3	PM_{10} Mass

Note: For consistency across all parameters, the IMPROVE data for $PM_{2.5}$ Fine Mass and PM_{10} Mass total mass is generally reported in ng/m^3. Conversion to $\mu g/m^3$ is accomplished by multiplying by 1000.

Table 3-4. Commonly Reported Composite Variables

COMPOSITE VARIABLES FOR FINE PARTICLES (Brackets [ ] indicate the mass concentration of aerosol species or elements)			
Abbreviation	Component	Module	Composite Equation
KNON	Nonsoil Potassium	A	[K] - 0.6[Fe]; a qualitative smoke tracer
NHSO	Ammonium Sulfate $[(NH_4)_2SO_4]$	A	4.125[S]; a standard form of sulfate
SOIL	Soil (fine soil)	A	2.20[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] + 1.94[Ti]
OMH	Organic Mass by Hydrogen (assumes all sulfur is ammonium sulfate and there is no hydrogen from nitrate)	A	13.75([H] - [S]/4)
NHNO	Ammonium Nitrate $[(NH_4)NO_3]$	B	$1.29[NO_3^-]$; a standard form of nitrate
OC	Total Organic Carbon	C	[OC1] + [OC2] + [OC3] + [OC4] + [OP]
OMC	Organic Mass by Carbon	C	1.4[OC]
LAC	Light Absorbing Carbon	C	[EC1] + [EC2] + [EC3] - [OP]
TC	Total Carbon	C	[OC1] + [OC2] + [OC3] + [OC4] + [EC1] + [EC2] + [EC3]
RCMC	Reconstructed without Nitrate	A & C	[NHSO] + [SOIL] + [OMC] + [LAC] + 1.4[KNON] + 2.5[Na]
CM	Coarse Mass	A & D	PM_{10} - $PM_{2.5}$
RCFM	Reconstructed Fine Mass with Nitrate	A to C	[NHSO] + [NHNO] + [LAC] + [OMC] + [SOIL]

3.7 DATA REPORTING AND ARCHIVE

3.7.1 Data Reporting

Aerosol data reports are prepared quarterly and annually. A separate data report is prepared for each instrument type; aerosol data reports contain only IMPROVE sampler data. Reporting consists of various text discussions and graphics presentations concerning the instrumentation and collected data. Specific contents of the reports are defined by the contracting agency.

Quarterly reports are normally completed within three months after the end of a monitoring season. Standard meteorological monitoring seasons are defined as:

Spring	(March, April, and May)
Summer	(June, July, and August)
Fall	(September, October, and November)
Winter	(December, January, and February)

Annual data reports are provided for each year, beginning with samples collected in March. The annual reports should contain the following major sections:

- Introduction
- Data Collection and Reduction
- Site Configuration
- Seasonal and Annual Data Summaries
- Summary
- References

The introduction should contain a conceptual overview of the purpose of the monitoring program and a description of the monitoring network(s). The data collection and reduction section should include data collection methods, data file review, data validation, application of validity codes, processing through various validation levels and discussion of file formats, and identification of meteorological and optical interferences that may affect the calculation of reconstructed b_{ext} from IMPROVE sampling measurements.

The site configuration section should contain a brief discussion of instrumentation at each aerosol monitoring site, basic principles of operation, measurement principles, and data collection specifications, including:

- A map depicting the location of all monitoring network sites.

- A Monitoring History Summary Table, listing for each monitoring site the name, type of instrumentation, and period of operation for each instrument type.

- A Site Specifications Summary Table, listing for each monitoring site the site name, abbreviation, latitude, longitude, and elevation of the IMPROVE sampler, the weekly sampling schedule, and the operating period during the season.

Data summaries are prepared for each site that operated during the reporting period. Summaries should include concentrations and distributions of major and trace elements as well as fine mass and its components, including determined composite variables. An example Seasonal Aerosol Data Summary is presented as Figure 3-4. Sample recovery rates which describe the percent of possible samples validated for each reported network site, by year, are reported as required.

A summary section that provides a synopsis of the aerosol monitoring network, including any changes in operation or analysis techniques and a general conclusion of the monitoring period in review, is included in the reports. A reference section should include technical references (documents cited in the report), and related reports and publications (including all prior reports pertaining to the monitoring program).

3.7.2 Data Archive

The digital tracking/analysis database is archived on a monthly basis. All raw and processed data for a given season, constants, calibration, and data processing files are archived on a seasonal basis after data have been finalized and reported. All data are archived in ASCII format. Files are stored in their original formats (Level-1, Level-2) on magnetic tape and on CD-ROM. At least two copies of each media are created; one copy is stored at the data processing location and the other off-site.

Filter media, supporting documentation, and reports are archived on a continual basis. Archives include site specifications, monitoring timelines, data coordinator/site operator correspondence, site operator log sheets, trip reports, summary plots, instrument calibration and maintenance logs, and file audit reports. All validated data are available in an FTP Internet site maintained by the central laboratory. For instructions on obtaining data, e-mail <wakabayashi@crocker.ucdavis.edu>. Supplemental quality assurance information is also on the site. The standard file format currently used for IMPROVE protocol aerosol data are shown in Figure 3-5.

SMOKY MOUNTAINS N.P. **MAR 01,1998 - MAY 31,1998**

26-OCT-98 **IMPROVE PARTICULATE NETWORK**

Major elements, tracer elements and SO_2

24-hour concentrations in nanograms/cubic meter

					Soil elements						Smoke
DATE	HOUR	H	S	SO2	SI	K	CA	TI	MN	FE	KNON
03/04/98	0000	513.6	1286.8	997	70.3	34.5	22.7	*2.2	2.0	21.2	21.8
03/07/98	0000	226.3	401.7	459	29.9	34.3	3.3	*1.4	*0.8	3.1	32.5
03/11/98	0000	293.7	774.1	3204	55.4	33.5	22.1	6.0	2.6	23.0	19.7
03/14/98	0000	581.9	1173.0	4077	96.5	54.0	37.7	*1.8	2.2	35.9	32.5
03/18/98	0000	217.7	400.3	736	37.1	29.1	13.4	*2.2	*1.4	5.9	25.6
03/21/98	0000	184.7	420.7	366	24.7	11.5	4.5	*2.1	2.1	2.3	10.1
03/25/98	0000	485.7	1295.3	2043	66.5	49.8	22.1	3.8	*1.5	21.7	36.8
03/28/98	0000	536.3	1468.9	2034	152.5	89.9	60.6	6.3	2.3	41.6	65.0
04/01/98	0000	194.6	312.9	461	288.0	64.6	47.5	8.2	*1.3	72.7	21.0
04/04/98	0000	537.9	1598.2	483	157.2	41.6	24.1	6.5	*1.1	47.9	12.9
04/08/98	0000	969.3	2801.3	1691	287.6	123.8	87.9	9.0	*1.6	73.1	80.0
04/11/98	0000	300.4	690.2	2414	414.1	117.9	142.2	15.5	4.2	118.5	46.8
04/15/98	0000	791.5	2455.3	1205	183.4	137.0	63.5	5.3	*1.6	47.1	108.8
04/18/98	0000	483.9	1198.8	344	80.0	64.9	20.6	7.5	*1.5	19.3	53.3
04/22/98	0000	262.6	674.8	433	37.7	28.5	6.1	*2.0	*1.2	6.1	24.9
04/25/98	0000	1004.4	2978.0	2647	168.1	55.6	51.5	*3.2	*2.0	50.0	25.6
04/29/98	0000	615.7	1581.6	2086	161.5	103.6	55.8	10.3	6.6	51.8	72.5
05/02/98	0000	522.7	1411.3	591	178.0	56.9	46.3	7.1	*1.4	56.3	23.2
05/06/98	0000	897.0	2610.5	5675	184.4	60.7	46.1	10.5	4.1	49.4	31.1
05/09/98	0000	1227.3	3956.4	2134	105.1	41.3	23.2	6.6	3.0	35.0	20.2
05/13/98	0000	1298.9	3238.5	4571	216.0	96.9	54.8	9.5	*2.1	61.9	59.8
05/16/98	0000	2270.6	4455.3	7190	338.8	254.8	84.0	17.2	7.2	109.2	189.3
05/20/98	0000	1855.4	3924.2	3933	405.2	131.4	114.7	12.1	6.7	113.5	63.4
05/23/98	0000	1601.4	3685.9	2166	281.9	170.4	65.5	9.9	*2.4	79.7	122.6
05/27/98	0000	1038.8	2088.7	1262	162.2	152.3	48.9	3.7	*1.8	45.3	125.1
05/30/98	0000	1057.7	2595.8	1126	151.0	93.1	32.4	*2.4	*1.4	41.4	68.2

		Marine		Metallic tracers							.
DATE	HOUR	NA	CL-	V	NI	CU	ZN	AS	SE	BR	PB
03/04/98	0000	*19.28	?-13.2	*1.86	0.25	0.68	7.27	*0.07	0.72	2.48	2.82
03/07/98	0000	*11.13	?-10.4	1.80	*0.12	0.35	2.44	*0.06	0.36	1.30	1.91
03/11/98	0000	*12.81	?4.0	?1.63	*0.13	0.66	6.47	*0.07	1.10	2.08	2.33
03/14/98	0000	*16.62	?-12.5	*1.49	*0.17	2.00	12.67	0.45	1.12	4.98	2.89
03/18/98	0000	33.85	?-6.7	5.23	*0.14	*0.17	1.90	?0.16	*0.09	1.79	1.07
03/21/98	0000	*14.27	?-4.6	*1.76	*0.14	0.23	1.83	*0.07	*0.08	0.54	0.78
03/25/98	0000	*19.64	?-11.9	*2.05	*0.14	0.87	6.48	0.91	1.17	3.36	2.61
03/28/98	0000	576.15	?1.7	*2.08	*0.14	0.31	3.64	0.43	0.84	8.23	0.97
04/01/98	0000	*16.76	?-78.2	*1.88	*0.15	0.30	2.14	0.27	*0.08	1.55	0.65
04/04/98	0000	*19.60	?-2.5	?1.77	*0.13	0.58	6.54	0.59	1.16	1.94	2.26
04/08/98	0000	203.84		6.10	*0.18	1.93	5.57	0.68	1.03	4.73	1.63
04/11/98	0000	*20.84	?-4.1	*1.89	*0.19	1.07	8.86	1.08	1.17	3.23	3.35
04/15/98	0000	271.13		*2.32	*0.15	0.53	5.74	0.96	1.09	7.83	1.20
04/18/98	0000	*21.47	?-7.3	2.62	*0.14	0.69	4.60	0.34	0.80	2.46	2.11
04/22/98	0000	*15.53	?-5.3	2.99	0.18	0.77	2.20	0.42	1.18	1.03	0.78
04/25/98	0000	84.30		*2.77	*0.18	0.87	11.28	1.16	1.13	3.31	3.34
04/29/98	0000	129.38	?-3.8	*2.15	*0.16	1.21	12.06	1.46	0.93	4.60	4.94
05/02/98	0000	*22.47	?-6.6	*1.99	*0.15	0.52	6.38	0.45	0.86	2.18	2.45
05/06/98	0000	*30.35		*2.03	*0.17	2.76	8.21	0.60	1.41	2.42	3.22
05/09/98	0000	*37.99		*2.34	*0.15	1.27	8.76	0.54	2.16	1.75	2.89
05/13/98	0000	116.09		*2.99	*0.19	1.39	10.42	0.89	1.50	3.37	3.12
05/16/98	0000	*58.33	24.0	*3.57	*0.23	1.08	17.40	*0.11	3.00	7.39	5.59
05/20/98	0000	*54.87		*3.28	*0.20	1.17	14.06	0.86	2.19	5.41	2.34
05/23/98	0000	100.25	31.7	5.80	0.64	0.74	8.67	0.96	1.64	4.63	1.96
05/27/98	0000	*31.10	20.0	*2.53	*0.16	1.89	10.65	0.42	1.18	4.30	1.96
05/30/98	0000	*29.18	?10.5	5.11	*0.14	0.86	5.97	0.74	1.32	4.08	1.63

*=minimum detectable limit ?= < (2 x uncertainty) #= MASS>PM10; diff<uncertainty

Figure 3-4a. Quarterly Data Report: Site Specific Elements

GREAT SMOKY MOUNTAINS N.P. **MAR 01,1998 - MAY 31,1998**

26-OCT-98

IMPROVE PARTICULATE NETWORK

Fine mass and its major components.
24-hour concentrations in micrograms/cubic meter

DATE	HOUR	PM10	MASS	RCMC	RCMA	NHSO	NHNO	SOIL	OMCN	OMH	LACN
03/04/98	0000	9.79	8.19	8.12	9.02	5.31	0.56	0.27	2.14	2.64	0.34
03/07/98	0000	8.12	6.13	4.04	4.18	1.66	0.06	0.11	1.90	1.73	0.32
03/11/98	0000	9.24	5.16	4.87	5.40	3.19	0.32	0.31	1.02	1.38	0.31
03/14/98	0000	#11.41	#11.49	9.98	10.23	4.84	0.59	0.40	4.14	3.97	0.55
03/18/98	0000	9.07	3.24	3.45	4.04	1.65	0.11	0.14	1.31	1.62	0.23
03/21/98	0000		3.14	2.67	3.17	1.74	0.09	0.08	0.70	1.09	0.12
03/25/98	0000	11.70	10.30	8.92	9.22	5.34	0.29	0.34	2.66	2.23	0.49
03/28/98	0000	18.67	12.03	11.74	11.69	6.06	0.72	0.76	3.03	2.32	0.36
04/01/98	0000	6.61	4.20	4.61	4.43	1.29	?-0.03	1.30	1.79	1.60	0.18
04/04/98	0000	11.99	8.82	9.31	10.05	6.59	0.25	0.72	1.61	1.90	0.35
04/08/98	0000	22.43	16.25	17.43	18.55	11.56		1.30	3.50	3.70	0.46
04/11/98	0000	14.27	7.45	7.35	7.39	2.85	0.92	2.05	1.94	1.76	0.42
04/15/98	0000	21.20	16.49	15.63	15.40	10.13		0.69	3.49	2.44	0.49
04/18/98	0000	15.20	9.75	8.29	8.89	4.95	0.23	0.30	2.47	2.53	0.47
04/22/98	0000	10.56	4.23	4.28	4.66	2.78	0.14	0.13	1.08	1.29	0.24
04/25/98	0000	20.67	17.32	16.55	18.38	12.28		0.75	2.77	3.57	0.51
04/29/98	0000	22.90	14.66	11.65	12.72	6.52	0.36	0.87	3.03	3.03	0.79
05/02/98	0000	11.83	11.71	8.86	9.93	5.82	0.38	0.86	1.81	2.34	0.31
05/06/98	0000	19.09	15.34	15.14	16.44	10.77		0.87	2.87	3.36	0.55
05/09/98	0000	29.64	23.09	19.92	21.41	16.32		0.41	2.57	3.28	0.55
05/13/98	0000	28.32	21.81	20.33	22.78	13.36		0.81	5.08	6.73	0.70
05/16/98	0000	56.61	44.96	35.31	39.86	18.38	0.83	1.59	13.71	15.91	1.30
05/20/98	0000	41.57	31.10	27.35	32.53	16.19		1.90	8.21	12.02	0.90
05/23/98	0000	41.11	29.97	25.92	28.16	15.20	0.38	1.24	8.33	9.35	0.72
05/27/98	0000	22.44	18.25	15.66	17.72	8.62	0.45	0.61	5.64	7.10	0.58
05/30/98	0000	30.18	26.19	16.60	18.31	10.71	0.18	0.54	4.60	5.62	0.62

Fine mass and its major components.
24-hour concentrations in micrograms/cubic meter and percent of fine mass.

DATE	HOUR	MASS	RCMC%	RCMA%	NHSO%	NHNO%	SOIL%	OMCN%	OMH%	LACN%
03/04/98	0000	8.19	99%	110%	65%	7%	3%	26%	32%	4%
03/07/98	0000	6.13	66%	68%	27%	1%	2%	31%	28%	5%
03/11/98	0000	5.16	94%	105%	62%	6%	6%	20%	27%	6%
03/14/98	0000	#11.49	87%	89%	42%	5%	3%	36%	35%	5%
03/18/98	0000	3.24	106%	125%	51%	4%	4%	40%	50%	7%
03/21/98	0000	3.14	85%	101%	55%	3%	3%	22%	35%	4%
03/25/98	0000	10.30	87%	90%	52%	3%	3%	26%	22%	5%
03/28/98	0000	12.03	98%	97%	50%	6%	6%	25%	19%	3%
04/01/98	0000	4.20	110%	105%	31%	? -1%	31%	43%	38%	4%
04/04/98	0000	8.82	106%	114%	75%	3%	8%	18%	22%	4%
04/08/98	0000	16.25	107%	114%	71%		8%	22%	23%	3%
04/11/98	0000	7.45	99%	99%	38%	12%	27%	26%	24%	6%
04/15/98	0000	16.49	95%	93%	61%		4%	21%	15%	3%
04/18/98	0000	9.75	85%	91%	51%	2%	3%	25%	26%	5%
04/22/98	0000	4.23	101%	110%	66%	3%	3%	26%	31%	6%
04/25/98	0000	17.32	96%	106%	71%		4%	16%	21%	3%
04/29/98	0000	14.66	79%	87%	44%	2%	6%	21%	21%	5%
05/02/98	0000	11.71	76%	85%	50%	3%	7%	15%	20%	3%
05/06/98	0000	15.34	99%	107%	70%		6%	19%	22%	4%
05/09/98	0000	23.09	86%	93%	71%		2%	11%	14%	2%
05/13/98	0000	21.81	93%	104%	61%		4%	23%	31%	3%
05/16/98	0000	44.96	79%	89%	41%	2%	4%	30%	35%	3%
05/20/98	0000	31.10	88%	105%	52%		6%	26%	39%	3%
05/23/98	0000	29.97	86%	94%	51%	1%	4%	28%	31%	2%
05/27/98	0000	18.25	86%	97%	47%	2%	3%	31%	39%	3%
05/30/98	0000	26.19	63%	70%	41%	1%	2%	18%	21%	2%

*=minimum detectable limit ?= < (2 x uncertainty) #= MASS>PM10; diff<uncertainty

Figure 3-4b. Quarterly Data Report: Site Specific Mass and Major Components

GREAT SMOKY MOUNTAINS N.P. **MAR 01,1998 - MAY 31,1998**

26-OCT-98 **IMPROVE PARTICULATE NETWORK**

Distribution of Concentrations in nanograms/cubic meter

	Cases	% of cases Significant	Arithmetic Mean	Minimum	Median	Maximum	Maximum occurs
H	26	100%	768.07	184.75	559.91	2270.65	05/16/98
S	26	100%	1903.02	312.88	1525.29	4455.30	05/16/98
SO2	26	100%	2089.53	344.10	1862.80	7190.30	05/16/98
SI	26	100%	166.65	24.68	159.32	414.12	04/11/98
K	26	100%	82.01	11.50	62.69	254.83	05/16/98
CA	26	100%	46.21	3.35	46.20	142.22	04/11/98
TI	26	69%	6.62	1.39	6.43	17.20	05/16/98
MN	26	42%	2.53?	0.85	1.95?	7.16	05/16/98
FE	26	100%	47.42	2.33	46.21	118.47	04/11/98
KNON	26	100%	53.56	10.10	34.66	189.32	05/16/98
NA	26	30%	75.66?	11.13	29.76?	576.15	03/28/98
CL-	19	15%	-3.96?	-78.20	-5.30?	31.70	05/23/98
V	26	26%	2.77?	1.49	2.24?	6.10	04/08/98
NI	26	11%	0.18?	0.12	0.16?	0.64	05/23/98
CU	26	96%	0.96	0.17	0.81	2.76	05/06/98
ZN	26	100%	7.39	1.83	6.51	17.40	05/16/98
AS	26	76%	0.57	0.06	0.50	1.46	04/29/98
SE	26	88%	1.13	0.08	1.12	3.00	05/16/98
BR	26	100%	3.50	0.54	3.27	8.23	03/28/98
PB	26	100%	2.34	0.65	2.30	5.59	05/16/98

Distribution of Concentrations in micrograms/cubic meter

	Cases	% of cases Significant	Arithmetic Mean	Minimum	Median	Maximum	Maximum occurs
PM10	25	100%	20.18	6.61	15.20	56.61	05/16/98
MASS	26	100%	14.67	3.14	11.87	44.96	05/16/98
RCMC	26	100%	12.85	2.67	10.81	35.31	05/16/98
RCMA	26	100%	14.02	3.17	10.96	39.86	05/16/98
NHSO	26	100%	7.85	1.29	6.29	18.38	05/16/98
NHNO	19	94%	0.36	-0.03	0.29	0.92	04/11/98
SOIL	26	100%	0.74	0.08	0.71	2.05	04/11/98
OMCN	26	100%	3.52	0.70	2.72	13.71	05/16/98
OMH	26	100%	4.02	1.09	2.59	15.91	05/16/98
LACN	26	100%	0.49	0.12	0.48	1.30	05/16/98

Distribution of Concentrations in micrograms/cubic meter and percent of fine mass

	Cases	% of cases Significant	Arithmetic Mean	Minimum	Median	Maximum	Maximum occurs
MASS	26	100%	14.67	3.14	11.87	44.96	05/16/98
RCMC%	26	100%	91%	63%	91%	110%	04/01/98
RCMA%	26	100%	98%	68%	98%	125%	03/18/98
NHSO%	26	100%	54%	27%	51%	75%	04/04/98
NHNO%	26	96%	3%	0%	2%	12%	04/11/98
SOIL%	26	100%	6%	2%	4%	31%	04/01/98
OMCN%	26	100%	25%	11%	25%	43%	04/01/98
OMH%	26	100%	28%	14%	26%	50%	03/18/98
LACN%	26	100%	4%	2%	4%	7%	03/18/98

A significant value is greater than 2 times the uncertainty of that value.

?=the percentage of significant values is less than 65%

Figure 3-4c. Quarterly Data Report: Site Specific Means and Distributions

```
SITE  SAMDAT JULIAN STRTIM    ETA  FLOWA     ETB  FLOWB     ETC  FLOWC     ETD  FLOWD     MF       MF_ERR
ACAD1 03 01 1997  59 0000  -99.00  -99.0  -99.00  -99.0  -99.00  -99.0  -99.00  -99.0     -99.00    -99.00…
ACAD1 03 05 1997  63 0000   24.00   22.0   24.00   22.0   24.00   22.0   24.00   22.0   6281.60    245.80…
ACAD1 03 08 1997  66 0000   24.00   22.2   24.00   22.2   24.00   22.2   24.00   22.2   4817.30    213.00…
ACAD1 03 12 1997  70 0000   24.00   22.0   24.00   22.0   24.00   22.0   24.00   22.0   5618.70    230.90…
ACAD1 03 15 1997  73 0000   24.00   22.0   24.00   22.0   24.00   22.0   24.00   22.0   2746.20    178.00…

        MF_ERR  MF_MDL MF_STAT  MT       MT_ERR  MT_MDL MT_STA
      … -99.00    -99.00 NA    -99.00    -99.00    -99.00 NA …
      … 245.80    315.70 NM  16455.30    528.50    377.40 NM …
      … 213.00    312.80 NM   6558.60    275.50    385.80 NM …
      … 230.90    315.70 NM  10924.30    385.50    406.10 NM …
      … 178.00    315.70 NM   8373.00    320.10    396.80 NM …
```

A value of -99.00 indicates an invalid value.

All species amounts, errors, and minimum detectable limits are in nanograms per cubic meter.

Start times are in military hours.
Sample durations are in decimal hours.
Flow rate is in liters per minute (ambient).

SPECIES STATUS CODES:

NM	=	Normal
QU	=	Questionable; Undetermined
QD	=	Questionable Data
AA	=	Organic Artifact Corrected
AP	=	Possible Organic Artifact (No correction performed)
NA	=	No Analysis Available for this Species

NOTE: From 9/90 through 2/92 we received some Teflon filters with an organic contamination. This artifact influenced only the Hydrogen and Fine Mass measurements in less than 7% of the samples (marked AA). All other measurements of Hydrogen and Fine Mass during this period are marked with a status AP.

SPECIES CODES:

MF	=	Fine Mass (UCD)
MT	=	PM-10 Mass (UCD)
H	=	Hydrogen (UCD)
BSO4	=	Sulfate on Nylon (RTI, GGC)
NO2-	=	Nitrite (RTI, GGC)
NO3-	=	Nitrate (RTI, GGC)
CL-	=	Chloride (RTI, GGC)
SO2	=	Sulfur Dioxide (DRI)
O1	=	Organic carbon, ≤120 °C (DRI)
O2	=	Organic carbon, 120 °C - 250 °C (DRI)
O3	=	Organic carbon, 250 °C - 450 °C (DRI)
O4	=	Organic carbon, 450 °C - 550 °C (DRI)
OP	=	Pyrolized organic, 550 °C, 2% O2, reflectance ≤ initial (DRI)
E1	=	Elemental carbon + pyrolized organic, 550 °C, 2% O2 (DRI)
E2	=	Elemental carbon, 550 °C - 700 °C, 2% O2 (DRI)
E3	=	Elemental carbon, 700 °C - 800 °C, 2% O2 (DRI)

All other species are elemental values from UCD Elemental Analysis.

Figure 3-5. Standard ASCII File Format IMPROVE Protocol Aerosol Data.

3.8 SUPPLEMENTAL ANALYSIS INCLUDING COMPOSITE VARIABLES

At most continental sites, fine aerosol species are classified into five major types: sulfates, nitrates, organic mass, elemental and light-absorbing carbon, and soil. Methods for apportionment of measured mass to the various aerosol species are detailed in Malm et al. (1994). Major aerosol types are composites of the elements and ions measured by IMPROVE samplers. Concentrations or masses are calculated from the masses of the measured elements and ions according to their presumed or probable composition as summarized below and in Table 3-3 and Table 3-4. The convention used to denote the mass concentration of a measured element, ion, or species is enclosing its symbol in brackets ([ ]).

Sulfates

In the West, most sulfur is in the form of ammonium sulfate. In the East, or other environments where ammonia can be limited, acidic species, such as ammonium bisulfate and sulfuric acid, are common. However, for a first approximation, all elemental sulfur and sulfate ion is interpreted as being in the form of ammonium sulfate, and ammonium sulfate concentrations are estimated by multiplying elemental sulfur concentrations by 4.125, or sulfate ion concentration by 1.375. For simplicity, ammonium sulfate is referred to as sulfate.

At sites where NH_4+, NO_3-, and SO_4= are measured, but not H+, it is possible to calculate the dry weight of sulfate, even is it not fully neutralized. The assumption is that there is an ionic balance between H+,NH_4+, NO_3-, and SO_4=. The concentration for actual sulfate is given by:

$$[\text{sulfate}] = 1.021\ [\text{SO4=}] + 0.944\ [\text{NH4+}] - 0.274\ [\text{NO3-}] \qquad (3\text{-}3)$$

Ammonium ion measurements have been made at three IMPROVE sites in the Appalachian mountains, Shenandoah National Park, Dolly Sods Wilderness, and Great Smoky Mountains National Park. These sites have the highest sulfur concentrations in the IMPROVE network and probably have the most acidic aerosol in the network. For one year of measurements starting in June 1997 at these three sites, the actual sulfate calculated by Equation 3-3 averages 10% less than the calculation assuming ammonium sulfate. For the average site, the ammonium sulfate assumption will probably be only slightly larger than the actual sulfate.

Nitrates

Particulate nitrate is assumed to be present as fully neutralized ammonium nitrate (NH_4NO_3). (HNO_3 is a gas.) The concentration of ammonium nitrate is 1.29 times the concentration of nitrate ion and is referred to as nitrate.

Organic Mass

Organic mass (by carbon) concentrations (organics, OMC) is estimated by:

$$[\text{OMC}] = 1.4\ [\text{OC}] \qquad (3\text{-}4)$$

where OC is the total organic carbon defined by equation 3-1. The factor 1.4 assumes that organic mass contains a constant 71% carbon by weight (Watson et al., 1988). The actual factor depends on the compounds present. Organic carbon from industrial emissions may well have a different factor than organic carbon from biomass combustion.

Organic mass can also be estimated from hydrogen by:

$$[OMH] = 13.75\ ([H] - [S] / 4) \qquad (3\text{-}5)$$

assuming all sulfur is ammonium sulfate and there is no hydrogen from nitrate. The factor of 13.75 gives excellent agreement when the organic mass is primarily from wood smoke. At sites in the eastern United States, a factor that is 20% lower (11) gives a better fit with organic carbon (assuming a carbon factor of 1.4).

A more accurate calculation that accounts for acidity is possible if NH_4+, NO_3-, and SO_4= are all measured. However, since nitrate volatilizes from Teflon during sampling, the equation cannot account for the hydrogen in $(NH_4)NO_3$.

Elemental Carbon/Light Absorbing Carbon

The total elemental carbon is given by Equation 3-2.

Soil

Soil mass concentration is estimated by summing the elements predominantly associated with soil, plus oxygen for the normal oxides (Al_2O_3, SiO_2, CaO, K_2O, FeO, Fe_2O_3, TiO_2), plus a correction for other compounds such as MgO, Na_2O, water, and carbonate. There are two weaknesses in this methodology. (1) Some of these elements, such as Fe, may be associated with industrial emissions rather than suspended soil. This problem is more important in urban sampling than in remote sampling. It can be important in some remote sites, if there are nearby iron smelters. (2) For both urban and rural sites, K may be associated with smoke as well as soil. The particle diameters of this smoke K is always must less than 2.5 µm. One possible approach is to estimate the fraction of K as smoke and subtract this from the soil estimate. In the nomenclature of the IMPROVE network, this nonsoil potassium is called KNON. The approach is to determine the K to Fe ratio for typical soils and use this factor in calculating the $PM_{2.5}$ soil concentration. Based on measurements made at mostly western sites between 1979 and 1986 with the stacked filter sampler (which collects particles greater than 2.5 µm on a separate filter), the K/Fe ratio for coarse particles averages 0.6. A final equation for fine soil is:

$$[SOIL] = 2.2[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe]+ 1.94[Ti] \qquad (3\text{-}6)$$

The equation for nonsoil potassium is:

$$[KNON] = [K] - 0.6 * [Fe] \qquad (3\text{-}7)$$

Components of these factors were confirmed in comparisons of local resuspended soils and ambient aerosols in the western United States (Cahill, et al., 1981; Pitchford et al., 1981).

Na (Marine)

Sodium is an important factor in the $PM_{2.5}$ mass only at marine sites. If this is assumed to be NaCl, the total mass is 2.5 times the Na concentration. An alternative calculation would be to use 1.6 times the Cl elemental or ionic concentration. In a highly reactive atmosphere some of the Cl may be lost before reaching the sampler or during sampling.

Reconstructed Fine Mass

The sum of the above seven composite variables should provide a reasonable estimate of the ambient dry $PM_{2.5}$ mass concentration in the atmosphere. The inclusion of nitrate in the calculation is optional. If the concern is the reconstructed dry mass concentration in the atmosphere, then nitrate should be included. However, if the concern is comparison with the gravimetric mass on the Teflon filter, then it is recommended excluding nitrate. The reason is that a variable fraction of nitrate will volatilize from the Teflon filters during sampling. If all of the water on the particles were to be removed before gravimetric analysis, the gravimetric mass would be between the two calculations. The equations for reconstructed without nitrate (RCMC) and with nitrate (RCFM) are:

$$[RCMC] = 4.125\ [S] + 1.4\ [OC] + [EC] + [SOIL] + 1.4\ [KNON] + 2.5\ [Na] \qquad (3\text{-}8)$$

$$[RCFM] = [RCMC] + 1.29\ [NO3\text{-}] \qquad (3\text{-}9)$$

Note that the sum of [SOIL] and 1.4 [KNON] includes the measured K as K_2O independent of the validity of the assumed K/Fe ratio. At most sites in the IMPROVE network, nitrate is a small component of the fine mass. Therefore, the RCFM is only slightly larger than RCMC.

Coarse Mass

Coarse mass (CM) is estimated gravimetrically by subtracting fine mass ($PM_{2.5}$) concentration from total aerosol mass (PM_{10}) concentration:

$$[CM] = [PM_{10}] - [PM_{2.5}] \qquad (3\text{-}10)$$

In the IMPROVE Program, additional chemical analysis is not carried out on the coarse fraction. However, it is known that in rural or remote areas of the country the primary constituent of coarse mass is naturally occurring wind-blown dust along the some vegetative material (Noll, 1991).

3.9 QUALITY ASSURANCE

Quality assurance of aerosol monitoring data consists of comparing operational flow rates during annual field audits and Level-1 validation, and determining the concentration and precision of measured variables during Level-2 validation.

3.9.1 Instrument Audits

Quality assurance field audits are performed annually by field specialists and include the determination of system flow rate measurement error and verification of the performance of the aerosol sampler and routine filter sampling schedules.

Flow Rate Audit Procedures

All flow rates and air volumes in IMPROVE are based on local conditions and are not corrected for standard temperature and pressure. At a flow rate of 22.8 lpm, the IMPROVE cyclone has a 50% efficiency for 2.5 µm aerodynamic diameter particles. At a flow rate of 25 lpm (+10%) the cut point is 1.74 µm. At a flow rate of 20.5 lpm (-10%) the cut point is 3.26 µm.

Operational flow rates are calculated from the sampler's pressure transducers, as well as the temperature of the air and the elevation of the site. The $PM_{2.5}$ modules have are two transducers, one measuring the pressure drop across the cyclone and the other measuring the pressure in front of the critical orifice. The PM_{10} module has only the transducer in front of the critical orifice. Each transducer has a specific calibration equation determined by the audit procedures. Audit flow rates are determined by inserting a calibrated orifice in the inlet stack and measuring the pressure drop using an audit transducer. The audit device is calibrated at the central laboratory using an NIST-traceable spirometer.

Flow audits may be conducted by personnel from the central laboratory or by the site operator. This is normally performed during one of the non-sampling days. Equipment needed for a flow audit includes:

- a removable magnetic card with appropriate programs and site-specific information,
- four filter cartridges, with each cartridge having four filters with different pressure drops,
- one calibrated audit device for $PM_{2.5}$ modules and one for the PM_{10} module,
- a log sheet and an instruction sheet

The initial step is to remove all existing filter cartridges and replace the normal removable magnetic card with the audit magnetic card. The appropriate cartridge is installed in the module and the pressure values of both system transducers for each of the four filters are read. These are recorded on the magnetic card and on the log sheet. The audit device is inserted in the inlet and the pressure values for the audit transducer is similarly recorded. The program then calculates the calibration equations, checks for consistency , and compares with the previous equations. If the nominal flow rate differs from the desired nominal flow rate, the critical orifice needs adjustment. The operator will make the necessary adjustment, with assistance by the processor. The flow audit will then be repeated for this module. The entire process will be repeated for the remaining modules.

The normal filter cartridges will then be returned to the sampler and the standard magnetic card installed. The program will be instructed to use the revised calibration equations. After audits performed by the site operator, the equipment will be returned to the central laboratory. When received by the central laboratory, the calibration of the audit device using the spirometer will be repeated.

Annual calibration and flow rate audit procedures are described further in the–Crocker Nuclear Laboratory SOP 176, *Calibration, Programming, and Site Documentation* and TI201A *IMPROVE Aerosol Sampler Operations Manual*.

3.9.2 Concentration and Precision of Measured Variables

The self consistency and overall quality of the aerosol measurements are assured by redundancy and intercomparisons between independently measured species. A detailed description of validation and quality assurance procedures are available (Malm et al., 1994; Sisler et al., 1993; and Eldred et al., 1988). In the most general sense, validation is a matter of comparing chemically-related species that have been measured by different module filters. Fortunately, the design of the IMPROVE sampler allows for redundancy between certain Module A measurements and Module B and C measurements of the ions and carbons enabling quality control checks (Sisler, et al., 1996). IMPROVE network quality assurance includes comparisons of the following:

- PIXE and XRF measurements
- Sulfur by PIXE on Teflon and Sulfate by Ion Chromatography on nylon
- Organic mass from carbon (OMC) and organic mass from hydrogen (OMH)
- Light-absorbing carbon (LAC) and b_{abs}
- Fine mass with reconstructed mass (from Module A) and fine mass with reconstructed mass (from Module A plus C)

IMPROVE procedures for evaluating the precision of measured species follow.

The general equation for the concentration of a given variable is

$$c = \frac{A - B}{V} \qquad (3\text{-}11)$$

where A is the measured mass of the variable (i.e. chemical species), B is the artifact mass determined from field blanks or secondary filters, and V is the volume determined from the average flow rate and the sample duration. Artifact B may be produced by contamination in the filter material, in handling and analysis, and by adsorption of gas during collection. The artifact is negligible for all Teflon measurements. It is determined from designated field blanks for ions and from secondary filters for carbon.

Precision in each concentration is included in the database. Overall precision is a quadratic sum of four components of precision. These are:

1. Fractional volume precision, f_v, primarily from the flow rate measurement. A value of 3% is used based on third-party audits.

2. Fractional analytical precision associated with calibration or other factors, f_a. This is zero for gravimetric analysis. The values for all other methods are determined from replicate analyses. Most variables have a fractional analytical precision of around 4% so that the combined volume and analytical precision is around 5%.

   For the eight carbon fractions, the primary source of fractional uncertainty is the separation into temperature fractions. This may be associated with temperature regulation, but it may also be from inherent variability of the species involved. The fractional uncertainty of the sum of all carbon species is around 3% to 4%. The fractional uncertainty for the fractions range from 11% to 40%, averaging 22%. Thus for sums of fractions, such as total organics, the uncertainties are less than would be estimated from the individual fractions. This will be discussed in the section on carbon composites.

3. Constant mass per filter precision, σ_a, from either the analysis or artifact subtraction. These are determined from the standard deviations in the designated field blanks, secondary filters, or system control filters. For large concentrations, this is small compared to the fractional terms. This is zero for X-Ray Fluorescence (XRF), PIXE, and PESA.

4. Statistical precision based on the number of counts in the spectrum, σ_{stat}. This is used for XRF, PIXE, and PESA. For large concentrations, this is small compared to the fractional terms.

The equation for the total precision is:

$$[s(c)]^2 = [f_v c]^2 + [f_a c]^2 + \left[\frac{s_a}{V}\right] + \left[\frac{s_{stat}}{V}\right]^2 \qquad (3\text{-}12)$$

The relative precision depends on the concentrations. For large concentrations, only the fractional terms (1 and 2) are important so the relative precision is around 5%. For small concentrations, the constant analysis/artifact term (3) or the statistical term (4) is important. At the minimum detectable limits (mdl), the precision increases to 50%.

Table 3-5 separates the relative precisions of key measured variables into three groups. The relative precision is defined as the ratio of the mean precision from all sources divided by the mean concentration. Most variables are in the most precise group, 4% to 7%.

Table 3-5 Relative Precision of Key Measured Variables,
Ratio of Mean Precision Divided by Mean Concentration

Range	Before 6/1/92	After 6/1/92
4% to 7%	$PM_{2.5}$, PM_{10}, H, S, Si, K, Ca, Fe, Zn, $SO_4^=$, NO_3^-, SO_2	$PM_{2.5}$, PM_{10}, S, Si, K, Ca, Fe, Cu, Zn, $SO_4^=$, NO_3^-, SO_2
8% to 15%	Na, Al, Ti, Cu, Br, Pb	H, Na, Ti, Se, As, Br, Sr, Pb, O4, E1
>15%	V, Mn, Se, As, Sr, all carbon fractions	V, Mn, O1, O2, O3, OP, E2, E3

The average minimum detectable limits (mdl) are provided with each concentration in the database. A concentration is assumed to be statistically significant only if it is larger than the mdl. For ion chromatography and carbon, the mdl corresponds to twice the precision of the field blanks or secondary filters. For mass and absorption, the minimum detectable limit corresponds to twice the analytical precision determined by controls. For PIXE, XRF, and PESA, the minimum detectable limit is based on the background under the peaks in the spectrum and is calculated separately for each case. The assumption for all elements except arsenic is that there is no interference from other elements. Because the measurement for arsenic requires subtracting the value for lead, the mdl for arsenic depends on the lead concentration and is generally larger than the value estimated from the background. When calculating averages, if the value is below the minimum detectable limit, one-half of the minimum detectable limit is used as the concentration and the precision in the concentration. In all cases, the relative precisions are around 50% at the mdl.

The minimum detectable limits of trace elements heavier than iron changed in June 1992 with the addition of a high-sensitivity XRF systemThe minimum detection limits for iron through lead decreased by a factor of 10. The minimum detectable limits of standard network samples for elements measured by PIXE and XRF are given in Table 3-6. Arsenic is not included because the mdl depends on the lead concentration. Also important is the fraction of cases with statistically significant concentrations (above the mdl). This depends on the relationship between the mdl and the ambient concentrations. Table 3-7 separates these into four ranges. A significant change for aluminum occurred with samples beginning February 1993. Because of detector problems, aluminum, which is on the shoulder of the spike, was often not detected. Before this date, aluminum was observed on 65% of all samples; afterward it was found on almost every sample. Sodium, chlorine, and chloride ion were observed in significant amounts only at sites with marine influences.

Table 3-6 Minimum Detectable Limits of Elements in ng/m^3

Dates	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
before 5/92	8.70	2.90	1.80	1.40	1.30	1.20	1.30	0.83	0.64	0.57	0.50	0.41	0.39
after 6/92	13.00	4.80	3.00	2.20	1.90	1.90	2.00	1.20	0.90	0.81	0.69	0.57	0.52
	Fe	Ni	Cu	Zn	Ga	Se	Br	Rb	Sr	Zr	Pb		
before 5/92	0.34	0.24	0.24	0.21	0.20	0.22	0.25	0.37	0.42	0.65	0.57		
after 5/92	0.11	0.05	0.05	0.05	0.03	0.03	0.03	0.06	0.07	0.11	0.06		

Table 3-7. Fraction of Cases with Statistically Significant Concentrations

Range	Before 6/1/92	After 6/1/92
90% to 100%	$PM_{2.5}$, PM_{10}, H, S, Si, K, Ca, Ti, Fe, Zn, Br, $SO_4^=$, NO_3^-, SO_2, OP, E1	$PM_{2.5}$, PM_{10}, H, S, Si, K, Ca, Fe, Cu, Zn, Br, Pb, $SO_4^=$, NO_3^-, SO_2, O4, OP, E1
70% to 90%	Cu, Pb, O2, O3, O4, E2	Ti, Se, Sr, O2, O3, E2
60% to 70%	Mn	Mn, As, Rb
<40%	P, V, Ni, Se, As, Rb, Sr, Zr, O1, E3	P, V, Ni, Zr, O1, E3

3.9.3 Concentration and Precision of Composite Variables

The composite variables listed in Table 3-4 can be derived from the measured variables based on reasonable assumptions.

The uncertainty in all composites except for the four involving the quartz measurements is calculated by quadratically adding the uncertainties of the constituent terms times the appropriate multiplicative constant. For example, the uncertainty for soil would be:

$$[s\,(SOIL)]^2 = [2.20\ s\,(Al)]^2 + [2.49\ s\,(Si)]^2 + [1.63\ s\,(Ca)]^2 + [2.42\ s\,(Fe)]^2 + [1.94\ s\,(Ti)]^2 \quad (3\text{-}13)$$

Because temperature separation plays a much larger role for carbon fractions than for composites, and because the fractions are not independent, the above calculation method cannot be followed for OC, OMC, LAC, and TC. For these fractions the following equations for 24-hour samples are recommended:

$$s\,(OC) = \sqrt{(120)^2 + (0.05 * OC)^2}$$

$$s\,(OMC) = \sqrt{(168)^2 + (0.05 * OMC)^2}$$

$$s\,(LAC) = \sqrt{(34)^2 + (0.07 * LAC)^2}$$

$$s\,(TC) = \sqrt{(133)^2 + (0.05 * TC)^2} \quad (3\text{-}14)$$

The constant terms (120, 168, 34, 133) are appropriate for volumes near 32.4 m^3, which is typical for 24-hour samples. For other volumes they should be multiplied by (32.4/V). For typical 12-hour samples, the constant terms should be multiplied by two.

Ammonium Sulfate (NHSO)

The sulfur on the Teflon filter is always present as sulfate. In most cases the sulfate is fully neutralized ammonium sulfate, which is 4.125 times the sulfur concentration. The sulfate at eastern sites during the summer is not always fully neutralized, but overall the occurrences are rare. If 100% of the sulfur were sulfuric acid, the correct sulfate mass would be 74% of the calculated NHSO. The uncertainty in NHSO is 1.4 times the uncertainty in S. To calculate sulfate ion from sulfur multiply by 3.0.

Ammonium Nitrate (NHNO)

As with sulfate, the nitrate is expected to be fully neutralized ammonium nitrate. This is 1.29 times the nitrate ion concentration. The uncertainty in NHNO is 2.9 times the uncertainty in NO_3^-.

Total Organic Carbon (OC) and Organic Mass by Carbon (OMC)

The total organic carbon concentration is assumed to be the sum of the four organic fractions plus the pyrolized fraction, OP. To obtain organic mass, multiplying the total carbon by 1.4, which assumes that carbon accounts for 71% of the organic mass, is recommended. The ratios for various typical compounds range from 1.2 to 1.8.

Organic Mass by Hydrogen (OMH)

The hydrogen on the Teflon filter is associated with sulfate, organics, nitrate, and water. Since the analysis is done in vacuum, all water will volatilize. It is also assumed that no significant hydrogen from nitrate remains. If one assumes that the sulfate is fully neutralized ammonium sulfate, one can estimate the organic concentration by subtracting the hydrogen from sulfate and multiplying the difference by a constant representing the fraction of hydrogen. (A constant of 13.75 is suggested. This gives the best comparison with OMC for the network samples. However, a value near 10 is suggested by various typical organic compounds.) The OMH variable is defined only when both H and S are valid measurements.

The OMH calculation is invalid when (1) there is high nitrate relative to sulfate, and (2) the sulfur is not present as ammonium sulfate. This latter includes sites with marine sulfur and sites in the eastern United States with unneutralized sulfate. For the summer of 1996 at 30 sites in the western United States (excluding 6 with elevated nitrate or marine influences), the correlation coefficient (r^2) between OMH and OMC was 0.96 and the slope of the best fitting line was 0.98. The main advantage of using OMH at these sites is that its precision is better than that for OMC during periods of low organics as winter in the west. At sites in the east, OMH is often low because of unneutralized sulfate and imprecise because of the high sulfate relative to organics. The relationship under acidic conditions is considerably improved when ammonium ion is also available. However, there is still a problem with precision.

An organic artifact was found on a batch of Teflon filters used between September 1990 and November 1991. Approximately 7% of the samples had OMH significantly larger than OMC. The artifact was apparently completely organic (there was no elevated sulfur) and appeared during collection. For these samples, both H and fine mass were invalidated. These variables were not invalidated on the remaining 93% but flagged as less reliable than normal. No other variables were invalidated. The test for this effect is included in the acceptance procedures. The condition has not recurred.

Elemental or Light-Absorbing Carbon from Module C (LAC)

This is the sum of elemental carbon fractions. The pyrolized fraction is subtracted. Preliminary analyses indicate that some of the OC4 fraction may absorb light and that OP may overestimate the pyrolytic mass.

Soil (SOIL)

This is a sum of the soil derived elements (Al, Si, K, Ca, Ti, Fe) along with their normal oxides. The variable does not depend on the type of soil, such as sediment, sandstone, or limestone. One fine element, K, however, may partly derive from smoke as well as soil. This has been eliminated from the calculation and Fe has been substituted as a surrogate. This is discussed in nonsoil potassium below.

Nonsoil Potassium (KNON)

Fine potassium has two major sources, soil and smoke, with the smoke potassium in much smaller particles than the soil potassium. The potassium in coarse particles will be solely produced from soil. The soil potassium is estimated from the measured concentration of Fe and the ration of K/Fe of 0.6 measured on coarse samples (2.5 µm to 15 µm) collected between 1982 and 1986. This ratio depends on the soil composition and varies slightly from site to site. If the ratio were slightly smaller (i.e., 0.5 µm), the KNON values will be negative when there is no smoke influence. The residual potassium, K - 0.6 * Fe, is then assumed to be produced by smoke. The burning of most organic fuels will produce potassium vapor. During transport, this vapor will transform into fine particles. The KNON parameter is not a quantitative measure of the total smoke mass, since the ratio of nonsoil potassium to total smoke mass will vary widely, depending on the fuel type and the transport time. However, the KNON parameter can be used as an indicator of a nonsoil contribution for samples with large KNON. In some situations there may be some fine Fe from industrial sources which could cause occasional smoke episodes to be lost.

Reconstructed Mass (RCMC)

The reconstructed mass is the sum of sulfate (assuming ammonium sulfate), soil, and sodium from the Teflon filter (Module A) and organic and elemental carbon from the quartz filter (Module C). The nitrate from the nylon filter (module B) is not included. The reason is the RCMC is generally used as a comparison with the gravimetric mass measured on the Teflon filter. Because the Teflon filter loses a large fraction of the particulate nitrate by volatilization during sampling, it would be preferred not to include the nitrate from the nylon filter in the reconstruction. At most sites, the nitrate mass is a few percent of the reconstructed mass.

Precision

The precisions of the composite variables are estimated by quadratically adding the precisions of the components. This assumes that the precisions are independent. Since this is not quite valid, the calculated precisions for composites formed by adding (SOIL, OMC, LAC, RCMC, RCMA) are slightly smaller than they should be. For example, the average calculated precision for SOIL of 4% should probably be closer to 5%. The composite formed by subtraction (OMH) may have a slightly smaller precision than reported.

3.10 DATA ANALYSIS AND INTERPRETATION

Aerosol data can be used to describe the spatial and temporal variation of visibility as measured by the chemical composition of the visibility-degrading aerosol. Data can also be used for source apportionment and as background information for New Source Review and PSD modeling applications. Aerosol data are also used to further explore the relationship between optical extinction (absorption and scattering) and various aerosol species. In-turn, reconstructed extinction data can be used to depict visibility changes for NSR and PSD modeling applications. Several application examples and analysis considerations are presented in the following subsections.

3.10.1 Calculating Reconstructed Aerosol Extinction

Atmospheric extinction can be estimated from the mass of various particulate species collected with the IMPROVE samplers if the scattering cross section of each species is known, and if the hourly ambient relative humidity during sampling is also known. The equations used to determine reconstructed aerosol extinction follow IMPROVE Program protocol and are outlined below.

Species that contribute to atmospheric extinction are classified as:

- Sulfates
- Nitrates
- Organics
- Soil
- Coarse Mass
- Particle Absorption (b_{abs})
- Atmospheric Rayleigh Scattering (b_{Ray})

In general, the higher the relative humidity (RH) the greater the scattering of soluble aerosols. The relationship between RH and scattering efficiency for ammonium sulfate aerosols with a mass mean diameter of 0.3 µm and a geometric size distribution of 1.5 is shown in Figure 3-6. This function, referred to as *f*(RH), is given by:

$$f(RH) = b_{scat}(RH) / b_{scat}(0\%) \tag{3-15}$$

where $b_{scat}(0\%)$ and $b_{scat}(RH)$ are the dry and wet scattering, respectively. Ammonium sulfate and ammonium nitrate mass are associated with this function.

An equation used by the IMPROVE Program to estimate reconstruct aerosol extinction is:

$$
\begin{aligned}
b_{ext} = &\ (3)\ f(RH)\ [Sulfate] \\
&+ (3)\ f(RH)[Nitrate] \\
&+ (4)\ [OMC, Organic\ Mass\ Carbon] \\
&+ (1)\ [Soil] \\
&+ (0.6)\ [CM, Coarse\ Mass] \\
&+ b_{abs}
\end{aligned}
\qquad (3\text{-}16)
$$

where the first 5 components represent the light scattering by aerosol species, b_{abs} represents the coefficient of light absorption for fine particles, and b_{Ray} represents the light scattered by molecules of gas in the natural atmosphere which varies with atmospheric pressure and is a site-specific measurement based on altitude. Brackets indicate the mass concentration of the aerosol species or element. Three (3) m^2/g is the dry scattering efficiency of sulfates and nitrates, four (4) m^2/g is the dry scattering efficiency of organics, and one (1) m^2/g and 0.6 m^2/g are the respective scattering efficiencies for soil and coarse mass (Sisler, 1996).

Caution should be taken when comparing reconstructed extinction with measured extinction from optical transmissometer measurements (Section 4.1). Reconstructed extinction is typically 70% - 80% of the measured extinction. The following differences/similarities are considered:

- Data collection. Reconstructed extinction measurements represent 24-hour samples collected twice per week. Transmissometer extinction estimates represent continuous measurements summarized as hourly means, 24 hours per day, 7 days per week.

- Point versus path measurements. Reconstructed extinction represents an indirect measure of extinction at one point. The transmissometer directly measures the irradiance of light (which calculated gives a direct measure of extinction) over a finite atmospheric path.

- Relative humidity (RH) cutoff. Daily average reconstructed measurements are flagged as invalid when the daily average RH is greater than 98%. Hourly average transmissometer measurements are flagged invalid when the hourly average RH is greater than 90%. These flagging methods often result in data sets that do not reflect the same period of time, or do not properly interpret short-term meteorological conditions.

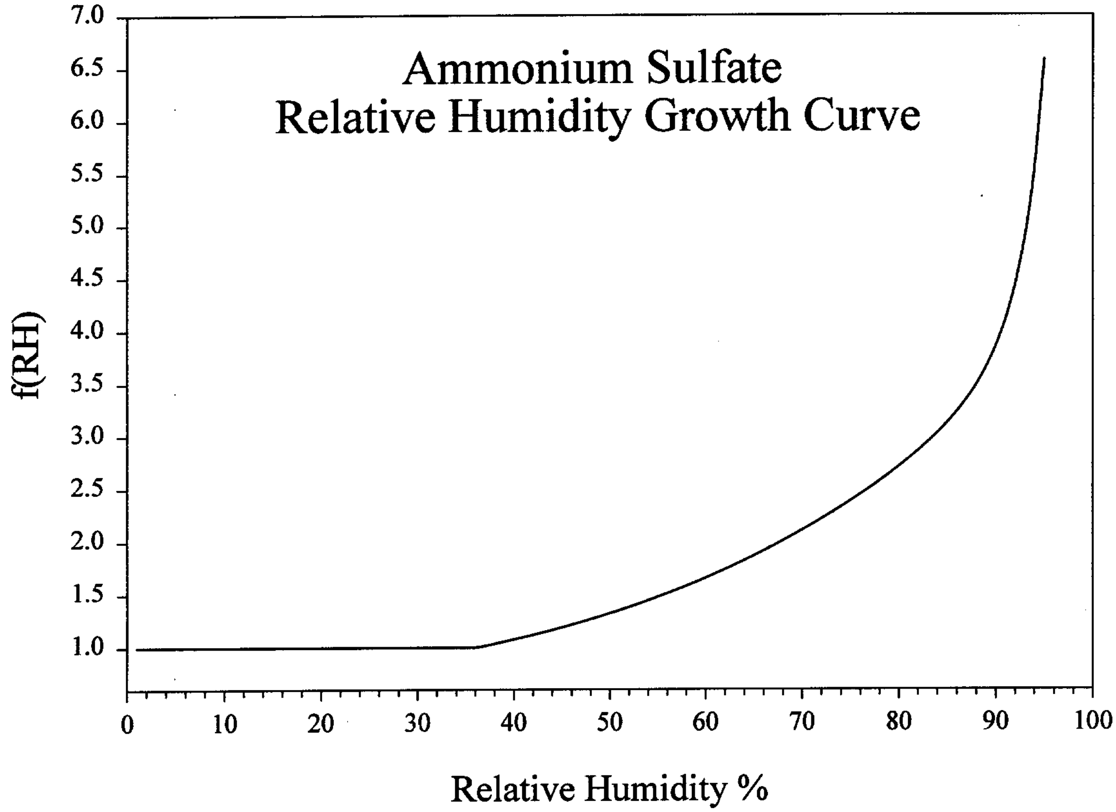


Figure 3-6. The Relationship Between Scattering Efficiency and Relative Humidity

3.10.2 Source-Type Tracer Analysis

Tracer analysis is another analysis approach that uses aerosol data to identify source types or individual sources. For example, the presence of arsenic is a good indicator of copper smelter emissions. Table 3-7 summarizes the common source types of a number of measured trace elements by abundances in percent mass (Chow, 1995). Tracer analysis can also be used to estimate source contributions and to identify general transport patterns.

Table 3-8

Common Source Types of Measured Trace Elements (Chow, 1995)

	Dominant		Chemical Abundances in Percent Mass		
Source Type	*Particle Size*	*<0.1%*	*0.1 to 1%*	*1 to 10%*	*>10%*
Paved Road Dust	Coarse (2.5 to 10 μm)	Cr, Sr, Pb, Zr	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Zn, Ba, Ti	Elemental Carbon (EC), Al, K, Ca, Fe	Organic Carbon (OC), Si
Unpaved Road Dust	Coarse	NO_3^-, NH_4^+, P, Zn, Sr, Ba	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Ba,Ti	OC, Al, K, Ca, Fe	Si
Construction	Coarse	Cr, Mn, Zn, Sr, Ba	$SO_4^=$, K^+, S, Ti	OC, Al, K, Ca, Fe	Si
Agriculture Soil	Coarse	NO_3^-, NH_4^+, Cr, Zn, Sr	$SO_4^=$, Na^+, K^+, S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Natural Soil	Coarse	Cr, Mn, Sr, Zn, Ba	Cl^-, Na^+, EC, P, S, Cl, Ti	OC, Al, Mg, K, Ca, Fe	Si
Lake Bed	Coarse	Mn, Sr, Ba	K^+, Ti	$SO_4^=$, Na^+, OC, Al, S, Cl, K, Ca, Fe	Si
Motor Vehicle	Fine (0 to 2.5 μm)	Cr, Ni, Y, Sr, Ba	Si, Cl, Al, Si, P, Ca, Mn, Fe, Zn, Br, Pb	Cl^-, NO_3^-, $SO_4^=$, NH_4^+, S	OC, EC
Vegetative Burning	Fine	Ca, Mn, Fe, Zn, Br, Rb, Pb	NO_3^-, $SO_4^=$, NH_4^+, Na+, S	Cl^-, K^+, Cl, K	OC, EC
Residual Oil Combustion	Fine	K^+, OC, Cl, Ti, Cr, Co, Ga, Se	NH_4^+, Na^+, Zn, Fe, Si	V, OC, EC, Ni	S, $SO_4^=$
Incinerator	Fine	V, Mn, Cu, Ag, Sn	K^+, Al, Ti, Zn, Hg	NO_3^-, Na^+, EC, Si, S, Ca, Fe, Br, La, Pb	$SO_4^=$, NH_4^+, OC, Cl
Coal-Fired Boiler	Fine	Cl, Cr, Mn, Ga, As, Se, Br, Rb, Zr	NH_4^+, P, K, Ti, V, Ni, Zn, Sr, Ba, Pb	$SO_4^=$, OC, EC, Al, S, Ca, Fe	Si
Oil Fired Power Plant	Fine	V, Ni, Se, As, Br, Ba	Al, Si, P, K, Zn	NH_4^+, OC, EC, Na, Ca, Pb	S, $SO_4^=$
Smelter Fine	Fine	V, Mn, Sb, Cr, Ti	Cd, Zn, Mg, Na, Ca, K, Se	Fe, Cu, As, Pb	S
Antimony Roaster	Fine	V, Cl, Ni, Mn	$SO_4^=$, Sb, Pb	S	None reported
Marine	Fine and Coarse	Ti, V, Ni, Sr, Zr, Pd, Ag, Sn, Sb, Pb	Al, Si, K, Ca, Fe, Cu, Zn, Ba, La	NO_3^-, $SO_4^=$, OC, EC	Cl^-, Na^+, Na, Cl

3.11 AEROSOL MONITORING STANDARD OPERATING PROCEDURES AND TECHNICAL INSTRUCTIONS

The Crocker Nuclear Laboratory document entitled *IMPROVE Particulate Monitoring Network Standard Operating Procedures* is available as a pdf file on http://www.nature.nps.gov/ard/vis/sop/index.html. This includes the following aerosol-related Standard Operating Procedures and Technical Instructions:

Document Number	Title
SOP 101	Procurement and Acceptance Testing
TI 101A	Filter Procurement and Acceptance Testing
TI 101B	Sampler Construction and Testing
TI 101C	Filter Cassette Construction
SOP 126	Site Selection
SOP 151	Installation of Samplers
TI 151A	Installation of Controller Module
SOP 176	Calibration, Programming, and Site Documentation
TI 176A	Calibration of Audit Devices Using Spirometer
TI 176B	Final Flow Rate Audit Calculations
TI 176C	Flow Rate Audits and Adjustment
SOP 201	Sampler Maintenance by Site Operators
TI 201A	IMPROVE Aerosol Sampler Operations Manual
TI 201B	Forms for Flow Audits by Site Operators
SOP 226	Annual Site Maintenance
TI 226A	Sampler Wiring Diagrams
SOP 251	Sample Handling
SOP 276	Optical Absorption Analysis
SOP 301	X-Ray Fluorescence Analysis
SOP 326	PIXE and PESA Analysis
SOP 351	Data Processing and Quality Assurance
SOP 376	Data Archiving and Reporting

4.0 OPTICAL MONITORING

As an example of an existing visibility-related optical monitoring program, this section describes IMPROVE optical monitoring and data management techniques. References made to manufacturers or trade names are not intended to constitute EPA endorsement or recommendations for use. New or improved instruments, instrument upgrades, and methods of monitoring are continually being developed.

Optical monitoring provides a quantitative measure of ambient light extinction (light attenuation per unit distance) or its components to represent visibility conditions. IMPROVE protocols collect continuous measures of b_{ext} and/or b_{scat} using ambient long-path transmissometers and/or nephelometers respectively. A tabular summary of optical instrument specifications are provided in Table 4-1. Water vapor in the air can affect visibility, therefore IMPROVE protocols state that temperature and relative humidity sensors must be collocated with the chosen optical instrument.

Sections 4.1 and 4.2 describe the measurement criteria, instrumentation, installation and site documentation, routine operations, data collection, reduction and validation, reporting and archive, quality assurance, and analysis and interpretation required for transmissometer and nephelometer monitoring respectively. Operation manuals and manufacturer's specifications are provided in Appendix B.

4.1 TRANSMISSOMETER

4.1.1 Measurement Criteria and Instrumentation

Transmissometers directly measure the irradiance of a light source after the light has traveled over a finite atmospheric path. The transmittance of the path is calculated by dividing the measured irradiance at the end of the path with the calibrated initial intensity of the light source. Using Bouger's law, the average extinction of the path is calculated from the transmittance and length of the path. It is attributed to the average concentration of all atmospheric gases and ambient aerosols along the path. Transmissometers make a completely ambient measurement of b_{ext} without perturbing or selectively sampling atmospheric aerosols or gases.

Several measurement criteria cautions should be considered. Transmissometers require path lengths of a few kilometers to achieve the necessary sensitivity to resolve extinctions near the Rayleigh limit. In areas with non-uniform distribution of aerosols, comparison of measured extinction and reconstructed extinction from concurrent particulate samples can often be misleading. Extinction measurements from transmissometers also are affected by any meteorological or optical interferences present along the path which are independent from the ambient aerosol. An additional concern for transmissometers is the lack of an absolute calibration standard. Uncertainty measurements associated with these measurement cautions are presented in Section 4.1.8.

Table 4-1

IMPROVE Protocol Monitoring
Optical Instrument Specifications

Parameter	Instrument	Sample Frequency	Reporting Interval	System Accuracy	System Precision	Resolution	Range	Sensor Specifications	Traceability	Probe Placement	Calibration
Atmospheric Extinction Coefficient b_{ext} (at 550 nm)	Optec LPV-2 Long Range Transmissometer	a. 10-minute average of 1-minute, integrated samples taken once an hour between 3 and 13 minutes after the hour. b. Hourly average of 1-minute integrated samples.	Hourly	! No absolute calibration standard ! Accuracy inferred from comparison to (b_{scat} + b_{abs}) and reconstructed b_{ext} from aerosol measurements	Path dependent: ±0.003 km^{-1} for 10 km working path and 0.010 nominal extinction value or ±3% transmission	0.001 km^{-1}	0.001 km^{-1} to 1.0 km^{-1}	! 550 nm ±2 nm center wavelength and 10 nm ±1 nm bandwidth ! Output analog - b_{ext}; 0 V to 10 V, 0.01 V = 0.001 km^{-1} - VR; 0 V to 10 V, 0.01 V = 1 km - raw counts; 0 V to 10 V - Std. Dev. (N-1 samples) of 1-minute integrated samples ! Output serial (RS232) 8 bits, 1 stop bit, no parity, 9600 baud default ! Power required 12V DC ! 2 components include a transmitter & receiver separated by ~1 km to 10 km based on average visual air quality ! Operating temperature range -20°C to +45°C nominal	N/A (see system accuracy statement)	! 1 km to 10 km separation between transmitter and receiver depending on average visual air quality ! Ends placed near terrain drop offs to avoid surface heating-based optical interferences ! Secure optical mounting platforms/mounts required	! No absolute calibration ! System with operational and reference lamps calibrated at 300 m path distance ! Calibrations performed annually, prior to field installation, and immediately after field removal ! Calibrations compared with collocated reference transmissometer during annual site visit
Ambient Scattering Coefficient b_{scat} (at 550 nm)	Optec NGN-2 Open Air Integrating Nephelometer	a. 2-minute integrated sample every 5 minutes reduced to hourly averages.	Hourly	±10% of true value for air near Rayleigh and using two minutes of integration (longer integrations will increase the accuracy i.e., 10 minutes of integration will increase accuracy to ±4.5%)	! Calculated from regular (usually weekly) zero/span calibrations ! Generally less than 10%	±1 count, (Serial Output) (one Rayleigh is ~12 counts) ±2.44 mv (Analog Channel 1 or 2) (one Rayleigh is ~12.0 mv)	0 to 32,768 count (Serial Output) (typically equal to 0.01 km^{-1} to 24.00 km^{-1} after post processing) 0 volts to 10.00 volts (Analog Channel 1 or 2) (typically equal to 0.01 km^{-1} to 7.00 km^{-1} after post processing)	! 550 nm center wavelength, 100 nm bandwidth photopic response ! 2 analog channels, 0 V to 10.000 volt, 0.00244 volt steps or 0 V to 5.000 volt, 0.00122 volt steps, jumper selected, 2 Ω output impedance, current limited Channel 1: NORMALIZED SCATTERED LIGHT Channel 2: STATUS value ! Output serial RS-232, RX, TX, GND 8 data bits, 1 stop bit, no parity, televideo 920 emulation, FULL-DUPLEX mode, 9600 baud default, others selectable STATUS, Raw SCATTERED LIGHT Count, Raw LAMP BRIGHTNESS Count, NORMALIZED SCATTERED LIGHT Count, INTEGRATION TIME in Minutes, TEMPERATURE, DATE in year:month:day, TIME in hour:minutes ! Power required: 13.8 volt ±0.3 volt DC, 4.5 amps, regulated required ! Operating temperature range -20°C to +45°C nominal	N/A	Normally at 3 m to 5 m above ground at probe height of collocated particulate samplers	zero: particle free Rayleigh air provided internally with filters at 6-hour intervals span: upscale span usually performed weekly using SUVA 134a refrigerant gas with a known scattering coefficient zero and span calibrations are also performed during installation, removal, and laboratory testing

The Optec, Inc. LPV-2 long-path transmissometer has been in use since 1986. Over 30 instruments are currently operating in various visual air quality monitoring programs in North America, from highly-polluted urban areas to pristine wilderness environments. The system consists of a constant output light source transmitter and a computer-controlled photometer receiver. Other specific transmissometer system components include transmitter and receiver alti-azimuth bases, a terminal strip, an air temperature/relative humidity sensor, a DCP and antenna, and a strip chart recorder. A general diagram of the standard transmissometer system components is provided in Figure 4-1. Detailed information regarding transmissometer instrumentation or operation can be found in *Model LPV Long Path Visibility Transmissometer Technical Manual for Theory of Operation and Operating Procedures* (Optec, Inc., 1991) and *Standard Operating Procedures and Technical Instructions for Transmissometer Systems* (Air Resource Specialists, Inc., 1993-1996).

The transmitter emits a uniform, chopped, incandescent light beam of constant intensity at regular intervals for a programmed duration. It has two components: an electronic control box, and a light source or transmitter. Transmitter optics concentrate light from a 15 watt tungsten filament lamp into a narrow, well-defined uniform cone, magnifying the beam to the equivalent of a bare 1500 watt lamp, allowing the operator to precisely aim the light beam at the receiver. Although a 1° cone of light is emitted from the transmitter, only the center 0.17° portion is used for routine monitoring. Field and laboratory measurements of beam isotropy have indicated that the central 0.17° cone has less than 1% variation.

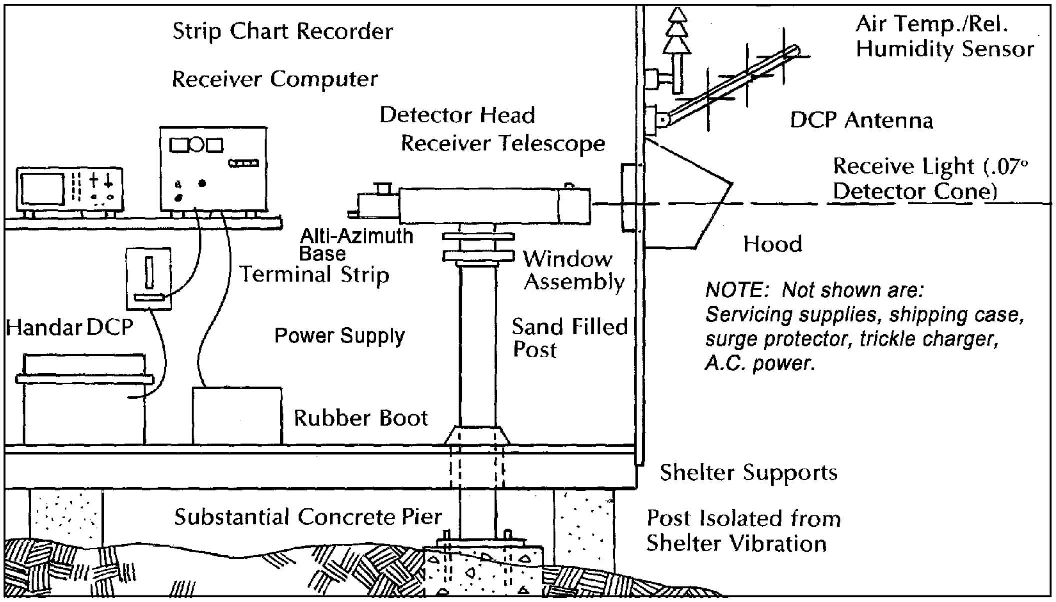
Light intensity emitted from the transmitter is precisely controlled by an optical feedback system, that continuously samples the center 0.17° portion of the outgoing beam and performs fine adjustments to keep the light output constant. Light emitted from the transmitter is "chopped" at 78 pulses a second by a mechanical spinning disk in front of the lamp. This allows the receiver computer to differentiate the lamp signal from background or ambient lighting. An eyepiece lets the operator precisely aim the light beam.

The receiver gathers light from the transmitter, converts it to an electrical signal, isolates and measures the received transmitter light, and calculates and outputs visibility results in the desired form. The receiver has three components: a long focal-length telescope, a photodetector eyepiece assembly, and a low power computer.

The telescope gathers the transmitter light, which includes both background illumination and the transmitter signal, focuses it through a narrow band 550 nm interference filter, and focuses it on a photodiode that converts it to an electrical signal. The receiver computer "locks-on" to the transmitter light's chopped frequency and separates the transmitter light from ambient lighting. The computer compares the measured transmitter light with the known (calibrated) transmitter light to calculate the transmission of the intervening atmosphere.

Effects of atmospheric turbulence are minimized by using 6,250 samples of the signal to calculate a one-minute average reading. The resultant reading is held in the computer and is available to a datalogger (DCP) until the next value is calculated. Like the transmitter, the receiver is equipped with an eyepiece to precisely aim the detector, and an interval timer to control the interval and duration of measurements.

Receiver Station
(6′x 6′x 8′)



Transmitter Station
(3′x3′x4′6″)

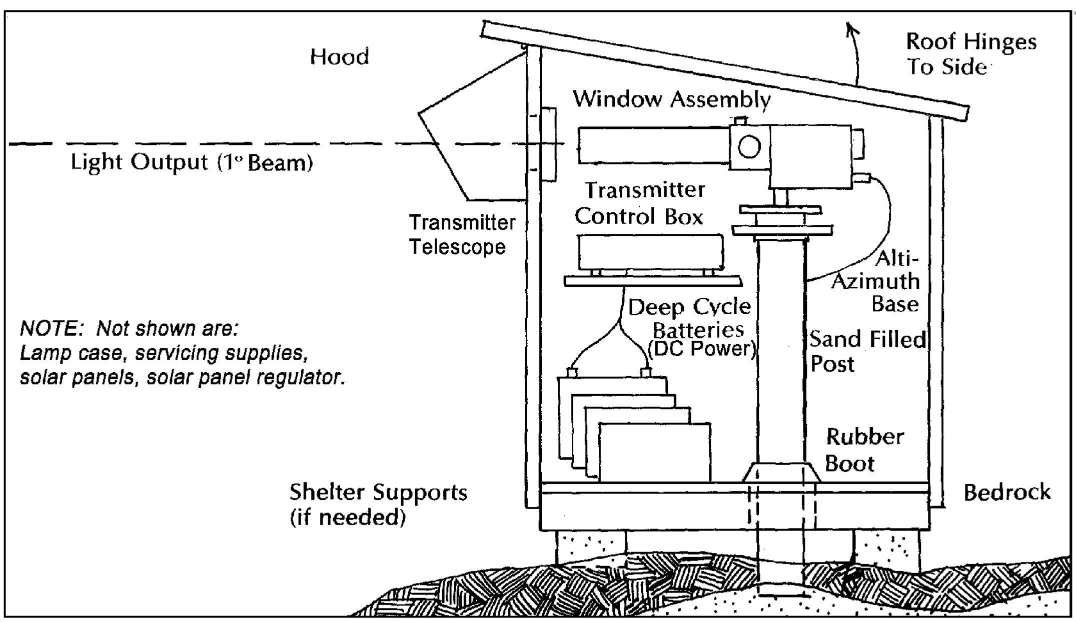


Figure 4-1. Transmissometer Receiver and Transmitter Components.

4.1.2 Siting Criteria

The fundamental requirement for operation of the LPV-2 transmissometer is a clear, unobstructed line-of-sight (sight path) between the transmitter and receiver. To reduce the effects of thermal turbulence, the sight path should be elevated as far above the terrain surface as practical. In rural applications, the transmitter and receiver are typically located near terrain drop-offs; in urban applications, the sight path can be from one building to another. If possible, locating the sight path over a body of water should be avoided due to the increased frequency of temperature inversions, fog, etc.

The primary consideration in determining whether a path length is acceptable, is the expected range of visual air quality in that area. Generally, remote areas in the western United States require path lengths from 4-8 km, while eastern sites require 1-4 km lengths. If the mean visual range for the area is known, a usable path distance can be calculated as follows:

$$Sight\ Path\ Length\ =\ Mean\ Visual\ Range\ x\ 0.033 \tag{4-1}$$

Unless otherwise specified in the monitoring objectives for a transmissometer site, the sight path should be as level as possible. If siting constraints result in a significant (>1.0°) sight path vertical angle, orientation of the receiver telescope to lighting conditions throughout the year should be thoroughly considered (e.g., a receiver telescope viewing approximately south at an upward angle could be susceptible to periods of receiver detector saturation, especially with low winter sun angles). It is generally preferable in such situations to configure the site with the receiver at the higher point and viewing downward toward the transmitter.

The primary siting criterion is to ensure that the air mass along the entire sight path between the receiver and transmitter is representative of the larger air mass to be monitored. Selected transmissometer sites should have most of the following characteristics:

- Be located in an area representative of the air mass to be monitored
- Have a clear, unobstructed sight path between the receiver and transmitter
- Have adequate sight path length and height for representative monitoring of the air mass
- Be representative of the same air mass measured by other aerosol or optical monitoring
- Have AC power or adequate solar exposure for continuous year-round operation
- Be oriented so that lighting conditions do not affect measurements
- Be removed from local pollution influences (e.g., vehicle exhaust,wood smoke, road dust, etc.)
- Be secure from vandalism
- Have available servicing personnel (operator)
- Be reasonably accessible during all months of the year

Various siting criteria to be considered as they apply to the actual transmitter and receiver station locations are:

- Stability of ground surface -- frost-heaving, downslope soil movement, soil saturation, and other earth movements will affect instrument alignment.

- Lightning exposure -- sites that are susceptible to lightning strikes should be avoided.

- Local land manager or land owner cooperation -- establish whether the local land manager or land owner will be cooperative in allowing installation of the sites and continuous access to the sites for the duration of the study.

- Vegetation growth -- growth of vegetation into the sight path must be taken into account.

- Data collection platform (DCP) transmission clearance -- verify that DCP transmissions will not be blocked by vegetation, geographical features, or structures.

- Isolation from radio interference -- instrument circuitry is sensitive to strong radio signals. Avoid siting close to broadcast antennas or repeaters.

- Snow accumulation -- the effects of significant snowfall accumulations on instrument, DCP, and solar panel operation should be considered.

- Avoidance of lighting interference -- sunlight reflecting from solar panels, large windows, or other large reflective surfaces near the transmitter can saturate the receiver detector and affect readings.

4.1.3 Installation and Site Documentation

Transmissometer installation requires stable mounting posts, adequate sheltering, and a reliable power supply. Continuous, correct transmitter and receiver telescope alignment is critical for proper transmissometer operation. The transmitter and receiver mounting posts must be installed in such a manner that any movement due to earth movement, temperature fluctuations, vibration, etc. is minimized. Mounting posts can be attached to pre-existing rock or concrete surface, to a concrete pier in the soil, or to a concrete pad. Alti-azimuth instrument bases allow precise alignment of the transmitter and receiver telescopes. Sheltering must be waterproof, but heating or cooling are not recommended.

Transmissometer installations may be powered by line power (AC) or solar power (DC). A standard receiver station solar panel array is comprised of two large solar panels which charge four deep-cycle batteries. A third, smaller solar panel provides power to a data collection platform (DCP). A standard transmitter station solar panel array is comprised of three large solar panels which charge four deep-cycle batteries.

After component installation, a distance measurement must be made from the front of the receiver telescope tube to the front of the transmitter telescope tube. Transmissometer calibration numbers using this accurate distance value are then recalculated and dialed in on the receiver computer.

System operation is verified after the instrument settings and system timing have been set at the transmitter and receiver. Upon completing the installation and verifying system operation, all operators, back-up operators, and any other involved or interested on-site personnel should be trained, including reviewing a site operator's manual. The manual contains standard operating procedures and technical instructions for operator maintenance, troubleshooting, system diagrams, replacing and shipping components, annual site visit procedures, field audit procedures, and manufacturer's manuals (ARS, Inc. SOP 4110, TI 4110-3100, TI 4110-3300, TI 4110-3350, TI 4110-3375, SOP 4115, TI 4115-3000, SOP 4710, *Technical Manual for Theory of Operation and Operating Procedures* (Optec, Inc.), and *Instruction Manual for Primeline 6723* (Soltec Distribution, Inc.). A copy of the manual should be left at the transmitter site, the receiver site, and at the office of on-site personnel. Other on-site documentation includes the completion of a site visit trip report, photographic documentation (including photographs of the shelters, all components, shelter supports, sight path, power supply, etc.), and documentation of any miscellaneous information necessary to make a complete site description, including site map and site specifications (latitude, longitude, instrument elevations, elevation angle, sight path distance, etc.).

4.1.4 System Performance and Maintenance

System performance and maintenance includes routine servicing, annual site visits, instrument calibration, and annual servicing.

4.1.4.1 Routine Servicing

Site operators should perform routine servicing by visiting both the receiver and transmitter shelters at 7 to 10 day intervals. Routine servicing involves documenting the initial condition and operation of the components, inspecting and correcting alignment of both the transmitter and receiver, cleaning optics of the system (including shelter windows, telescope lenses, and solar panels), recording the lamp voltage and battery voltages, and recording receiver display readings and switch settings. Timing should be checked and corrected if necessary. The transmissometer system should follow the following timing sequence:

HR:MI:SEC	Action
XX:00:00	Transmitter lamp turns on
XX:03:00	Receiver begins 10-min. average reading (cannot be observed)
XX:13:20	Receiver finishes reading, updates display, and changes toggle state
XX:16:00	Transmitter lamp turns off
XX:00:00	Sequence repeats hourly

Additional routine servicing, to be performed monthly or at a two-month interval, includes checking the transmitter lamp status (changing the lamp every two months), inspecting the physical condition of solar panels, batteries, battery fluid levels, DCP antenna, and strip chart recorder operation.

4.1.4.2 Annual Site Visits

Annual site visits are performed to exchange the existing transmissometer system for a newly serviced system, and to train site operators in servicing and maintaining the monitoring system components. Primary tasks for a typical annual site visit include:

- Documenting initial conditions of the components
- Verifying instrument operation
- Conducting site inventory
- Performing site servicing
- Conducting an annual field audit
- Performing a post-audit verification check

Site operator training should be performed to discuss the purpose of the monitoring program and theory of transmissometer system operation.

4.1.4.3 Instrument Calibration

Calibration of the LPV-2 transmissometer involves determining the irradiance from the transmitter lamp that would be measured by the receiver if the optical sight path between the two units allowed 100% transmission. All components of the LPV-2 transmissometer must be calibrated as a unit. Each transmissometer lamp has its own calibration number for use at a specific site with a specific transmissometer system. Receiver computers are individually calibrated during annual servicing and may be interchanged for emergency maintenance or for use with the audit instrument. Recalibration of an instrument with a receiver computer other than the one used at calibration does not require instrument recalibration, but only recalculation of calibration numbers. No other system component, including lamps, may be interchanged with another transmissometer without recalibration.

All calibrations are currently performed at the Fort Collins Transmissometer Calibration and Test Facility, located at Colorado State University's Christman Field. The facility includes sheltering and all support equipment required to conduct operational transmissometer calibrations. The calibration path (the distance between transmitter and receiver during calibration) is 0.3 km. At this distance, the atmospheric transmission can be estimated with a high degree of accuracy for use in calculating the calibration number. Because lamp brightness is dependent on lamp voltage, the lamp voltage is measured in the laboratory prior to calibration, at the test facility during calibrations, and again in the laboratory following calibration. A shift in lamp voltage may indicate damage to the lamp or a malfunction of the lamp control circuitry.

To ensure that the detector alignment is valid over a longer path, a detector uniformity test is performed at the test facility as the first step in performing any calibration.

Calibrations should be performed annually, prior to field installation, and immediately after field removal. Pre-field calibration includes the following procedures:

- Burn-in of transmissometer lamps
- Measurement of pre-calibration lamp voltages
- Setup of instrumentation at the test facility
- Measurement of receiver detector uniformity
- Preliminary calibration of 4 lamps
- Final calibration of 10 lamps
- Documentation of calibration configuration, weather and visibility conditions, and lamp voltage measurements on the calibration form
- Measurement of pre-field lamp voltages
- Quality assurance review of calibration data
- Entry of calibration data into the calibration database
- Calculation of site-specific pre-field calibration numbers for each lamp

All transmissometer lamps require a 72-hour burn-in cycle prior to being assigned to an operational instrument. The burn-in cycle should be performed in the laboratory to stabilize the filament position and reduce the incidence of premature lamp failure in the operational network.

A standardized calibration number is used in calculating lamp brightening and varies from instrument to instrument. The standardized calibration number is calculated using the following equation:

$$Calibration\ No. = (CP/WP)^2 * (WG/CG) * (WA/CA)^2 * (1/FT) * WT * (1/T) * CR \qquad (4\text{-}2)$$

where:

CP = calibration path length, 0.300 km
WP = working path length, 0.500 to 10.000 km
(5.000 km for standardized calibration number)

CG = calibration gain, nominal values are 100, 300, 500, 700, or 900
WG = working gain, nominal values are 100, 300, 500, 700, or 900
(500 for standardized calibration number)

CA = calibration aperture, 101.51 mm
WA = working aperture, approximately 110.00 mm
(110.00 for standardized calibration number)

FT = calibration filter (NDF) transmittance, 2.74% or 0.0274
WT = total window transmittance for the operational system (typically 80% or 0.800)
(1.000 for standardized calibration number)

T = estimated atmospheric transmittance for the calibration path ($T=e^{-bext*CP}$)
CR = normalized average of 10-12 readings over the calibration path

Post-field calibration should be performed prior to any cleaning or servicing of the instrument and includes: a receiver detector uniformity check, calibration of all operational lamps, and calculating a lamp brightening factor for each post-calibrated lamp.

The transmitted light intensity of transmissometer lamps increases (brightens) with increased hours of lamp use. On a lamp-by-lamp basis, this brightening factor is calculated by comparing the pre-field and post-field calibration numbers and applying this change over the total number of lamp hours accumulated during field operation. Calculating a lamp brightening factor in this manner assumes a linear increase in lamp brightness. A lamp brightening database has been developed, which includes the shift in lamp brightness (based on a comparison of pre-field and post-field calibration numbers) as a function of lamp-use hours. All post-calibrated lamp data are added to this database. Lamp brightening statistics are then analyzed (using a set of lamps with specific lamp factors such as operating voltage or lamp manufacturer). A lamp brightening curve is defined for these lamps and a lamp drift correction factor applied to the operational transmissometer data.

Calibration of a shelter window for use in a transmissometer network requires measurement of light loss as transmitted light passes through the window. Initial measurements of window transmittance should be performed at the test facility and follow the basic measurement procedures described for other calibrations. Individual and combined transmittance should be measured for the transmitter and receiver windows. The transmittance is determined by measuring the light received at the receiver with the window(s) in place and the window(s) removed. The ratio of the average readings with the windows in to the average readings with the windows out, is the window transmittance.

4.1.4.4 Annual Servicing

Each transmissometer returned from a field site for annual laboratory maintenance should be inspected and tested prior to initiating any servicing procedures that could invalidate the instrument calibration. Annual servicing includes a post-field instrument inspection, functional test, and calibration. Maintenance also performed includes:

- Disassembly and cleaning
- Optics alignment checks and realignment
- Chopper motor replacement
- Instrument timing checks
- Receiver computer gain measurements and calibration checks
- Internal batteries replacement
- Operational lamps replacement
- Instrument upgrades and modifications (as required)
- Pre-field calibration

4.1.5 Data Collection

Transmissometers operate in a cycled mode, collecting a 10-minute average of the transmitter irradiance at the start of each hour of the day. The receiver is programmed to begin sampling three minutes after the transmitter lamp turns on. Over the next 10 minutes, the receiver collects and stores 10 one-minute averages. The receiver then uses the 10 one-minute averages to calculate and output an analog 10-minute average value for the received lamp irradiance.

Data are logged on data collection platforms (DCPs) and are processed by several entities before being available for downloading via modem. Monitoring stations with DCPs undergo the following data downloading sequence:

- The DCP logs transmissometer data at pre-programmed intervals.
- At three-hour intervals, the DCP transmits the past three hours' data (three 10-minute averages) and its internal battery voltage to the GOES (Geostationary Orbiting Earth Satellite).
- The GOES satellite retransmits the data to a downlink facility.
- The data are made available via the dissemination facility.
- The data are downloaded via telephone modem.

Data can be automatically collected from the DCP via computer software through telephone modem. For periods when data are lost due to failure of on-site dataloggers, strip charts from the backup recorders can be mailed and reviewed to retrieve as much useful data as possible. Air temperature and relative humidity data should also be collected with transmissometer data.

4.1.6 Data Reduction and Validation

4.1.6.1 Data Reduction

Transmissometer data should be compiled into site-specific Level-A files. These files include hourly data (one 10-minute average) and should be reviewed daily by data analysts to determine the operational characteristics of each site. Any apparent problem should result in a telephone call to the site operator in an attempt to resolve the inconsistencies.

Raw data plots may be generated bi-monthly from raw data files. Data from operator log sheets should be checked against data collected via data collection platform (DCP) to identify inconsistencies and errors.

Level-A transmissometer data should be plotted bi-monthly and reviewed monthly. Inconsistent or suspicious data can then be identified and troubleshooting procedures initiated. As completed log sheets from transmissometer sites are received, the pertinent information (visibility conditions, alignment, system timing, instrument problems, etc.) should be manually transferred to the bi-monthly plots. This procedure helps to identify the exact time of lamp changes, alignment corrections, and other actions done by the site operator affecting instrument operation. This information is used to update the lamp and code files for Level-A validation.

4.1.6.2 Data Validation

Transmissometer data should undergo three validation levels: Level-A, Level-0, and Level-1. All three levels of validation include hourly average data. Level-A validation includes visual review and examination of the raw data and error files. Level-0 validation includes searching for questionable or physically unrealizable data. Level-1 validation includes calculating uncertainty values and identifying values affected by weather or optical interferences.

Level-A data files should be compiled into seasonal data files for each site. Standard meteorological seasons are defined as:

Winter	December, January, and February
Spring	March, April, and May
Summer	June, July, and August
Fall	September, October, and November

Site-specific code files should be updated to include the most current information available regarding calibration parameters, instrument and support equipment operation, operator notes, and validity codes. The seasonal Level-A files should be checked for inconsistencies with a screening program that verifies data integrity and assigns validity codes. Level-A validity codes should include:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from an alternate logger
6	=	Valid:	b_{ext} data exceeds maximum (overrange)
8	=	Missing:	Data acquisition error
9	=	Valid:	b_{ext} data below Rayleigh (underrange)
A	=	Invalid:	Misalignment
L	=	Invalid:	Defective lamp
S	=	Invalid:	Suspect data
W	=	Invalid:	Unclean optics

Level-0 data files should be generated from the Level-A data with a separate but redundant data screening program. At Level-0, transmissometer data are corrected for lamp brightening and converted to b_{ext} using site-specific calibration information. The lamp brightening correction is based on the calculated average drift of a number of lamps. The algorithm for calculating the drift-related offset applied to each $\boldsymbol{b}_{\mathbf{ext}}$ value is:

Let	$\boldsymbol{t_1}$	=	16; number of minutes per hour the lamp is on.
	$\boldsymbol{t_2}$	=	60; number of minutes in an hour.
	$\boldsymbol{t_3}$	=	number of lamp-on hours for current lamp.
	$\boldsymbol{L}$	=	number of hours the lamp resides in the transmitter.
	$\boldsymbol{r}$	=	path length.

The lamp-on time ($\boldsymbol{t_3}$) for the current lamp is:

$$t_3 = L * t_1 / t_2 \tag{4-3}$$

The lamp drift correction factor (***F*****drift**) is a function of the lamp-on hours (***t*****3**) defined by the following curve for Olympus lamps operating at a nominal voltage of 5.9 VDC:

$$F_{drift}\ (\%) \ = \ 0.270 \ * \ t_3^{0.4405} \qquad (4\text{-}4)$$

The lamp drift corrected transmittance (***T*****corr**) is:

$$T_{corr} \ = \ [1 - \ (F_{drift} \,/\, 100)] * T \qquad (4\text{-}5)$$

where ***T*** is the measured transmittance. The drift corrected ***b*****ext** is:

$$b_{ext,corr} \ = \ +\ln(\frac{1}{T_{corr}}) \,/\, r \qquad (4\text{-}6)$$

where ***r*** = path distance.

Level-1 data should be generated from the Level-0 files with a third data and validity code screening and the addition of:

! Calculation of uncertainty values for all hourly data, and

! Identification of hourly valid b_{ext} data that may be affected by meteorological or optical interferences.

Level-1 validity codes are:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from an alternate logger
4x	=	Weather:	A letter code representing specific conditions as noted below:

Condition	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > 90%	x		x		x		x		x		x		x		x
b_{ext} > maximum threshold		x	x			x	x			x	x			x	x
b_{ext} uncertainty > threshold				x	x	x	x					x	x	x	x
Δb_{ext} > Delta threshold								x	x	x	x	x	x	x	x

(Letter Code)

Z Weather observation between two other weather observations.

Threshold values are different for each site.

8	=	Missing:	Data acquisition error
9	=	Invalid:	b_{ext} data below Rayleigh (underrange)
A	=	Invalid:	Misalignment
L	=	Invalid:	Defective lamp
S	=	Invalid:	Suspect data
W	=	Invalid:	Unclean optics

Validity codes for meteorological data include:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from an alternate logger
5	=	Invalid:	Data > maximum or < minimum
8	=	Missing:	Data acquisition error

A -99 in any data field indicates missing or invalid data.

See Section 4.1.8, Quality Assurance, for a detailed discussion regarding uncertainty measurements.

A screening program should be used to again check all data and validity codes for inconsistencies. The data should then be reduced to four-hour average values of extinction (b_{ext}), standard visual range (SVR), and haziness (dv). The time periods of the four-hour average values are:

0300	0000 - 0359 hours
0700	0400 - 0759 hours
1100	0800 - 1159 hours
1500	1200 - 1559 hours
1900	1600 - 1959 hours
2300	2000 - 2359 hours

Seasonal data plots can then generated and reviewed to identify data reduction and validation errors, instrument operation problems, and calibration inconsistencies. Any identified problems should be immediately investigated and resolved by following the procedures detailed in standard operating procedures and technical instructions.

4.1.7 <u>Data Reporting and Archive</u>

4.1.7.1 Data Reporting

Data reports should be prepared in a format that generally conforms to the *Guidelines for Preparing Reports for the NPS Air Quality Division* (AH Technical Services, 1987). A separate data report should be prepared for each instrument type; transmissometer data reports should contain only transmissometer data. Reporting consists of various text discussions and graphics presentations concerning the instrumentation and collected data. Specific contents of the reports are defined by the contracting agencies' COTR.

Seasonal transmissometer reporting should be completed within three months after the end of a monitoring season, and annual reporting within three months after the end of the last reported season. Standard meteorological monitoring seasons are defined as:

Winter	(December, January, and February)
Spring	(March, April, and May)
Summer	(June, July, and August)
Fall	(September, October, and November)

Reports should contain the following major sections:

! Introduction

! Data Collection and Reduction

! Site Configuration

! Data Summary Description

! Transmissometer Data Summaries

! Summary

! References

The introduction should contain a conceptual overview of the purpose of the monitoring program and a description of the monitoring networks. The data collection and reduction section should include data collection methods, data file review, data validation, application of validity codes, processing through various validation levels, and discussion of file formats, theoretical concepts of uncertainty measurements, and identification of meteorological and optical interferences that affect the calculation of b_{ext} from transmissometer measurements. Various units of measurement, including haziness (dv), extinction (b_{ext}), and standard visual range (SVR) should be discussed.

The site configuration section should contain a brief discussion of instrumentation at each transmissometer site, basic principles of operation, measurement principles, and data collection specifications, including:

! A map depicting the location of all monitoring network sites.

! A Monitoring History Summary Table, listing for each monitoring site the name, type of instrumentation, and period of operation for each instrument type.

! A Site Specifications Summary Table, listing for each monitoring site complete site specifications. Site specifications include site name and abbreviation, latitude and longitude of both the receiver and transmitter, elevation of both the receiver and transmitter, the sight path distance between the two components, azimuth, and elevation angle (receiver to transmitter) of the sight path. The table should also include the number of readings taken each day, and the operating period during the season.

A data summary description section describes seasonal and annual data summaries. Annual data summaries should be prepared for each site that operated during the reporting period, and should be based on a calendar year instead of season. An example Seasonal Transmissometer Data Summary is presented as Figure 4-2 and an example Annual Transmissometer Data Summary is presented as Figure 4-3. The following is a detailed explanation of the contents of the data summaries in each report.

Seasonal Transmissometer Data Summaries include the following five data presentations:

- 4-Hour Average Variation in Visual Air Quality (Excluding Weather-Affected Data) - Plot of four-hour averaged b_{ext}, SVR, and dv geometric mean values (without weather-influenced observations) for each day of the reporting season. A mean value is calculated for each four-hour period from the valid transmissions for that day. Gaps in the plot indicate that data were missing, weather-influenced, or failed edit procedures. For example, values are not calculated if the transmissometer was misaligned. The left axis of the graph is labeled as haziness (dv) and the right axis as b_{ext} and SVR.

- Relative Humidity - Timeline of four-hour averaged relative humidity measurements. This allows rapid determination of the effect of increasing relative humidity on measured b_{ext} and SVR. Long periods of relative humidity near 100% usually result in corresponding periods of high b_{ext} (low SVR), and are likely associated with precipitation events. This assumption can only be verified by reviewing simultaneous photographic data.

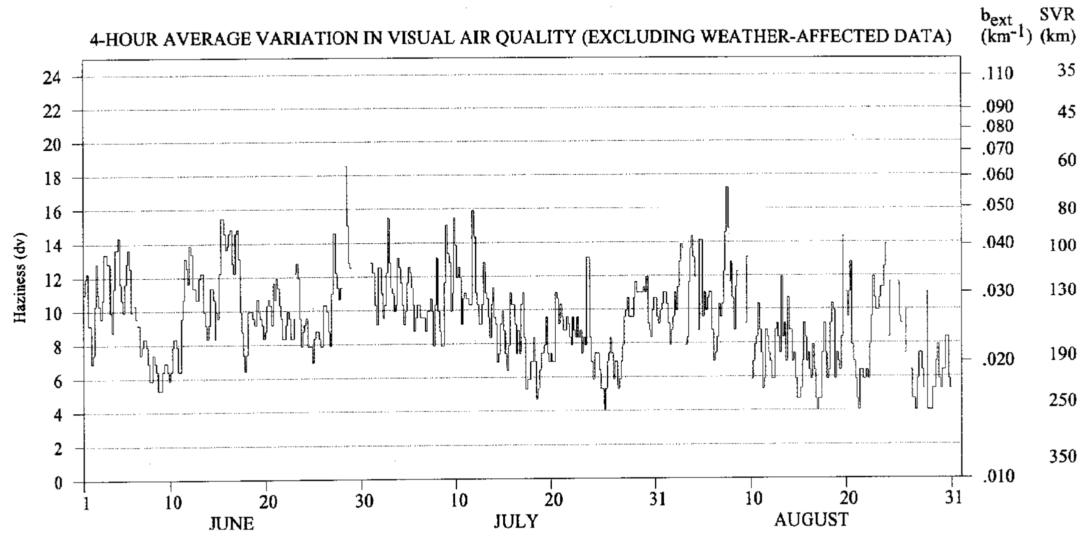
- Frequency of Occurrence: Hourly Data - This plot is a frequency distribution of hourly average b_{ext}, SVR, and haziness values, both with and without weather-influenced data. The 10% to 90% values are plotted in 10% increments. The 10%, 50%, and 90% cumulative frequency values for b_{ext} are listed to the right of the plot and haziness to the left of the plot. SVR values are listed in the corresponding cumulative frequency summary table. Note that SVR and b_{ext} are inversely related; for example, as the air becomes cleaner, b_{ext} values decrease and SVR values increase.

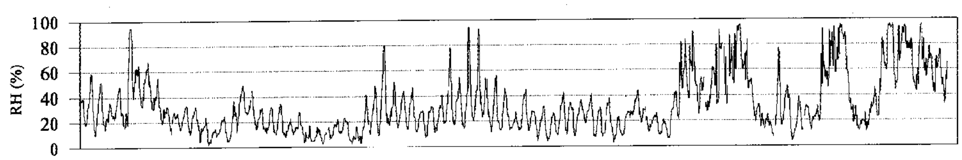
  For deciview, the 10%, 50%, and 90% values are linear with respect to b_{ext} changes. A one dv change is approximately a 10% change in b_{ext}. Clean days are characterized by low haziness values (small dv) and dirty days are characterized by high haziness values (large dv).

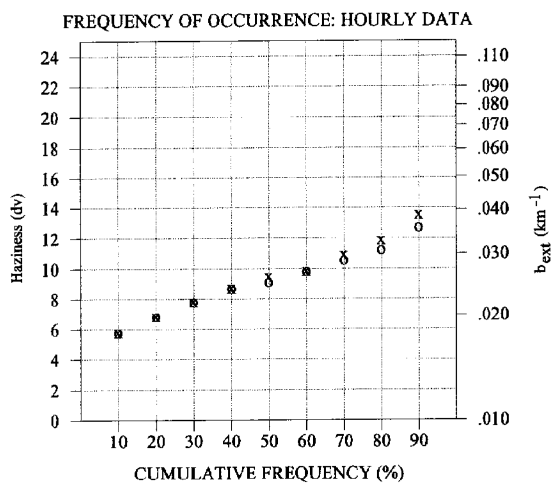
GRAND CANYON NATIONAL PARK (SOUTH RIM), ARIZONA

Transmissometer Data Summary

Summer Season: June 1, 1993 - August 31, 1993







CUMULATIVE FREQUENCY SUMMARY

%	Excluding Weather [o] dv	b_{ext}	SVR	Including Weather [x] dv	b_{ext}	SVR
10	5.9	.018	210	5.9	.018	210
20	6.9	.020	189	6.9	.020	189
30	7.9	.022	173	7.9	.022	173
40	8.8	.024	159	8.8	.024	159
50	9.2	.025	153	9.6	.026	147
60	9.9	.027	141	9.9	.027	141
70	10.6	.029	132	11.0	.030	128
80	11.3	.031	124	11.9	.033	116
90	12.8	.036	107	13.6	.039	99

VISIBILITY METRIC (EXCLUDING WEATHER)

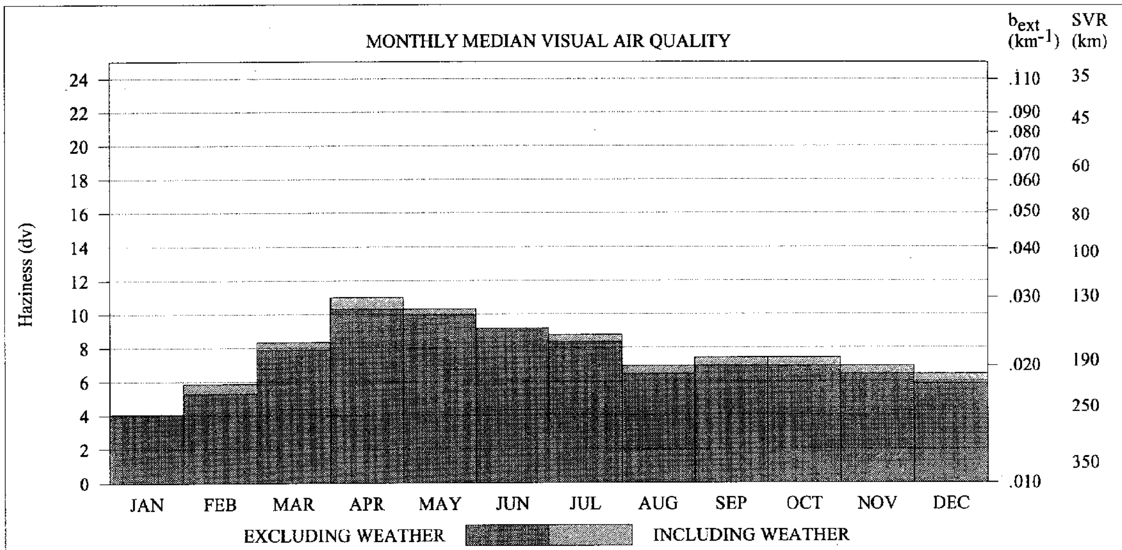
	dv	b_{ext}	SVR
Mean of cleanest 20%	5.8	.018	213
Mean of all data	9.3	.026	155
Mean of dirtiest 20%	13.1	.037	105

TRANSMISSOMETER DATA RECOVERY	NUM	%
Total Possible Hourly Averages In The Time Period	2208	100
Valid Hourly Averages Including Weather-Affected Data	2137	97
Valid Hourly Averages Excluding Weather-Affected Data	1962	89
Percent Of All Valid Hourly Averages Not Affected By Weather		92

L:01/25/96 T:01/23/95 W:08/22/94 1:37 p P:02/06/96 V1.8:5/4/95

Figure 4-2. Example Seasonal Transmissometer Data Summary.

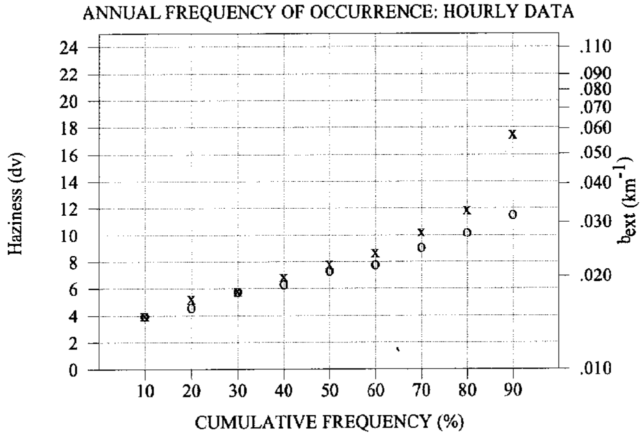
GRAND CANYON NATIONAL PARK (SOUTH RIM), ARIZONA
Annual Transmissometer Data Summary
All Data: January 1, 1994 - December 31, 1994



MONTHLY CUMULATIVE FREQUENCY SUMMARIES

		EXCLUDING WEATHER						INCLUDING WEATHER						DATA RECOVERY STATISTICS						
		10%		50%		90%		10%		50%		90%		POSS.	COLLECTED		VALID:IN. WX.		VALID:EX. WX.	
MONTH	YEAR	bext	dv	bext	dv	bext	dv	bext	dv	bext	dv	bext	dv	NUM	NUM	%	NUM	%	NUM	%
JAN	1994	0.012	1.8	0.015	4.1	0.022	7.9	0.012	1.8	0.015	4.1	0.044	14.8	744	744	100	743	100	637	86
FEB	1994	0.014	3.4	0.017	5.3	0.021	7.4	0.014	3.4	0.018	5.9	0.675	42.1	672	657	98	657	98	446	66
MAR	1994	0.018	5.9	0.022	7.9	0.030	11.0	0.018	5.9	0.023	8.3	0.082	21.0	744	735	99	735	99	603	81
APR	1994	0.018	5.9	0.028	10.3	0.040	13.9	0.018	5.9	0.030	11.0	0.246	32.0	720	717	100	717	100	554	77
MAY	1994	0.022	7.9	0.027	9.9	0.036	12.8	0.022	7.9	0.028	10.3	0.038	13.4	744	744	100	744	100	680	91
JUN	1994	0.018	5.9	0.025	9.2	0.036	12.8	0.018	5.9	0.025	9.2	0.036	12.8	720	714	99	555	77	534	74
JUL	1994	0.014	3.4	0.023	8.3	0.033	11.9	0.014	3.4	0.024	8.8	0.043	14.6	744	742	100	499	67	426	57
AUG	1994	0.015	4.1	0.019	6.4	0.028	10.3	0.015	4.1	0.020	6.9	0.031	11.3	744	744	100	536	72	460	62
SEP	1994	0.015	4.1	0.020	6.9	0.027	9.9	0.015	4.1	0.021	7.4	0.039	13.6	720	709	98	679	94	545	76
OCT	1994	0.016	4.7	0.020	6.9	0.031	11.3	0.016	4.7	0.021	7.4	0.037	13.1	744	727	98	722	97	629	85
NOV	1994	0.014	3.4	0.019	6.4	0.027	9.9	0.015	4.1	0.020	6.9	0.107	23.7	720	714	99	714	99	566	79
DEC	1994	0.015	4.1	0.018	5.9	0.026	9.6	0.015	4.1	0.019	6.4	0.675	42.1	744	744	100	744	100	531	71
ALL DATA		0.015	4.1	0.021	7.4	0.032	11.6	0.015	4.1	0.022	7.9	0.058	17.6	8760	8691	99	8045	92	6611	75

ANNUAL FREQUENCY OF OCCURRENCE: HOURLY DATA



ANNUAL CUMULATIVE FREQUENCY SUMMARY

	Excluding Weather [o]			Including Weather [x]		
%	dv	b_{ext}	SVR	dv	b_{ext}	SVR
10	4.1	.015	250	4.1	.015	250
20	4.7	.016	235	5.3	.017	222
30	5.9	.018	210	5.9	.018	210
40	6.4	.019	199	6.9	.020	189
50	7.4	.021	181	7.9	.022	173
60	7.9	.022	173	8.8	.024	159
70	9.2	.025	153	10.3	.028	137
80	10.3	.028	137	11.9	.033	116
90	11.6	.032	120	17.6	.058	67

FOR A GIVEN % OF THE TIME THE HAZINESS IS LESS THAN OR EQUAL TO THE CORRESPONDING dv VALUE.

D:10/03/95 2:52 p P:02/20/96

V1.03:09/06/94

Figure 4-3. Example Annual Transmissometer Data Summary.

- Visibility Metric (Excluding Weather) - This table presents mean values excluding weather for dv, b_{ext}, and SVR. The best, worst, and average conditions using the arithmetic means of the 20th percentile least impaired visibility, the 20th percentile most impaired visibility, and for all data for the season are presented.

- Data Recovery Statistics

  Total Possible Hourly Averages in the Time Period - The total possible category is calculated by subtracting the number of hourly averages included in periods when the instrument was removed due to conditions unrelated to system performance (construction, site relocation, etc.) from the theoretical maximum number of hourly average periods possible during a season.

  Valid Hourly Averages Including Weather-Affected Data - The number of all valid hourly averages collected during a season. The percentage represents the number of valid hourly averages compared to the total possible hourly averages.

  Valid Hourly Averages Excluding Weather-Affected Data - The number of valid hourly averages (excluding any data affected by weather) collected during a season. The percentage represents the number of valid hourly averages compared to the total possible hourly averages.

  Percent of All Valid Hourly Averages Not Affected by Weather - This percentage collection efficiency represents the number of valid hourly averages (excluding any data affected by weather) compared to the number of all valid hourly averages.

Annual Transmissometer Data Summaries include three data presentations:

- Monthly Median Visual Air Quality - Plot of median monthly b_{ext}, SVR, and dv values both with and without weather-affected data. The left axis of the graph is labeled as haziness (dv) and the right axis as b_{ext} and SVR. Note that SVR and b_{ext} are inversely related.

- Monthly Cumulative Frequency Summaries: All Data - Table of cumulative frequency distribution average b_{ext} and dv values both with and without weather-influenced data. The 10% to 90% values are presented in 10% increments. Also included are data recovery statistics (total possible readings, number of collected readings, and number of valid (both with and without weather-affected data).

- Annual Frequency of Occurrence: Hourly Data - This plot is a frequency distribution of hourly average b_{ext}, SVR, and haziness values, both with and without weather-influenced data. The 10% to 90% values are plotted in 10% increments.

Transmissometer data summaries should follow their description. Summaries should be prepared for each site that operated during the reporting period. A brief discussion of events and circumstances that influence data recovery should follow the data summaries. Operational status throughout the reporting period should be presented for each site in an operation summary table, listing for each site, site name and abbreviation, the actual time period during the season that each site collected data, data collection losses or problem description, and problem resolutions. An analysis summary table should also be prepared (for all data and for all data excluding weather events) based on actual monitoring periods. The table lists for each site, site name and abbreviation, the number of seasonal hourly averages possible, the number and percentage of hourly averages usable, and the cumulative frequency distribution (10%, 50%, and 90% dv, b_{ext}, and SVR values).

Finally, a summary section should be included in reports, and provide a synopsis of the transmissometer network, including changes in operational techniques, and a general conclusion of the monitoring period in review. A reference section should include technical references (documents cited in the report), and related reports and publications (including all prior reports pertaining to the monitoring program).

4.1.7.2 Data Archive

Archiving of raw digital data should be performed on a monthly basis. Archiving of all raw and processed digital data for a given season, and constants, calibration, and data processing files should be performed on a seasonal basis, after data have been finalized and reported. All files should be in ASCII format. Files should be stored in their original formats (raw, Level-A, Level-0, and Level-1) on magnetic tape and CD-ROM. At least two copies of each media should be created; one copy should be stored at the data processing location and the other off-site.

Hard copies of supporting documentation and reports should be duplicated and archived on a continual basis, and include site specifications, monitoring timelines, data coordinator/site operator correspondence, site operator log sheets, trip reports, bi-monthly and seasonal summary plots, instrument calibration records, instrument maintenance logs, and field audit reports. All validated Level-1 data should be delivered as ASCII files (on PC-compatible diskettes and/or CD-ROM) to the COTR with the quarterly and annual reports. The standard file format currently used for IMPROVE protocol transmissometer data is presented in Figure 4-4.

Transmissometer data and accompanying site and calibration information should also be kept current on a database. The database should contain both raw and Level-1 validated data.

4.1.8 Quality Assurance

Quality assurance of transmissometer data is performed during Level-1 validation, and includes precision and accuracy of the instrument, and various uncertainty measurements. Annual field audits are also a component of quality assurance.

4.1.8.1 Instrument Precision and Accuracy

Precision of extinction estimates from transmittance measurements should be determined. The average extinction ($\boldsymbol{b}_{\mathbf{ext}}$) of the transmissometer optical path (***r***) is calculated from the transmittance measurement (***T***) by:

$$b_{ext} = -\ln(T)/r \qquad (4\text{-}7)$$

Since the path length ***r*** is measured to an extremely high precision, the precision in $\boldsymbol{b}_{\mathbf{ext}}$ can be

$$\delta_{bext} = \pm U_T / r \qquad (4\text{-}8)$$

approximated from propagation of error analysis as:

Field Number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
GRCA	900702	183	700	12	1	4	0	18	10	300	0	17	1	0	38	3	0	134
GRCA	900702	183	800	-99	-99	0	4	18	10	300	4H	-99	-99	0	-99	-99	0	-99

Field	**Description**
1	Site abbreviation
2	Date in year/month/day format
3	Julian Date
4	Time using a 24-hour clock in hour/minute format
5	b_{ext} (Mm^{-1})
6	b_{ext} uncertainty (Mm^{-1})
7	Number of readings in average
8	Number of readings not in average due to weather
9	Uncertainty threshold (Mm^{-1})
10	Δ threshold (Mm^{-1})
11	Maximum threshold (Mm^{-1})
12	b_{ext} validity code [1]
13	Temperature (°C)
14	Temperature uncertainty (°C)
15	Temperature validity code [2]
16	Relative humidity (%)
17	Relative humidity uncertainty (%)
18	Relative humidity validity code [2]
19	Haziness (dv x 10)

[1] b_{ext} validity codes:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from alternate logger
4x	=	Weather:	A letter code representing specific conditions as noted below:

Condition	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > 90%	x		x		x		x		x		x		x		x
b_{ext} > maximum threshold		x	x			x	x			x	x			x	x
b_{ext} uncertainty > threshold				x	x	x	x					x	x	x	x
Δb_{ext} > delta threshold								x	x	x	x	x	x	x	x

Letter Code

Z Weather observation between 2 other weather observations.

Threshold values may be different for each site.

8	=	Missing:	Data acquisition error
9	=	Invalid:	b_{ext} below Rayleigh
A	=	Invalid:	Mis-alignment
L	=	Invalid:	Defective Lamp
S	=	Invalid:	Suspect Data
W	=	Invalid:	Unclean optics

[2] Meteorology validity codes:

0	=	Valid	
1	=	Invalid:	Site operator error
2	=	Invalid:	System malfunction or removed
3	=	Valid:	Data reduced from alternate logger
5	=	Invalid:	Data > maximum or < minimum
8	=	Missing:	Data acquisition error

A -99 in any data field indicates missing or invalid data.

Figure 4-4. Standard ASCII File Format IMPROVE Protocol Transmissometer Visibility Data.

The relative uncertainty in transmittance leads to an additive uncertainty in extinction that depends on the path length of the transmittance measurement.

Bias in extinction calculations should also be determined. The calibration equation assumes clean glass surfaces of constant transmittance. Any change in the window transmittance results in a bias to the calculated extinction. If the window transmittance decreases the calculated extinction will increase. If the window transmittance increases the calculated extinction will decrease. As with the precision, the bias is a function of the relative change in window transmittance and path distance:

$$\textit{Bias} = (\textit{relative change in window transmittance})/r \qquad (4\text{-}9)$$

The possibility exists for errors to arise from changes in the transmittance of the windows due to:

- Pitting of the windows by wind blown dirt.
- Staining of the windows by pollution.
- Dirt collecting on the window surface due to dust, rain, or snow.
- Fogging of the windows at high humidities.
- Improper servicing resulting in smudging of the windows.
- Removal of the windows due to breakage.

4.1.8.2 Measurement Uncertainties

Measurement uncertainties are considered during Level-1 validation. Uncertainties include transmittance uncertainties, meteorological data uncertainties, and optical interferences uncertainties.

Transmittance uncertainties are based on various parameters. Operationally the basic equation used to calculate path transmittance is:

$$T = I_r / (F_{lamp} * I_{cal}) \qquad (4\text{-}10)$$

where:

T = Transmittance of atmosphere of path r
I_r = Intensity of light measured at r
F_{lamp} = Variability function of lamp output
I_{cal} = Calibration value of transmissometer

The relative uncertainty (U_x) of any measured parameter x is defined as:

$$U_x = \delta_x / \bar{x} \qquad (4\text{-}11)$$

where:

$\bar{x}$ = arithmetic mean of all x measurements
δ_x = precision of measurements x defined as

$$\delta_x = \left[\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2\right]^{1/2} \qquad (4\text{-}12)$$

Using propagation of error analysis the relative uncertainty of the path transmittance can be calculated from the relative uncertainties of the measured variables as:

$$U_T = (U_{Ir}^2 + U_{Ical}^2 + U_{lamp}^2)^{1/2} \qquad (4\text{-}13)$$

where:

U_{T} = relative uncertainty of T
U_{Ir} = relative uncertainty of I_r
U_{Ical} = relative uncertainty of I_{cal}
U_{lamp} = relative uncertainty of F_{lamp}

Understanding the uncertainty of a transmittance measurement requires a thorough investigation of the precision of each of the following:

- Precision in calibration to determine I_{cal}
- Precision in the measurement of I_r
- Precision in the measurement of F_{lamp}

Relative Uncertainty of I_{cal} - The precision in calibration value I_{cal} can be determined by investigating the calibration equation. I_{cal} is the value that would be measured by the transmissometer detector if the atmospheric path was a vacuum. I_{cal} incorporates the path distance r, transmittance of all windows in the path, and size of working aperture used. I_{cal} is determined from:

$$= (CP/WP)^2 \ x \ (WG/CG) \ x \ (WA/CA)^2 \ x \ WT \ x \ (1/FT) \ x \ (1/T) \ x \qquad (4\text{-}14)$$

Using propagation of uncertainty analysis the relative uncertainty in I_{cal} can be shown to be:

$$U_{cal} = \left(2U_{CP}^2 + 2U_{WP}^2 + U_{WG}^2 + U_{CG}^2 + 2U_{WA}^2 + 2U_{CA}^2 + U_{WT}^2 + U_{FT}^2 + U_{CR}^2\right)^{1/2} \qquad (4\text{-}15)$$

Path distances are measured using a laser range finder. Calibration apertures are measured with a precision micrometer. Gain settings are measured with a precision voltmeter. Window and neutral density filter (NDF) transmittances are measured with a reference transmissometer by differencing techniques, thus they do not require absolute calibration. The standard deviation of the raw readings (CR) are calculated at each calibration. The typical working values, measurement precision, and relative uncertainties of these values are:

Parameter		Value	Precision	Relative Uncertainty
CP	Calibration Path	0.3 km	1×10^{-6} km	3.3×10^{-6}
WP	Working Path	5.0 km	1×10^{-6} km	2.0×10^{-7}
CG	Calibration Gain	100	1×10^{-2}	1.0×10^{-4}
WG	Working Gain	500	1×10^{-2}	2.0×10^{-5}
CA	Calibration Aperture	100 mm	1×10^{-2} mm	1.0×10^{-4}
WA	Working Aperture	110 mm	1×10^{-2} mm	9.1×10^{-5}
WT	Window Transmittance	0.810	0.001	1.2×10^{-3}
FT	NDF Transmittance	0.274	-0.001	3.6×10^{-3}
T	CP Transmittance	0.975	0.003	3.1×10^{-3}
CR	Raw Readings	900	2.0	2.2×10^{-3}

Combining the above values into the uncertainty equation leads to a typical relative uncertainty for $\boldsymbol{I_{cal}}$: $\boldsymbol{U_{Ical}}$ = 0.005.

Relative Uncertainty of I_r - Under ambient operating conditions the irradiance measured by the transmissometer receiver will fluctuate due to:

- Atmospheric optical turbulence causing scintillation.
- Atmospheric optical aberrations causing beam wander.
- Varying meteorological conditions along the path: rain, snow, fog.
- Insect swarms causing beam interference.

The precision of each 10-minute irradiance measurement is calculated by the receiver computer as the standard deviation of the ten one-minute average irradiance measurements. The measured standard deviation is a direct estimation of atmospheric optical interference. Typical values of $\boldsymbol{I_r}$ and various operational precision estimates that have been observed in the monitoring network are listed below.

Ambient Extinction (km^{-1})	I_r Value	No Optical Interferences		Optical Interference	
		Precision	Relative Uncertainty	Precision	Relative Uncertainty
0.010	200	1	0.0050	20	0.100
0.020	190	1	0.0053	20	0.105
0.030	180	1	0.0056	20	0.111
0.050	163	1	0.0061	20	0.123
0.100	127	1	0.0079	20	0.158
0.500	17	1	0.0580	20	1.117

Working Path = 5.0 km, I_{cal} = 210

As can be seen the relative uncertainty of the measured intensity is a function of the extinction of the path. For typical extinction measurements free from optical interference in the network, the average relative uncertainty in $\boldsymbol{I_r}$ is approximately: $\boldsymbol{U_{Ir}}$ = *0.0055*.

Relative Uncertainty of F_{lamp} - The major source of uncertainty in the transmissometer data is lamp drift correction. The transmitter employs an optical feedback loop designed to maintain constant irradiance within the 10 nm bandwidth of the receiver filter/detector module. However, comparison of pre and post lamp calibrations show that the transmitter lamp output increases (brightens) with increased hours of lamp use. Tests have shown that the brightening is definitely a function of the lamp rather than the feedback circuit or filter. It is important to note that a 1% increase in irradiance over a path length of approximately five kilometers (the Grand Canyon sight path for example) results in the apparent extinction being decreased by 0.002 km^{-1} (20% of Rayleigh!!); i.e., the instrument measurement indicates the air to be cleaner than it actually is.

Lamp brightening percentages and lamp "on" hours for all systems and lamps post-calibrated at the Fort Collins, Colorado transmissometer calibration facility are entered into a lamp brightening database. The data in this database are used to create statistics on lamp brightening. Lamp brightening percentages for post-calibrated lamps are sorted into time bins based on lamp operational hours. The mean and standard deviation of operational hours and percent lamp brightening were calculated for each bin. Power law functions are fitted to these data to define a statistically based mean lamp brightening and the one sigma upper and lower bounds. Applying the mean function to the raw transmissometer irradiance readings corrects for lamp brightening. The precision of the correction is calculated from the upper and lower bounds for the number of hours on the lamp at the time of the reading.

If, upon post-calibration, a system exhibits abnormally high or low lamp brightening, previously reported extinction data are flagged for further review. The lamp brightening database is continually updated as additional lamps are post-calibrated. Periodically, the lamp brightening statistics are reanalyzed to provide a more accurate description of the lamp drift correction and the precision associated with this correction.

Variations in lamp brightening characteristics for a given lamp design may occur due to variations in manufacturing processes between manufacturers. All lamps used with the LPV-2 transmissometer are purchased from the transmissometer manufacturer, Optec, Inc.

The equation for calculating lamp brightening using this curve is:

$$Lamp\ \ Brightening(\%) = a_o * t^{a_1} \qquad (4\text{-}16)$$

where:

$\boldsymbol{t}$ = accumulated lamp "on" time (hours)
$\boldsymbol{a_0}$ = 0.2700
$\boldsymbol{a_1}$ = 0.4405

From the above analysis, the relative uncertainty in path transmittance can be calculated for each 10-minute transmittance measurement by the transmissometer. The typical values are:

Condition	Relative Uncertainty (U_T)
No Optical Interference	0.02
Optical Interference	0.20

Meteorological data uncertainties and limits are obtained from the manufacturer's literature. The values used are listed below:

U_{temp} = 1°C

U_{RH} = 2% (Rotronics MP100F Sensor)

Maximum temperature = 60°C

Minimum temperature = -50°C

Maximum relative humidity = 100%

Minimum relative humidity = 0%

Optical interferences uncertainties must also be considered. The transmissometer directly measures the irradiance of a light source after the light has traveled over a finite atmospheric path. The average extinction coefficient of the sight path is calculated from this measurement and is attributed to the average concentration of atmospheric gases and ambient aerosols along the sight path. The intensity of the light, however, can be modified not only by intervening gases and aerosols, but also by:

- The presence of condensed water vapor in the form of fog, clouds, and precipitation along the sight path.
- Condensation, frost, snow, or ice on the shelter windows.
- Reduction in light intensity by insects, birds, animals, or vegetation along the sight path, or on the optical surfaces of the instrumentation or shelter windows.
- Fluctuations in light intensity both positive and negative due to optical turbulence, beam wander, atmospheric lensing, and miraging caused by variations in the atmospheric optical index of refraction along the sight path.

An algorithm has been developed to identify transmissometer extinction data that may be affected by the interferences described above. This algorithm contains five major tests:

1) Relative Humidity
2) Maximum Extinction
3) Uncertainty Threshold
4) Rate of Change of Extinction
5) Isolated Data Points

Due to the large volume of extinction data collected by transmissometers as compared to aerosol monitors, the algorithm has been designed to be a conservative filter on the extinction data. That is, if an hourly extinction measurement indicates the slightest possibility of meteorological or optical interference by failing any one of the above tests, it is flagged with identifier codes in the Level-1 data file. The following describes each of the five tests:

Relative Humidity - When the relative humidity measured at the transmissometer receiver is greater than 90%, the corresponding transmissometer measurement is flagged as having a possible interference. The 90% level has been chosen due to the following considerations:

- The relative humidity is only measured at the receiver location and not at any other position along the sight path.

- A 1.5°C change in dew point temperature results in a 10% change in relative humidity.

- The atmosphere is continuously undergoing both systematic and random variations in its spatial and temporal properties.

- The typical precision of relative humidity measurements is ±2%.

The above considerations all indicate that inferring a precise knowledge of the meteorological conditions along a sight path at high relative humidity from a single point measurement is very difficult. When the relative humidity is above 90% at one end of the path, small random temperature or absolute humidity fluctuations along the path can lead to condensation of water vapor causing meteorological interferences. Thus, in accordance with the conservative philosophy expressed above, the 90% relative humidity limit was selected for this test.

Maximum Extinction. For every transmissometer sight path, a maximum b_{ext} can be calculated that corresponds to a 5% transmittance for the path. All sight paths were selected, such that based on historical visibility data, this maximum b_{ext} occurs less than 1% of the time. When the measured b_{ext} is greater than this threshold value, it is assumed that meteorological or optical interferences, not ambient aerosols, are causing the high extinction. All measurements greater than the calculated site-specific maximum threshold are flagged in the data file.

Uncertainty Threshold. The normal operating procedure for the transmissometer is to take 10 one-minute measurements of transmitter irradiance each hour, and report the average and standard deviation of the ten values. A mean hourly extinction and associated uncertainty is then calculated from these measurements. In remote, rural areas, the ambient aerosol concentration typically varies quite slowly with time constants on the order of a few hours rather than minutes. This leads to the expectation of relatively constant extinction during the 10 minutes of receiver measurements and a low standard deviation of measured transmitter irradiance. If only one of the ten irradiance values varies more than 20% from the mean, the uncertainty in b_{ext} will increase dramatically. The presence of any meteorological or optical interferences along the sight path will lead to large standard deviations in lamp irradiance, thus large uncertainties in b_{ext}. With the conservative assumption of constant b_{ext} during any ten minute measurement period, any increase in the uncertainty of b_{ext} above a selected threshold flags the measurement as affected by one of these interferences. The uncertainty threshold is determined for each sight path and is included in each Level-1 data file for reference.

Rate of Change of Extinction (Delta Threshold). Transmissometer data collected before September 1, 1990, did not include standard deviation of measured irradiance values. For data collected before this date, another test was developed to identify periods of interferences associated with rapidly fluctuating irradiance measurements. This test consists of comparing the hourly average extinction to the preceding and following hours, and calculating a rate of change in each direction. If the absolute value of this rate of change is greater than some assigned Delta threshold, the hourly b_{ext} value is flagged as being affected by interferences. Delta thresholds have been determined for each sight path by analyzing extinction data collected after September 1990, which have corresponding uncertainty thresholds to determine appropriate Delta thresholds for the sight path. The Delta threshold is typically not as low as the uncertainty threshold, due to the possibility of larger hourly variations in b_{ext} as compared to variations during ten minutes of measurements. Each sight path has its own Delta threshold and it is listed in the Level-1 data file for reference.

Isolated Data Points. This test is performed after the above four thresholds are applied to the hourly extinction data. It is used to identify data points that have passed the above thresholds, but are located between hourly b_{ext} data that have failed the above thresholds. The conservative assumption is, if data before and after the isolated hour indicates interferences, the hour in question probably is also affected by interferences. These data are also flagged as weather-affected.

4.1.8.3 Instrument Audits

The transmissometer field audit verifies accurate on-site and replacement transmissometer measurements by comparing measurements made with the audit reference transmissometer. The reference transmissometer should be calibrated at the test facility before and after each field audit to ensure that the accuracy of the measurements has not been affected by handling and/or transport of the instrument. To reduce the amount of equipment shipped to and from a transmissometer site, the audit transmissometer system should be operated with the replacement transmissometer computer during the audit. Gain measurements should be made on all instruments during instrument servicing. These gain measurements should then be incorporated into the calculation of calibration numbers generated for the audit transmissometer.

To ensure a quality audit, it is important that the audit be performed during a period of good weather and stable conditions. If the weather and/or conditions are not suitable, the audit should be rescheduled. The audit should be comprised of a defined series of 10-minute readings with various lamps calibrated with the on-site, audit, and replacement transmissometer units (2 lamps on-site, 2 lamps audit, and 3 lamps replacement). The sequence of instruments and lamps should be configured to provide the best possible intercomparison between individual lamps calibrated with a transmissometer system and also between respective transmissometer systems.

The transmissometer field audit also includes a window transmittance test, which verifies the combined transmittance of the transmitter and receiver station windows. This test is typically incorporated into the end of the audit, which is performed on site, but can also be performed separately if necessary. The window transmittance test should include three 10-minute reading segments with the first operational lamp of the replacement transmissometer. The first and last segments should be with the receiver and transmitter windows installed. The middle segment should be performed with both windows removed. This allows determination of window transmittance and provides an indication of the stability of ambient conditions.

The audit results verify the operational integrity of the on-site and replacement instruments. Audit results statistics should be used to define error limits for comparison of path transmittance measurements obtained with an instrument being audited or path transmittance measurements obtained with an audit instrument.

Lamps used operationally with transmissometers being removed from the field (on-site instruments) typically have accumulated 400 to 600 hours of "on" time. This accumulated operating time results in a shift in lamp brightness. Audit data for lamps used in the field should be corrected for lamp brightening. Three sets of audit results statistics should be created as follows:

- One set of audit result statistics should be generated for audit instrument and on-site instrument comparisons applying the standard lamp brightening correction factor. This data set should be used only as an early indicator of the quality of the data collected during the operational period for the on-site transmissometer.

- Operational instruments should be post-calibrated after removal from a site. On-site instrument audit data should be corrected using post-calibration lamp brightening factors. The second set of audit results statistics should be generated using these data. This data set should be incorporated into ongoing analyses of lamp brightening effects on data quality.

- The third set of audit results statistics should be based on measurement comparisons between the replacement transmissometer and the audit transmissometer. Because replacement instrument lamps should be calibrated prior to installing the instrument at a field site, the lamps should not have accumulated any "on" time prior to the audit and lamp brightening should not be a factor. These statistics should be used to define error limits for acceptance of replacement instrument audits.

4.1.9 Data Analysis and Interpretation

Transmissometer data are a complete, continuous measure of atmospheric extinction. Data are typically presented in three units: extinction, standard visual range, and deciview.

Extinction is expressed in inverse megameters (Mm^{-1}). These units are directly stored in the data files.

Standard visual range (SVR) can be interpreted as the farthest distance that a large, black feature can be seen on the horizon. It is a useful visibility index that allows for comparison of data taken at various locations.

$$SVR = \frac{3912}{(b_{ext} - b_{ray} + 10\,Mm^{-1})} \qquad (4\text{-}17)$$

SVR is calculated to normalize all visual ranges to a Rayleigh scattering coefficient of 10 Mm^{-1} or an altitude of 1.524 km (5000 ft.). The Rayleigh scattering coefficient, b_{ray}, for the mean sight path altitude is subtracted from the calculated extinction coefficient, b_{ext}, and the standard Rayleigh scattering coefficient of 10 Mm^{-1} is added back. The value 3912 is the constant derived from assuming a 2% contrast detection threshold. The theoretical maximum SVR is 391 km.

An easily understood visibility index uniformly describes visibility impairment. The scale of this visibility index, expressed in deciview (dv), is linear with respect to perceived visual changes over its entire range, analogous to the decibel scale for sound. A one dv change is about a 10% change in extinction coefficient, which is a small but perceptible scenic change under many circumstances. Since the deciview scale is near zero for a pristine atmosphere (dv=0 for Rayleigh conditions at about

1.8 km elevation) and increases as visibility is degraded, it measures perceived haziness. Expressed in terms of extinction coefficient (b_{ext}) and visual range (vr):

$$haziness(dv) = 10\ \ln\left(\frac{b_{ext}}{10\,Mm^{-1}}\right) = 10\ \ln\left(\frac{391km}{vr}\right) \qquad (4\text{-}18)$$

Ideally, a just noticeable change (JNC) in scene visibility should be approximately a one or two dv change in the deciview scale (i.e., a 10% to 20% fractional change in extinction coefficient) regardless of the baseline visibility level. Similarly, a change of any specific number of dv should appear to have approximately the same magnitude of visual change on any scene.

The dv scale provides a convenient, numerical method for presentation of visibility values. Any visibility monitoring data that are available in visual range or extinction coefficient are easily converted to the new visibility index expressed in deciview.

Use of the dv scale is an appropriate way to compare and combine data from different visibility perception and valuation studies. When results from multiple studies are presented in terms of a common perception index, the effects of survey approach and other factors influential to the results can be evaluated.

Transmissometer data provide a quantitative measure of real time visibility conditions. Data can be used to provide the basis for background conditions and trend analysis; however, data must be combined with associated meteorological and aerosol concentrations to understand the source and/or composition of the impairment observed.

Caution should be taken, however, when comparing reconstructed extinction with measured extinction. Reconstructed extinction is typically 70% - 80% of the measured extinction. The following differences/similarities should be considered:

- Data collection. Reconstructed extinction measurements represent 24-hour samples collected twice per week. Transmissometer extinction estimates represent continuous measurements summarized as hourly means, 24 hours per day, seven days per week.

- Point versus path measurements. Reconstructed extinction represents an indirect measure of extinction at one point source. The transmissometer directly measures the irradiance of light (which calculated gives a direct measure of extinction) over a finite atmospheric path.

- Relative humidity (RH) cutoff. Daily average reconstructed measurements are flagged as invalid when the daily average RH is greater than 98%. Hourly average transmissometer measurements are flagged invalid when the hourly average RH is greater than 90%. These flagging methods often result in data sets that do not reflect the same period of time, or properly interpret short-term meteorological conditions.

4.1.10 Transmissometer Standard Operating Procedures and Technical Instructions

The Air Resource Specialists, Inc. document entitled *Air Resource Specialists, Inc. Standard Operating Procedures and Technical Instructions for Transmissometer Systems*, includes the following transmissometer Standard Operating Procedures and Technical Instructions:

SOP 4050	Site Selection for Optical Monitoring Equipment (IMPROVE Protocol)
TI 4050-3010	Site Selection for Optec LPV-2 Transmissometer Systems
SOP 4070	Installation and Site Documentation for Optical Monitoring Equipment
TI 4070-3010	Installation and Site Documentation for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)
SOP 4110	Transmissometer Maintenance (IMPROVE Protocol)
TI 4110-3100	Routine Site Operator Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)
TI 4110-3300	Troubleshooting and Emergency Maintenance Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)
TI 4110-3350	Transmissometer Monitoring System Diagrams and Component Descriptions
TI 4110-3375	Replacing and Shipping Transmissometer Components
TI 4110-3400	Annual Laboratory Maintenance Procedures for LPV-2 Transmissometer Systems (IMPROVE Protocol)
SOP 4115	Annual Site Visits for Optical Monitoring Instrumentation (IMPROVE Protocol)
TI 4115-3000	Annual Site Visit Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)
SOP 4200	Calibration of Optical Monitoring Systems (IMPROVE Protocol)
TI 4200-2100	Calibration of Optec LPV-2 Transmissometers (IMPROVE Protocol)
TI 4200-2110	Transmissometer Lamp Preparation (Burn-in) Procedures
SOP 4250	Servicing and Calibration of Optical Monitoring Dataloggers
TI 4250-2000	Servicing and Calibration of Campbell Scientific 21XL Dataloggers
TI 4250-2010	Servicing and Calibration of the Handar 540/570 DCP
TI 4250-2020	Servicing and Calibration of Primeline 6723 Strip Chart Recorders
SOP 4300	Collection of Optical Monitoring Data (IMPROVE Protocol)

TI 4300-4000	Data Collection via DCP (IMPROVE Protocol)
TI 4300-4023	Transmissometer Daily Compilation and Review of DCP-Collected Data (IMPROVE Protocol)
TI 4300-4025	Transmissometer Data Collection via Strip Chart Recorder, January 1994
SOP 4400	Optical Monitoring Data Reduction and Validation
TI 4400-5000	Transmissometer Data Reduction and Validation (IMPROVE Protocol)
SOP 4500	Optical Monitoring Data Reporting
TI 4500-5100	Transmissometer Data Reporting (IMPROVE Protocol)
SOP 4600	Optical Monitoring Data Archives
TI 4600-5010	Transmissometer Data Archives (IMPROVE Protocol)
SOP 4710	Transmissometer Field Audit Procedures

4.2 NEPHELOMETER

4.2.1 Measurement Criteria and Instrumentation

The total light scattered out of a path is the same as the reduction of light along a path due to scattering. An ideal integrating nephelometer would collect all the light scattered by aerosols and gases from 0° to 180° in an enclosed sample volume through a defined band of visible wavelengths to yield a direct measurement of b_{scat}. Since a nephelometer makes a point measurement, direct comparisons to collocated aerosol measurements are practical. In addition, the system can be absolutely calibrated using clean (Rayleigh) air and various dense gases with a known multiple of Rayleigh scattering.

The Optec NGN-2 ambient nephelometer has been developed to minimize modification of ambient aerosols and address problems associated with Belfort nephelometers: sizing by the inlet, large truncation error, poorly-defined optical response, and outdated, unstable electronics. The system incorporates sensors, signal detection techniques, and electronics developed for the Optec transmissometer previously discussed. As shown in Figure 4-5, the ambient nephelometer features low-power (45-watt) operation, solid compact design, and digital electronics resulting in a stable linear performance over a wide temperature range. The complete system is contained in a single unit and is separated into three (3) chambers: optical, pump, and electronics. A cross sectional view of the Optec NGN-2 is represented in Figure 4-6. The optical chamber features a single large door that opens a complete side of the chamber to unrestricted ambient air flow. A stainless-steel, 24-mesh screen covers the inlet opening to prevent insects, leaves, or other large masses from entering the scattering chamber. The chamber is completely sealed by a double wall from the rest of the system to prevent either heat or air from modifying the ambient aerosol as it passes through the scattering volume. Separate and sealed from the electronics chamber, the pump chamber houses the exhaust fan, exhaust port door, lamp cooling heat sink, clean air pump, and span gas solenoid activated inlet valve. The exhaust air from the optical chamber passes across the finned heat sink as it exits, removing heat from the system. The electronics chamber contains the projector lamp, chopper motor, scattered light detector/electrometer, computer, interface board, and door motor. A thick metal shield around the lamp absorbs and conducts most of the waste heat from the bulb, infrared heat filter, and electronics into the heat sink located in the pump chamber. The internal CMOS computer controls all operating functions and outputs data and system parameters in digital and analog format.

The optical design of the detector field of view, illumination cone, and scattering volume allows for integration of scattered light from 5° to 175°. A low-voltage (13.8 VDC), quartz halogen projector bulb with dichroic reflector illuminates an opal glass diffuser. In the light path between the diffuser and bulb, a heat-absorbing filter blocks all radiation longer than 700 nm in wavelength and a mechanical chopper modulates the beam at 10 Hz. A telescope with a precisely defined field of view, collects the light from a cylindrical pencil (6 mm x 260 mm) of air slightly above the diffuser. The opposite end of the path terminates in a light trap. A small lens behind the field stop images the entrance pupil (objective lens) of the telescope onto the active area of a photodiode detector. This detector measures light scattered by the gases and aerosols in the scattering volume plus light reflected from the surfaces and stop edges in the optical chamber. This wall component of the measured light is constant and corrected for by zero and span calibrations.

Figure 4-5. Entire Nephelometer System Set on a Tower.

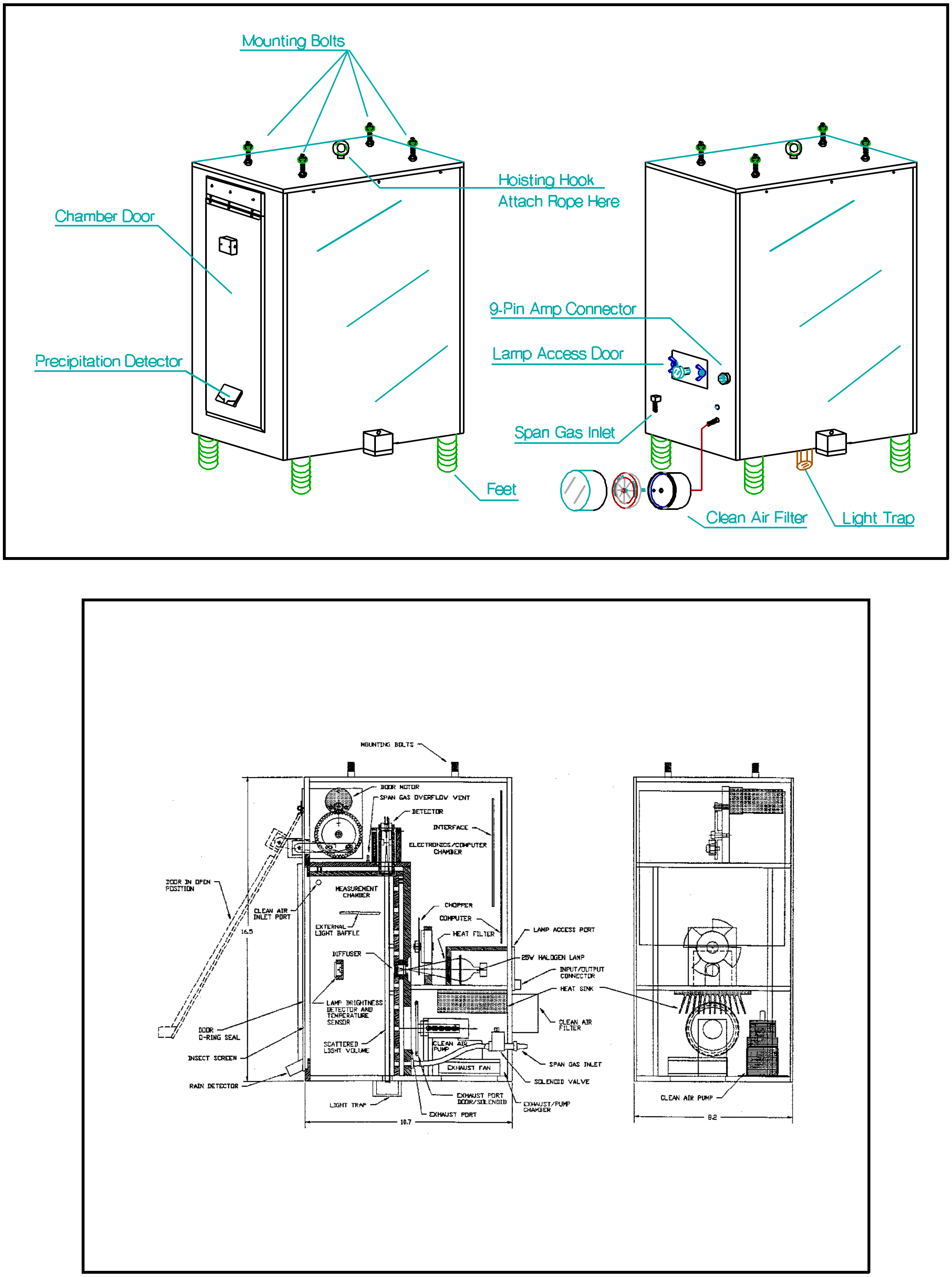


Figure 4-6. Close-Up of a Nephelometer and Cross-View of Its Internal Components.

Within the optical chamber, directly in front of the diffuser, is an identical photodiode detector. This detector directly measures the intensity of the lamp. Using the output of this detector to normalize the scattered light signal compensates for lamp brightness changes due to power supply fluctuations, lamp aging, and dust on the optical surfaces.

The single board computer controls all operating functions of the NGN-2 which include: scattered light measurement, clean-air zero calibration, span gas calibration, moisture detection to close the optical chamber door during rain or snow conditions, optical chamber temperature measurement, initial data reduction, various error detection schemes, and diagnostic tests.

Integrating nephelometers estimate the atmospheric scattering coefficient (b_{scat}) by directly measuring the light scattered by aerosols and gases in the sampled air volume. Scattered radiation from an illumination source is integrated over a large range of scattering angles, in a defined band of visible wavelengths. Because the total light scattered out of a path is the same as the reduction of light along a path due to scattering, the integrating nephelometer gives a direct estimate of b_{scat}.

The Optec, Inc. NGN-2 (Next Generation Nephelometer) uses a unique integrating open-air design that allows accurate measurement of the scattering extinction coefficient of ambient air. Because of the open-air design, relative humidity and temperature of the air sample are essentially unchanged, thus the aerosol is negligibly modified when brought into the optical measuring chamber. Extinction due to scatter can accurately be measured from Rayleigh to 100% saturated fog conditions.

The National Park Service instituted the use of ambient nephelometers in 1993. This new technology enhanced other methods of visibility monitoring and increased the accuracy with which ambient optical data are measured. The nephelometer has proven to be an effective method of collecting scattering data over a wide range of environmental conditions.

Detailed information regarding nephelometer instrumentation or operation can be found in *Model NGN-2 Open-air Integrating Nephelometer, Technical Manual for Theory of Operation and Operating Procedures* (Optec, 1993) and *Standard Operating Procedures and Technical Instructions for Nephelometer Systems* (Air Resource Specialists, Inc., 1993-1996).

4.2.2 Siting Criteria

The primary siting criteria involves selecting a location that represents the air mass of interest. A nephelometer can be easily collocated with other monitoring instrumentation such as a fine particulate sampler, camera system, meteorological instrumentation, or a criteria pollutant monitoring station. Because the nephelometer operates under ambient conditions, climate-controlled sheltering is not necessary, but a precipitation/solar radiation shield is suggested.

An external power supply, calibration span gas supply, and datalogging system are required. The low power requirements of the system accommodate line power or solar power installations.

Selected nephelometer sites should have most of the following characteristics:

- Be located in an area representative of the air mass to be monitored

- Be removed from local pollution sources and away from obstructions that could affect the air flow in the area of the instrument

- Have AC power and telephone lines available

- Allow for orientation of the nephelometer sample inlet towards true north

- Be representative of the same air mass measured by associated aerosol (particle monitors) and scene (camera) instrumentation

- Meet the same criteria used to site particle samplers, including:

  - Have a distance from the instrument to the nearest obstruction greater than 2.5 times the difference in heights of the instrument and the obstruction

  - Be representative of regional (not local) visibility

  - Be removed from local pollution influences (e.g., vehicle exhaust, wood smoke, road dust, etc.)

- Be secure from vandalism

- Have available servicing personnel (operator)

- Be reasonably accessible during all months of the year

4.2.3 Installation and Site Documentation

Nephelometer system components are typically mounted on a 4 meter (14 foot) meteorological tower. The tower must be installed with one face oriented to true north. The nephelometer will be mounted on this northward face. The tower may be placed in sand or loose soil, or rock, and is secured with guy wires. The nephelometer is mounted, along with a solar radiation and precipitation shield, a precipitation hood, a datalogging and control subsystem, an AT/RH sensor, a force-aspirated shield, and a span gas calibration system. The system is generally AC powered and a telephone line is generally required.

System operation is verified and calibration is performed after all components are installed. Upon completing the installation and verifying system operation, all operators, back-up operators, and any other involved or interested on-site personnel should be trained, including reviewing a site operator's manual. The manual contains technical instructions for operator maintenance, troubleshooting, system diagrams, replacing and shipping components, and a manufacturer's manual (ARS, Inc., TI 4100-3100, TI 4100-3350, TI 4100-3375, and *Model NGN-2 Open-Air Integrating Nephelometer Technical Manual for Theory of Operation and Operating Procedures* (Optec, Inc.).

Other site documentation includes completion of a site visit trip report, photographic documentation (including photographs of vistas in all directions from the tower, telephone and AC wiring, local sources or obstructions to air flow to the station, landmarks used to locate the site, the station itself, and other detailed close-ups), and documentation of any miscellaneous information necessary to make a complete site description, including site map and site specifications (latitude, longitude, instrument elevation, etc.)., dominating pollutant influences, (listing the source and pollutant), type of land use within 1/2 km of the site, collocated equipment, and general climate.

4.2.4 System Performance and Maintenance

System performance and maintenance includes routine servicing, annual site visits, instrument calibration, and annual servicing.

4.2.4.1 Routine Servicing

Routine site operator maintenance for a nephelometer should be performed weekly and includes the following general tasks:

! Inspecting the condition of all structural hardware, nephelometer components, support system components, and meteorological sensors.

! Verifying power system status.

! Checking system timing.

! Initiating a zero and upscale/span calibration check.

! Observing the Power-On Self Test (POST)

! Exchanging the data storage module.

! Documenting system readings.

The majority of nephelometer problems are due to moisture in the nephelometer, lamp malfunction, electrical power outages or surges, and lightning induced voltage spikes.

4.2.4.2 Annual Site Visits

Annual site visits are performed to exchange the existing nephelometer for a newly serviced instrument, and to train site operators in servicing and maintaining the monitoring components. Primary tasks for a typical annual site visit include:

! Documenting initial conditions of the components.

! Verifying existing system operation and calibration (pre-removal).

! Performing clean air (zero) and upscale span calibration of the existing system.

! Conducting site inventory.

! Replacing the nephelometer, datalogging and control subsystem, and AT/RH sensor.

- Verifying replacement system operation and calibration (post-installation).

- Performing clean air (zero) and upscale span calibrations of the replacement system.

Site operator training should be performed to discuss the purpose of the monitoring program and theory of nephelometer system operation.

4.2.4.3 Instrument Calibration

Two methods of calibrating nephelometers are the simple calibration and the complete calibration. Simple calibrations are initiated weekly by site operators and occasionally by field specialists to check the operation of the nephelometer system. Simple calibration includes:

- A span check consisting of ten (10) minutes of gas introduction, then an average of ten (10) 1-minute readings of a span gas with known scattering properties, usually SUVA-134a.

- A clean air zero check consisting of five (5) minutes of internal air filtering, then an average of ten (10) 1-minute readings of particle-free air, using the nephelometer's internal air filtering system.

Complete calibrations are performed by the field specialist or instrument technician during installations, removals, and laboratory testing. Complete calibrations are performed upon acceptance testing of a new instrument, installation or removal at a field site, during laboratory maintenance, or during annual or audit site visits. Complete calibration includes:

- Nephelometer Power-On Self Test (POST) information.

- Twenty 1-minute clean air zero readings.

- Twenty 1-minute span readings.

4.2.4.4 Annual Servicing

Nephelometers are precision instruments that require careful cleaning and inspection to ensure optimum measurement accuracy. This level of servicing must be performed in a laboratory environment using specialized electronic and optical test equipment. Nephelometers operating in the IMPROVE network are replaced in the field and serviced on an annual basis.

Each instrument must be fully serviced before it is reinstalled at a field site. Servicing includes the following major tasks:

- Visual inspection

- Post-field calibration

- Cleaning

- Hardware upgrade/modifications

- Component functional tests

- Pre-field calibration

4.2.5 Data Collection

The nephelometer outputs a two-minute integrated average value for measured ambient scattering, along with the associated status code at five-minute intervals. The on-site datalogger collects nephelometer data, along with instantaneous measurements of air temperature and relative humidity at five-minute intervals. At sites with telephone lines, the on-site datalogger is interrogated daily via telephone modem. At sites where telephone access is unavailable, preliminary data from the on-site datalogger are transmitted daily via GOES satellite and Handar data collection platforms (DCPs).

4.2.6 Data Reduction and Validation

4.2.6.1 Data Reduction

Nephelometer data should be compiled into site-specific Level-A files. Data processing includes processing each daily file into:

- 5-minute nephelometer, ambient temperature, and relative humidity data.

- Hourly average wind speed, wind direction, temperature, and relative humidity data.

- Hourly nephelometer status code and support system status code summaries. Data should be reviewed daily by data analysts to determine the operational characteristics of each site. Any apparent problem should result in a telephone call to the site operator in an attempt to resolve the inconsistencies.

Weekly plots are generated from raw data files. Information from operator log sheets should be checked against data collected to identify inconsistencies and errors. Inconsistent or suspicious data can then be identified and troubleshooting procedures initiated. As completed log sheets from nephelometer sites are received, the pertinent information (visibility conditions, instrument problems, etc.) should be manually transferred to the weekly plots. This procedure helps to identify the exact time of calibrations and other actions done by the site operator affecting instrument operation.

4.2.6.2 Data Validation

Nephelometer data should undergo three validation levels: Level-A, Level-0, and Level-1. Level-A includes visual review and examination of the raw data and extracting codes, Level-0 includes searching for questionable or invalid data, and Level-1 includes computing hourly averages and extracting data having meteorological influences.

Level-A data files should be compiled into seasonal data files for each site. Standard meteorological seasons are defined as:

Winter	December, January, and February
Spring	March, April, and May
Summer	June, July, and August
Fall	September, October, and November.

Level-A validation begins immediately after collection. Parameters are extracted from the raw data file and appended to site-specific seasonal data files. Automatic clean air zero calibrations and operator-initiated clean air zero and span calibrations are extracted from the raw data file and appended to nephelometer-specific quality assurance calibration files. The three validity codes extracted from the raw data and assigned to the Level-A data file are:

- The **power code**, generated by the datalogger, is an hourly summary of any AC or DC power problems that occurred during the previous hour.

- The **nephelometer status code**, is generated by the nephelometer to indicate the type of measurement (ambient, clean air zero or span calibration), or problem (rain, lamp out, chopper motor failure).

- The **type code**, indicates the source of nephelometer data (serial, analog, DCP).

Level-0 validation begins with updating the quality assurance database and calibration files. The QA database files are site-specific files containing data validation codes and comments detailing the history of the site's nephelometer. The QA calibration files contain all zero and span calibrations performed on a nephelometer during a specific time period, including the initial zero and span performed during installation. Uncertainty estimates generated with the QA calibration plots are entered manually in the QA database files. The uncertainty estimates appear in the Level-1 data file for reference. Level-0 validation of nephelometer and meteorological data is performed seasonally and serves as an intermediate data reduction step. Level-A data are reviewed to identify periods of invalid nephelometer data caused by the following:

- Burned out lamp

- Power failures

- Water contamination

- Sensor failures

- Other problems

Level-1 validation is performed seasonally and includes the following tasks:

- Computation of hourly averages from Level-0 data
- Automatic validation of QA calibration file entries
- Conversion of hourly average data to engineering units
- Overrange/underrange checks
- Identification of nephelometer b_{scat} data affected by meteorological interference
- Estimation of precision

Hourly averages are computed from Level-0 data. The zero calibration information in the QA calibration files is used to calculate a calibration line for each data point. The nephelometer scattering coefficient of total extinction is calculated by determining a calibration line for each raw nephelometer scattering data point as follows:

- The **zero** is determined by interpolating (in time) between the valid clean air calibrations prior to, and following the data point.
- The **initial span** is determined from the initial calibration of the instrument upon installation.

$$Initial\ span\ =\ Initial\ upscale\ span\ gas\ calibration\ -\ Initial\ clean\ air\ calibration \qquad (4\text{-}19)$$

- The **Rayleigh** coefficient is the site-specific altitude-dependent scattering of particle-free air.
- The **designated span** is determined by the span gas used during the initial calibration, and the Rayleigh coefficient. The span gas SUVA (HFC-134a) (Dupont) has been shown to scatter 7.1 times that of particle-free (Rayleigh) air.

$$Designated\ span\ =\ 7.1\ x\ Rayleigh \qquad (4\text{-}20)$$

- The slope and intercept of the calibration line are:

$$Slope\ =\ (designated\ span\ -\ Ray)\ /\ Initial\ span$$
$$Intercept\ =\ (Ray\ -\ slope\ x\ zero) \qquad (4\text{-}21)$$

- Nephelometer data and calibrations are in unitless counts. If the units for the Rayleigh coefficient are km^{-1}, the units for b_{scat} will also be in km^{-1}. Nephelometer scattering is calculated from the calibration line as follows:

$$b_{scat}\ =\ (slope\ x\ Raw\ Neph\ Value)\ +\ Intercept \qquad (4\text{-}22)$$

The following additional validation checks are performed to complete the Level-1 validation process:

- Data invalid at Level-0 are invalid at Level-1.
- Calculated b_{scat} data less than Rayleigh scattering are invalid.
- Meteorological data are not validated beyond Level-0.

Data are filtered to identify periods likely affected by meteorological interference. The following filter criteria are used to identify these periods:

- Rate of change: If the rate of change between hourly b_{scat} data exceeds 50 Mm^{-1}, the b_{scat} value is coded as filtered.
- Maximum: If the b_{scat} data exceeds 5000 Mm^{-1}, the b_{scat} value is coded as filtered.
- Relative humidity: If the RH corresponding to the b_{scat} value exceeds 95%, the b_{scat} value is coded as filtered.
- δ/μ: If the standard deviation of the hourly raw nephelometer data divided by the mean of the hourly raw data exceeds 10%, the value is coded as filtered.

Data identified as affected by meteorological interference are still considered valid.

Seasonal data plots can then be generated and reviewed to identify data reduction and validation errors, instrument operation problems, and calibration inconsistencies. Any identified problems should be immediately investigated and resolved by following the procedures detailed in standard operating procedures and technical instructions.

4.2.7 <u>Data Reporting and Archive</u>

4.2.7.1 Data Reporting

Data reports should be prepared in a format that generally conforms to the *Guidelines for Preparing Reports for the NPS Air Quality Division* (AH Technical Services, 1987). A separate data report should be prepared for each instrument type; nephelometer data reports should contain only nephelometer data. Reporting consists of various text discussions and graphics presentations concerning the instrumentation and collected data. Specific contents of the reports are defined by the contracting agencies' COTR.

Seasonal nephelometer reporting should be completed within three months after the end of a monitoring season, and annual reporting within three months after the end of the last reported season. Standard meteorological monitoring seasons are defined as:

Winter	(December, January, and February)
Spring	(March, April, and May)
Summer	(June, July, and August)
Fall	(September, October, and November)

Reports should contain the following major sections:

- Introduction
- Data Collection and Reduction
- Site Configuration
- Data Summary Description
- Nephelometer Data Summaries
- Summary
- References

The introduction should contain a conceptual overview of the purpose of the monitoring program and a description of the monitoring networks. The data collection and reduction section should include data collection methods, data file review, data validation, application of validity codes, processing through various validation levels and discussion of file formats, and identification of meteorological and optical interferences that affect the calculation of b_{scat} from nephelometer measurements.

The site configuration section should contain a brief discussion of instrumentation at each nephelometer site, basic principles of operation, measurement principles, and data collection specifications, including:

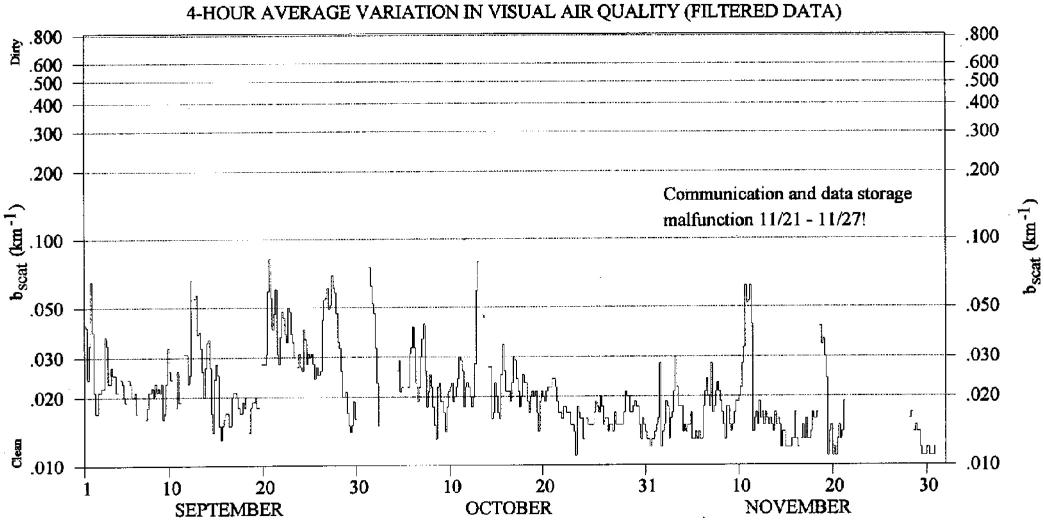
- A map depicting the location of all monitoring network sites.
- A Monitoring History Summary Table, listing for each monitoring site the name, type of instrumentation, and period of operation for each instrument type.
- A Site Specifications Summary Table, listing for each monitoring site the site name, abbreviation, latitude, longitude, and elevation of the nephelometer, the number of readings taken each day, and the operating period during the season.

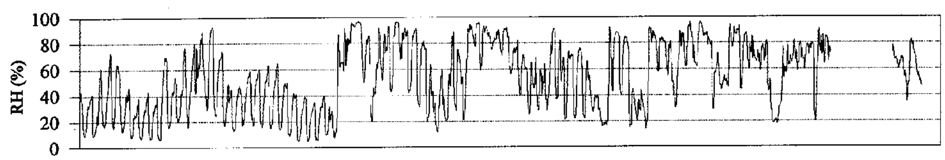
A data summary description section describes seasonal and annual data summaries. Annual data summaries should be prepared for each site that operated during the reporting period, and should be based on a calendar year instead of season. An example Seasonal Nephelometer Data Summary is presented as Figure 4-7 and an example Annual Nephelometer Data Summary is presented as Figure 4-8. The following is a detailed explanation of the contents of the data summaries in each report.

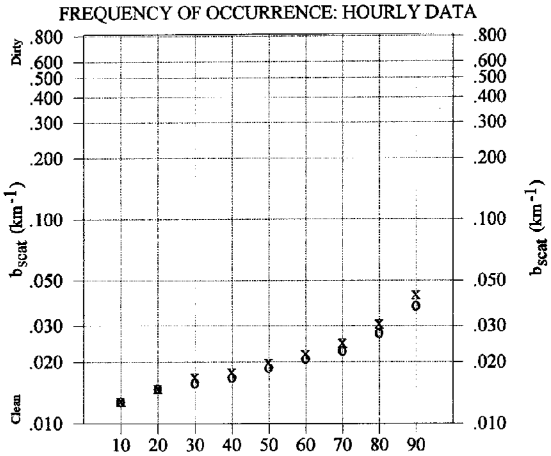
Seasonal Nephelometer Data Summaries include the following five data presentations:

- 4-Hour Average Variation in Visual Air Quality (Filtered Data) - Plot of four-hour averaged b_{scat} values (without interference-influenced observations) for each day of the reporting season. Gaps in the plot indicate that data were missing, interference-influenced, or failed validation procedures.

JARBIDGE WILDERNESS, NEVADA
IMPROVE Nephelometer Data Summary
Fall Season: September 1, 1994 - November 30, 1994







CUMULATIVE FREQUENCY SUMMARY

%	Unfiltered Data [x] b_{scat}	Filtered Data [o] b_{scat}
10	0.013	0.013
20	0.015	0.015
30	0.017	0.016
40	0.018	0.017
50	0.020	0.019
60	0.022	0.021
70	0.025	0.023
80	0.031	0.028
90	0.043	0.038

VISIBILITY METRIC (FILTERED DATA)

	b_{scat}
Mean of cleanest 20%	0.013
Mean of all data	0.023
Mean of dirtiest 20%	0.042

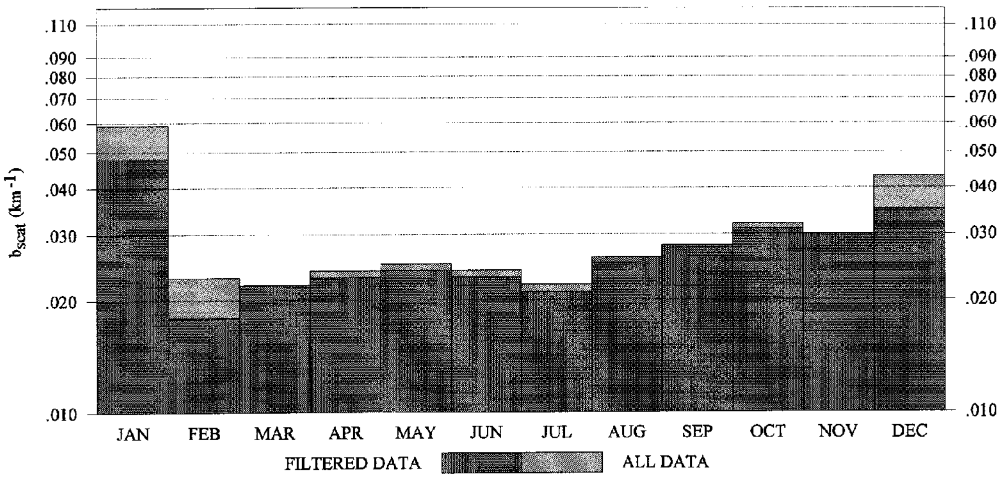
NEPHELOMETER DATA RECOVERY	NUM	%
Total Possible Hourly Averages In The Time Period	2184	100
Valid Hourly Averages (Filtered and Unfiltered)	1920	88
Valid Hourly Averages (Filtered)	1665	76
Filtered Data Percent Of Filtered and Unfiltered Hourly Averages		87

N11:02/08/95 11:43 a P:03/23/95[-99] V3.0:12/14/94

Figure 4-7. Example Seasonal Nephelometer Data Summary.

MOUNT RAINIER NATIONAL PARK, WASHINGTON
Annual Nephelometer Data Summary
All Data: January 1, 1992 - December 31, 1992

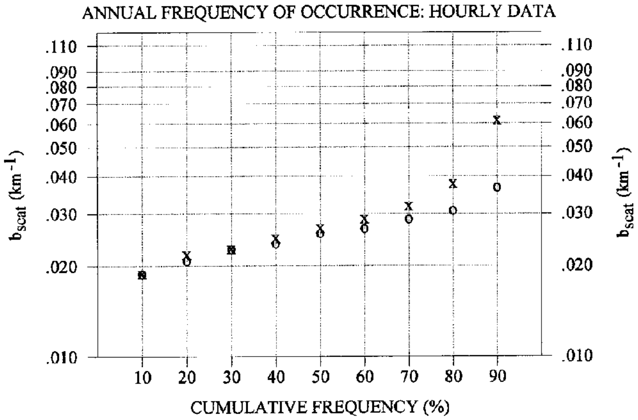
MONTHLY MEDIAN VISUAL AIR QUALITY



MONTHLY CUMULATIVE FREQUENCY SUMMARIES

		FILTERED DATA			ALL DATA			DATA RECOVERY STATISTICS						
		10%	50%	90%	10%	50%	90%	POSS.	COLLECTED		ALL		FILTERED	
MONTH	YEAR	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	NUM	NUM	%	NUM	%	NUM	%
JAN	1992	0.027	0.048	0.069	0.029	0.059	0.608	744	741	100	739	99	135	18
FEB	1992	0.015	0.018	0.031	0.015	0.023	0.076	696	693	100	692	99	371	53
MAR	1992	0.017	0.022	0.027	0.017	0.022	0.031	744	741	100	740	99	555	75
APR	1992	0.019	0.023	0.029	0.019	0.024	0.030	720	720	100	720	100	655	91
MAY	1992	0.019	0.024	0.030	0.020	0.025	0.033	744	744	100	744	100	554	74
JUN	1992	0.019	0.023	0.029	0.019	0.024	0.033	720	719	100	718	100	595	83
JUL	1992	0.017	0.021	0.028	0.017	0.022	0.030	744	742	100	741	100	654	88
AUG	1992	0.021	0.026	0.033	0.022	0.026	0.037	744	738	99	720	97	674	91
SEP	1992	0.025	0.028	0.035	0.025	0.028	0.036	720	708	98	707	98	685	95
OCT	1992	0.025	0.031	0.039	0.025	0.032	0.041	744	735	99	735	99	683	92
NOV	1992	0.024	0.030	0.038	0.024	0.030	0.044	720	717	100	717	100	623	87
DEC	1992	0.022	0.035	0.059	0.023	0.043	0.169	744	738	99	735	99	506	68
ALL DATA		0.019	0.026	0.037	0.019	0.027	0.062	8784	8736	99	8708	99	6690	76

ANNUAL FREQUENCY OF OCCURRENCE: HOURLY DATA



ANNUAL CUMULATIVE FREQUENCY SUMMARY

%	Filtered Data [o] b_{scat}	All Data [x] b_{scat}
10	.019	.019
20	.021	.022
30	.023	.023
40	.024	.025
50	.026	.027
60	.027	.029
70	.029	.032
80	.031	.038
90	.037	.062

D:01/20/94 1:48 p P:03/20/95

V1.01:3/20/95

Figure 4-8. Example Annual Nephelometer Data Summary.

- Relative Humidity - Timeline of hourly average relative humidity measurements. This allows for a comparison of the effect of increasing relative humidity on measured b_{scat}.

- Frequency of Occurrence: Hourly Data - This plot is a frequency distribution of hourly average b_{scat} values, both unfiltered and filtered for meteorological interference. The 10% to 90% values are plotted in 10% increments and are summarized in the table to the right of the plot.

- Visibility Metric (Filtered Data) - This table presents mean values of filtered b_{scat} data affected by meteorological interference. The best, worst, and average conditions using the arithmetic means of the 20th percentile least impaired visibility, the 20th percentile most impaired visibility, and for all data for the season are presented.

- Data Recovery Statistics

  Total Possible Hourly Averages in the Time Period - The total possible category is calculated by subtracting the number of hourly averages included in periods when the instrument was removed due to conditions unrelated to system performance (installation, construction, site relocation, etc.) from the theoretical maximum number of hourly average periods possible during a season.

  Valid Hourly Averages (Filtered and Unfiltered) - the number of valid hourly averages collected during a season. The percentage data recovery represents the number of valid hourly averages compared to the total possible hourly averages.

  Valid Hourly Averages (Filtered) - The number of valid hourly averages (excluding any data indicating meteorological interference) collected during a season. The percentage represents the number of valid hourly averages compared to the total possible hourly averages.

  Filtered Data Percent of Filtered and Unfiltered Hourly Averages - This percentage collection efficiency represents the number of filtered hourly averages compared to the number of all valid hourly averages.

Annual Nephelometer Data Summaries include three data presentations:

- Monthly Median Visual Air Quality - Plot of median monthly b_{scat} for all data and for filtered data only. As the visual air quality improves, b_{scat} values decrease. A Rayleigh atmosphere is defined by a b_{scat} of approximately 10 Mm^{-1}.

- Monthly cumulative Frequency Summaries - Table of cumulative frequency distribution average b_{scat} values for all data and for filtered data only. The 10%, 50%, and 90% values are presented. Also included are data recovery statistics (total possible readings, number and percent of collected readings, and number and percent of valid readings (both all data and filtered data only)).

- Annual Frequency of Occurrence: Hourly Data - This plot is a frequency distribution of hourly average b_{scat} values for all data and for filtered data only. The 10% to 90% values are plotted in 10% increments. Numerical values are presented in the adjacent cumulative frequency summary table.

Nephelometer data summaries should follow their description. Summaries should be prepared for each site that operated during the reporting period. A brief discussion of events and circumstances that influence data recovery should follow the data summaries. Operational status throughout the reporting period should be presented for each site in an operation summary table, listing for each site, site name and abbreviation, the number of seasonal hourly averages possible, the number and percentage of valid hourly averages for all data and for filtered data only, and the cumulative frequency distribution (10%, 50%, and 90% b_{scat} values) for all data and filtered data only.

Finally, a summary section should be included in reports, and provide a synopsis of the nephelometer network, including changes in operation techniques, and a general conclusion of the monitoring period in review. A reference section should include technical references (documents cited in the report), and related reports and publications (including all prior reports pertaining to the monitoring program).

4.2.7.2 Data Archive

Archiving of raw digital data should be performed on a monthly basis. Archiving of all raw and processed digital data for a given season, and constants, calibration, and data processing files should be performed on a seasonal basis, after data have been finalized and reported. All files are in ASCII format. Files should be stored in their original formats (raw, Level-A, Level-0, and Level-1) on magnetic tape CD-ROM. At least two copies of each media should be created; one copy should be stored at the data processing location and the other off-site.

Hard copies of supporting documentation and reports should be duplicated and archived on a continual basis, and include site specifications, monitoring timelines, data coordinator/site operator correspondence, site operator log sheets, trip reports, weekly, seasonal, and annual summary plots, instrument calibration and maintenance logs, and file audit reports. All validated Level-1 data should be delivered as ASCII files (on PC-compatible diskettes and/or CD-ROM) to the COTR with the quarterly and annual reports. The standard file format currently used for IMPROVE protocol nephelometer data is presented in Figure 4-9.

4.2.8 Quality Assurance

Quality assurance of nephelometer data is performed during Level-1 validation, and includes precision of the instrument, and annual field audits.

4.2.8.1 Instrument Precision

Precision of scattering measurements should be determined. The precision of meteorological data are defined by the factory-specified precision for the sensors. The estimated precision of nephelometer data for a given time period is based on calibrations performed during that time period. The precision estimates are recorded in the site-specific quality assurance files and placed in the Level-1 data files. The relative error (uncertainty) in scattering due to drift of the slope of the calibration line is evaluated based on the instrument-specific zero and span checks performed. The following statistical analysis was applied to calculate potential uncertainty:

```
NGN_PULL    V1.91:2/15/94    02-15-1994    14:12:39---------------------------------------------------------------------------------------------------------------------------------------------------
LEVEL-0:  NGN_SEAS  1.3  3/2/94  03-02-1994  15:01:19--------------------------------------------------------------------------------------------------------------------------------------------------
LEVEL-1:  NGN_SEAS  1.3  3/2/94  03-02-1994  17:43:10--------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
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---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

SITE YYMMDD  JD HHMM INS  BSCAT  PREC    VA  RAW-M   RAW-SD  #  N/A   SD/M  DEL   MAX     RH 0123456789MPM0T  YINTER   SLOPE     AT  AT-SD  #  AT-PR     CT  CT-SD  #   CT-PR    RH  RH-SD  #   RH-PR N/A
LOPE 931130 334 1900 014   57    0.000   XL  122.68  25.49  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0450 0.00083  -0.97  0.20  12   1.00   0.22   0.20 12   1.00  88.01   1.18 12   2.00XXXX
LOPE 931130 334 2000 014   80    0.000   V   151.25   8.71  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0457 0.00083  -1.47  0.11  12   1.00  -0.25   0.10 12   1.00  90.46   0.88 12   2.00XXXX
LOPE 931130 334 2100 014   87    0.000   V   160.71   8.58  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0465 0.00083  -1.78  0.28  12   1.00  -0.44   0.19 12   1.00  90.71   0.96 12   2.00XXXX
LOPE 931130 334 2200 014   72    0.000   XD  143.10  22.18  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0472 0.00083  -2.65  0.21  12   1.00  -1.16   0.19 12   1.00  92.16   0.32 12   2.00XXXX
LOPE 931130 334 2300 014   70    0.000   XD  142.32  21.74  12 -99.0  10.0  0.10  5.00   -99 0C0000000000000 -0.0479 0.00083  -3.17  0.15  12   1.00  -1.65   0.11 12   1.00  91.63   0.51 12   2.00XXXX

                                                                                      Column Number

        1         2         3         4         5         6         7         8         9        10        11        12        13        14        15        16        17        18        19        20
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901
```

Column	Data
1-4	Site Abbreviation
6-7	Year
8-9	Month
10-11	Day
13-15	Julian Day
17-18	Hour
19-20	Minute
22-24	Nephelometer Serial Number
26-32	b_{scat} (Mm^{-1})
34-40	b_{scat} Estimated Precision (%/100)
42-43	b_{scat} Validity/Interference Code
45-51	Raw Nephelometer Hourly Average (Counts)
53-59	Standard Deviation of Raw Nephelometer Average (Counts)
61-62	Number of Data Points in Hourly Nephelometer Average
64-68	(Not Used)
70-74	Standard Deviation/Mean Interference Threshold
76-81	b_{scat} Rate of Change Interference Threshold
83-88	Maximum b_{scat} Interference Threshold
90-92	Relative Humidity Interference Threshold
94-108	Composite Nephelometer Code Summary
110-116	Y-intercept of Calibration Line Used to Calculate b_{scat}
118-124	Slope of Calibration Line Used to Calculate b_{scat}
126-131	Average Ambient Temperature (°C)
133-138	Standard Deviation of Hourly AT Average
140-141	Number of Data Points in Hourly AT Average
143-148	Estimated Precision of Ambient Temperature
150-155	Average Nephelometer Chamber Temperature (°C)
157-162	Standard Deviation of Hourly CT Average
164-165	Number of Data Points in Hourly CT Average
167-172	Estimated Precision of Chamber Temperature
174-179	Average Relative Humidity (%)
181-186	Standard Deviation of Hourly RH Average
188-189	Number of Data Points in Hourly RH Average
191-196	Estimated Precision of Relative Humidity
197-200	(Not Used)

b_{scat} Validity/Interference Code (42-43):

V = Valid
I = Invalid
< = b_{scat} less than Rayleigh scattering
XZ = Data point immediately preceded and followed by interference
X? = Interference of type ?

Type (?) of Interference	Letter Code A B C D E F G H I J K L M N O
RH > max. threshold	x x x x x x x x
b_{scat} > max. threshold	x x x x x x x x
St. Dev./Mean>threshold	x x x x x x x
b_{scat} rate of change > threshold	x x x x x x x x

Composite Nephelometer Code Summary (94-108):

94-103	Nephelometer diagnostic code (internal use)
104	Number of missing data points
105	Number of power failure codes
106	Number of manual QA invalidation codes
107	Number of Level-0 invalidated data points
108	Number of times non-serial data were used

Note: The first 10 lines are for data reduction information.

Figure 4-9. Standard ASCII File Format IMPROVE Protocol Integrating Nephelometer Visibility Data.

$V(t)$ = Normalized nephelometer reading at time t
$V_o(t)$ = Normalized clean air reading at time t
$V_s(t)$ = Normalized SUVA 134a reading at time t
$b_{scat,o}$ = Scattering coefficient for clean air
$b_{scat,s}$ = Scattering coefficient for SUVA 134a
V_o = Average normalized clean air reading
V_f = Average normalized SUVA 134a reading
$b_{scat}(t)$ = Theoretical scattering coefficient tat time t
m = Slope of the calibration line used to calculate the theoretical scattering coefficient $b_{scat}(t)$

$$m = \frac{(b_{scat,s} - b_{scat,o})}{(V_s(t) - V_o(t))} \tag{4-23}$$

Given a normalized nephelometer reading V(t), the theoretical b_{scat} at time t is:

$$b_{scat}(t) = b_{scat,o} + m(V(t) - V_o(t)) \tag{4-24}$$

assuming that $V_o(t)$ and V(t) are known without error.

The slope of the calibration line is not constant as defined above, but changes (drifts) with time. The actual slope of the calibration line at time t is:

$$m(t) = (b_{scat,s} - b_{scat,o})/(V_s(t) - V_o(t)) \tag{4-25}$$

The actual b_{scat} (denoted b'_{scat}), given a nephelometer reading V(t), is:

$$b'_{scat}(t) = b_{scat,o} + m(t)\ (V(t) - V_o(t)) \tag{4-26}$$

The relative error between the theoretical b_{scat} and actual b'_{scat} is:

$$relative\ error = (b_{scat}(t) - b'_{scat}(t))/b_{scat}(t) \tag{4-27}$$

$$\begin{aligned} relative\ error &= ((m - m(t))\ (V(t) - V_o(t)))\ /\ (b_{scat,o} + m(V(t) - V_o(t))) \\ &= (m - m(t))\ /\ (b_{scat,o}\ /\ (V(t) - V_o(t)) + m) \\ &= |\ (m - m(t))\ /\ (b_{scat,o}\ /(V(t) - V_o(t)) + m)\ | \end{aligned} \tag{4-28}$$

The magnitude of the relative error is:

$$| \; relative \; error \; | \; = \; | \; (b_{scat}(t) \; - \; b'_{scat}(t)) \; / \; b_{scat}(t) \; | \qquad (4\text{-}29)$$

The magnitude of the relative error is bounded by the slopes such that:

$$| \; relative \; error \; | \; \leq \; | \; (m \; - \; m(t)) \; / \; m \; | \qquad (4\text{-}30)$$

Assuming that the calculated slopes, m(t), of the calibration lines are normally distributed about the average slope m with a standard deviation s, then for a probability (confidence level) of 95%:

$$| \; m \; - \; m(t) \; | \; \leq \; 2s \qquad (4\text{-}31)$$

so that

$$| \; (b_{scat}(t) \; - \; b'_{scat}(t)) / b_{scat}(t) \; | \; \leq \; | \; 2s \; / \; m \; | \qquad (4\text{-}32)$$

Assuming that s is estimated by s_m with k degrees of freedom, based on k+1 sample values of m(t), and using the two-tailed t distribution, the relative error at a 95% confidence level (which for a two tailed t distribution is read from the 97.5 column of the t table) is:

$$| \; relative \; error \; | \; \leq \; t_{k,0.025} \; * \; s_m \; / \; m \qquad (4\text{-}33)$$

4.2.8.2 Instrument Audits

The nephelometer field audit verifies accurate on-site nephelometer calibrations by comparing calibrations made with an audit calibration system. The audit results assess the validity of operator-performed calibrations, and how the instrument has changed since installation, by comparing the audit calibration to the installation calibration.

Nephelometers are typically audited at least once a year, but can be audited at any time. A standard audit begins with a pre-inspection audit calibration (checking the physical condition of the instrument, performing a calibration using the station calibration system, then a calibration using an audit calibration system). The nephelometer is then inspected to verify that the instrument is capable of making an ambient reading and that the instrument's components are not contaminated. The inspection includes checking the inlet screen, fan outlet, light trap, and clean air filter. Finally, a post-inspection is performed. The post-inspection audit calibration represents the state of the instrument after the audit is complete. The calibration is identical to the pre-inspection audit calibration.

Following the audit, the nephelometer components are verified that they are in their operational configuration and that the nephelometer is in ambient mode.

4.2.9 Data Analysis and Interpretation

Nephelometer data are a measure of the scattering component of atmospheric extinction. Data are typically presented in scattering units, expressed in kilometers (km^{-1}). These units are directly stored in the data files.

Nephelometer data provide a quantitative measure of visibility conditions. Data can be used to provide the basis for background conditions and trend analysis; however, data must be combined with associated meteorological and aerosol concentrations to understand the source and/or composition of the impairment observed. They must also be combined with absorption data to get values of total extinction.

4.2.10 Nephelometer Standard Operating Proccedures and Technical Instructions

The Air Resource Specialists, Inc. document entitled *Standard Operating Procedures and Technical Instructions for Nephelometer Systems*, includes the following nephelometer-related Standard Operating Procedures and Technical Instructions:

SOP 4050	Site Selection for Optical Monitoring Equipment (IMPROVE Protocol)
TI 4050-3000	Site Selection for Optec NGN-2 Nephelometer Systems
SOP 4070	Installation and Site Documentation for Optical Monitoring Equipment
TI 4070-3000	Installation of Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)
TI 4070-3001	Site Documentation for Optec NGN-2 Nephelometer Systems
SOP 4100	Nephelometer Maintenance (IMPROVE Protocol)
TI 4100-3100	Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)
TI 4100-3101	Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems (IMPROVE Protocol) Zirkel Special Study
TI 4100-3150	Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems (CASTNet Installations)
TI 4100-3350	NGN-2 Nephelometer Monitoring System Diagrams and Component Descriptions
TI 4100-3375	Replacing and shipping Nephelometer System Components
TI 4100-3400	Nephelometer Annual Laboratory Maintenance (IMPROVE Protocol)
SOP 4115	Annual Site Visits for Optical Monitoring Instrumentation (IMPROVE Protocol)

TI 4115-3005	Annual Site Visit Procedures for Optec NGN-2 Nephelometer Systems (IMPROVE Protocol)
SOP 4200	Calibration of Optical Monitoring Systems (IMPROVE Protocol)
TI 4200-2000	Calibration of Optec NGN-2 Nephelometers (IMPROVE Protocol)
SOP 4250	Servicing and Calibration of Optical Monitoring Dataloggers
TI 4250-2000	Servicing and Calibration of Campbell 21X Dataloggers
TI 4250-2010	Servicing and Calibration of the Handar 540A/570A DCP
SOP 4300	Collection of Optical Monitoring Data (IMPROVE Protocol)
TI 4300-4000	Data Collection Via DCP (IMPROVE Protocol)
TI 4300-4002	Nephelometer Data Collection Via Telephone Modem (IMPROVE Protocol)
TI 4300-4004	Nephelometer Data Compilation and Review of DCP-Collected Data (IMPROVE Protocol)
TI 4300-4006	Nephelometer Data Collection Via Campbell Scientific Data Storage Module (IMPROVE Protocol)
SOP 4400	Optical Monitoring Data Reduction and Validation
TI 4400-5010	Nephelometer Data Reduction and Validation (IMPROVE Protocol)
SOP 4500	Optical Monitoring Data Reporting
TI 4500-5000	Nephelometer Data Reporting (IMPROVE Protocol)
SOP 4600	Optical Monitoring Data Archives
TI 4600-5000	Nephelometer Data Archives (IMPROVE Protocol)
SOP 4700	Optec NGN-2 Nephelometer Audit Procedures (IMPROVE Protocol)

5.0 SCENE MONITORING

As an example of an existing visibility-related scene monitoring program, this section describes IMPROVE scene monitoring and data management techniques. References made to manufacturers or trade names are not intended to constitute EPA endorsement or recommendations for use. New or improved instruments, instrument upgrades, and methods of monitoring are continually being developed.

Scene monitoring provides a qualitative representation of the visual air quality in the area of interest. The photographic record documents the appearance of a scene. Scene characteristics include color, texture, contrast, clarity, observer visual range, and other descriptive terms. Photography is uniquely suited for identifying ground-based or elevated layers or plumes that may impact Class I or protected areas, as well as documenting conditions for interpreting aerosol and optical data.

IMPROVE protocols recommend that color photographs (35 mm slides) be taken several times a day. The data collection schedule can be tailored to capture periods when visibility impairment is most likely at specific sites. For example, photographs during stable periods may yield more information in areas susceptible to ground-based or elevated layered hazes. Time-lapse movies (generally time-lapse video or super 8 mm film) have also been used at selected monitoring sites and during special studies to document the visual dynamics of a scene or source. To the extent possible, the selected scene should be collocated with or include aerosol and optical monitoring equipment, so that conditions documented by photography can aid in the presentation of these data.

Sections 5.1 and 5.2 describe the monitoring criteria, instrumentation, installation and site documentation, system performance and maintenance, data collection, reduction, validation, reporting, and archive, quality assurance, and data analysis and interpretation required for 35 mm slide and time-lapse photography, respectively. Example users' manuals and manufacturers' specifications are provided in Appendix B.

5.1 35 mm SLIDE PHOTOGRAPHY

5.1.1 <u>Measurement Criteria and Instrumentation</u>

Automatic 35 mm camera systems take color photographs of selected vistas at user-selected times. Day-to-day variations in visual air quality captured on 35 mm color slides can be used to:

- Document how vistas appear under various visual air quality, meteorological, and seasonal conditions. Scene characteristics include observer visual range, scene contrast, color, texture, and clarity.

- Record the frequency that various visual air quality conditions occur (e.g., incidence of uniform haze, layered haze, or weather events).

- Provide a quality assurance reference for collocated measurements.

- Determine the visual sensitivity of individual areas or views to variations in ambient air quality.

- Identify areas of potential impairment.

- Estimate the optical properties of the atmosphere under certain conditions.

- Provide quality media for visually presenting program goals, objectives, and results to decision-makers and the public.

- Support computer image modeling of potential impairment.

- Support color and human perception research.

Photographic slides, however, do not provide quantitative information about the cause of visibility impairment. Aerosol and optical properties of the atmosphere must be independently monitored where cause and effect relationships are required.

Automatic camera systems should meet the following requirements:

- Have a rugged, reliable 35 mm camera body with automatic film winder. The camera's exposure meter must be designed so it is on only the actual time of exposure and not continuously operating.

- Have an appropriate size lens to capture the full extent of a scenic vista (usually a 135 mm or 50 mm lens).

- Have a databack that will imprint on the film the day and time the exposure was taken.

- Have a battery-powered, programmable timer that will trigger the camera at least three times daily, or on selected days of the week.

- Be able to operate within an ambient temperature range of 0°F to 120°F. (To achieve the specification of 0°F, a heated and insulated shelter requiring 110V line power is recommended).

- Be housed in a stand-alone, lockable, weatherproof environmental enclosure.

- Be able to operate unattended for at least 10 days or a maximum of 30 days.

Figure 5-1 is a photograph of the automatic camera station in a remote mountain location. Figure 5-2 shows the components of a station, including a weatherproof shelter and mounting post, cameras, automatic timers, and batteries. The station can be outfitted with a variety of camera configurations.

Detailed information regarding camera instrumentation or operation can be found in *Standard Operating Procedures and Technical Instructions for Automatic Camera Systems* (Air Resource Specialists, Inc., 1993-1996).

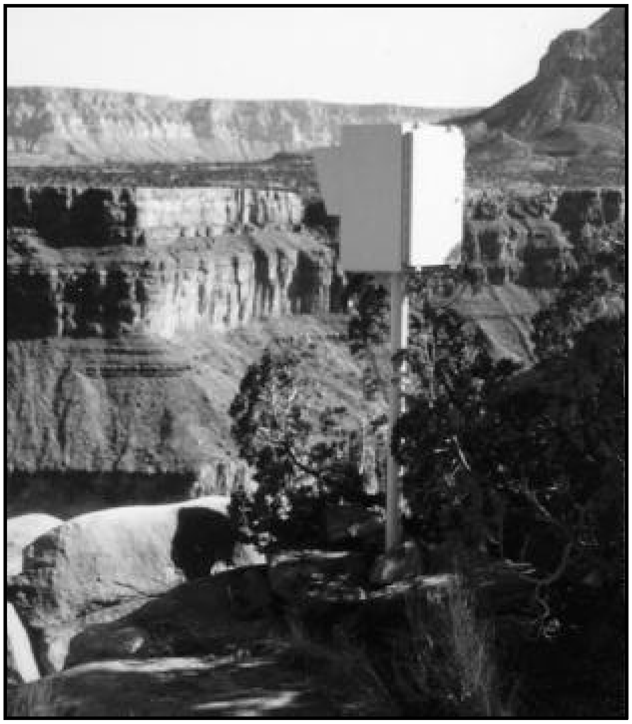

Figure 5-1. Automatic Camera System in a Remote Location.

Figure 5-2. Station Components.

5.1.2 Siting Criteria

Stations are normally located so that the camera views a recognizable, important vista that highlights the character of the area being monitored. When selecting a site, servicing, installation logistics, aesthetics, and security should also be considered. At many locations, the camera is located with other monitoring equipment such as a transmissometer, a nephelometer, an aerosol sampler or other monitoring systems that support comprehensive air quality evaluations.

To assure consistent, quality data and minimize data loss, selected camera sites should have most or all of the following characteristics:

- Be located to photograph a highly-visited scenic vista or important scenic features of the visibility sensitive area being monitored
- View north or away from direct sun angles to minimize lens flare and overexposure
- Include a vista encompassing the same air mass monitored by associated aerosol (particle monitors) and/or optical instrumentation
- Be removed from local pollution sources (e.g., vehicle exhaust, wood smoke, road dust, etc.)
- Be representative of regional (not local) visibility
- Be secure from vandalism
- Have available servicing personnel (operator)
- Be reasonably accessible during all months of the year
- Be located considering environmental factors (e.g., snow depth, temperature extremes, precipitation type and amount, relative humidity, etc.) that could affect camera operations or site accessibility
- Be located free from viewing obstructions or interferences
- Have local land manager or land owner cooperation

5.1.3 Installation and Site Documentation

Before the automatic camera system can be installed, a mounting post should be appropriately aligned on the selected monitoring vista (target). Mounting post installation procedures depend on the type of installation and surface material to which the post is mounted. The posts may be attached to pre-existing concrete or rock, in soil, in a wood platform, or to a new concrete pad. Enclosure installation involves three processes: mounting the sunshield, the enclosure, and the camera equipment.

Following the completion of the camera system installation and configuration, operator training should be performed. Site operators should be trained on camera system requirements and routine maintenance procedures. A Site Operator's Manual for Automatic Visibility Monitoring Camera Systems should be provided. This manual contains standard operating procedures and technical instructions applicable to the specific camera monitoring equipment located at the site. Additional manufacturer's instruction booklets and pertinent maintenance documentation forms should also be provided.

Site documentation for the automatic camera system visibility monitoring station includes completion of the Visibility Monitoring Photographic Site and Target Specifications Form, which includes: site name; focal length; number of observations per day; elevation, latitude, and longitude of the camera location; map reference; site abbreviation; installation date and name of the installer; site contacts and mailing/shipping address; vista name, distance, elevation, bearing, and elevation angle; and site path elevation; vista cover type; and photographic reference.

5.1.4 System Performance and Maintenance

System performance and maintenance of 35 mm automatic camera systems includes routine servicing and biannual laboratory servicing. Both of these servicing types are discussed in the following subsections.

5.1.4.1 Routine Servicing

Site operator maintenance for an automatic camera system should be performed on a routine basis. Routine servicing schedules are based on the number of photographs taken each day. A common monitoring schedule includes taking three photographs a day at 0900, 1200, and 1500. Assuming this schedule, site operators service the camera approximately every 10 days to change film, check the performance of the camera(s), clean the system components, and perform scheduled preventive maintenance. Identifying and troubleshooting system malfunctions are carried out as required.

Regular servicing and the identification and documentation of film rolls are essential. During each routine site visit, the operator should thoroughly document all pertinent data collection information, any maintenance performed, and any equipment or monitoring inconsistencies. If further action is necessary, immediate corrective action should be taken.

Regular maintenance performed at each film change includes:

- Inspecting the overall system and cleaning the shelter window.
- Verifying that the film has advanced in the camera and that camera settings are correct.
- Rewinding and removing the film, and completing a film canister label.
- Loading new film and completing a film canister label.
- Inspecting and cleaning the camera lens.
- Checking system batteries.

- Checking databack settings.
- Checking timer settings.
- Photographing the film documentation board.
- Aligning the camera.
- Verifying system operation.
- Completing documentation:
  - Documenting any equipment or monitoring discrepancies found.
  - Documenting all servicing or maintenance actions performed.
  - Describing weather conditions.
  - Describing visibility conditions.
- Closing and locking the camera enclosure.
- Mailing the film and a copy of the documentation.

Scheduled maintenance performed as required includes:

- Changing 35 mm databack batteries annually.
- Changing 35 mm camera batteries every 6 months.
- Changing 35 mm batteries every 6 months.

5.1.4.2 Biannual Laboratory Servicing

Servicing all cameras and support systems is performed by mailing replacement parts and/or systems to the site operators and repairing those components returned. Operational camera systems are biannually cycled out of a monitoring network. Shelters remain in place and the cameras and timers are cycled for laboratory maintenance.

Automatic camera system maintenance is normally provided by local factory-authorized repair facilities capable of performing the following:

- Cleaning, lubricating, and adjusting of all 35 mm camera components
- Automatic exposure calibration checks

- Ambient/cold testing of:
  - Current draw
  - Shutter speed and curtain travel time
  - Automatic exposure meter readout
  - Film transport

- Lens focus checks

- Battery and camera cabling integrity checks and necessary repair

- Timer circuitry checks

5.1.5 Data Collection

Collection procedures include site servicing visits to perform film changes at the required interval, and the mailing of exposed film rolls and accompanying documentation.

Kodachrome ASA-64 color slide film (36-exposure rolls) should be used. The film possesses fine grain and excellent color reproduction qualities. Enough film (from a single emulsion number) should be purchased from a Kodalux direct distributor to cover several months of a monitoring program. Film should be refrigerated or frozen until used.

When servicing a site, the operator should complete a film canister label and attach it to each new film roll loaded into the camera. A photograph of a photo documentation board should be taken as the first exposure of each roll. The board should contain monitoring site identification, date, time, and film roll number. Each camera should also be equipped with a databack that records the date and time that the photograph was taken on the lower right corner of each photograph. When the operator returns to remove the film, he or she should complete the information on the label, place the film in a padded envelope, and mail it along with a status/assessment sheet via first class mail for processing.

All film should be sent by courier to a Kodalux processing laboratory. Roll and film processing mailer numbers should be documented so all shipments can be tracked and traced if necessary, by the mailer number. Receipt of the developed film from Kodalux should be recorded. Film rolls should be stored chronologically in a pollutant-free controlled environment.

5.1.6 Data Reduction and Validation

5.1.6.1 Data Reduction

Processed 35 mm slides should be first checked for extraneous photographs. Only slides that represent the standard date and time sequence of the correct vista or were taken purposely for documentation or as a supplemental visibility document should be kept. Any blank slides preceding or following the normal date/time sequence should be discarded.

Extraneous 35 mm slides should be removed and documentation and target photographs should be arranged in polyethylene protector sheets by date and time. Following verification of slide arrangement, each slide should be numbered sequentially and stamped with a four-letter site code. The slide set should be placed in a manila folder along with a completed slide log and the associated status/assessment sheet.

Slides should also be reviewed to verify that the vista alignment is correct, the slides are in proper focus, the databack date and time is recorded on the film, the slides are arranged in proper order, and that no exposure inconsistencies exist. Any discrepancies should be documented by site and roll number and corrective action should be initiated.

5.1.6.2 Data Validation

Not all 35 mm slides undergo a qualitative coding process. Slides are only coded if summaries of observed slide conditions are required by the contracting agency. Each photographic slide designated for coding should be visually reviewed, chronologically numbered, and assigned a two-, four-, or client-specified-digit slide condition code. These codes document the visual conditions present on each slide, including sky conditions, observed hazes, plumes, weather conditions, unusable or missing observations, anomalies, or client-specified areas of interest.

Qualitative slide coding is normally performed at the end of a season on all slides collected during the season. Standard meteorological seasons are:

Winter	December, January, and February
Spring	March, April, and May
Summer	June, July, and August
Fall	September, October, and November

To begin the coding process, each valid slide should be viewed on a light table with the naked eye and an eight-power, hand-held lens. Codes should be marked directly on the slides (slide frames) and later entered into site-specific digital files. An example code key sheet is presented as Table 5-1. Codes may be tailored to the contracting agency's needs. For example, codes may be developed that define amount of urban or industrial activity in the view, or that define observed conditions in Class I and non-Class I areas of the view. Digital files are created after all slides from a season are coded and are then used to prepare qualitative summaries of observed haze types. Digital files can be searched in a variety of ways to fulfill specific data reports.

All photographs should be considered valid except for:

- Supplemental visibility photographs.
- Out-of-alignment photographs (e.g., the target is not in the picture).
- Blank photographs.
- Extremely under- or overexposed photographs.

Table 5-1

Example Slide Condition Code Key

Sky Conditions		Code Description
0	No clouds	No clouds visible anywhere in the sky.
1	Scattered clouds < half of sky	Less than one-half of the sky has clouds present.
2	Overcast > half of sky	More than one-half of the sky has clouds present.
5	Weather concealing scene	Clouds or precipitation are such that determination of the sky value is impossible.
9	No observation or cannot be determined	To be used with target code of 9 or if sky value cannot be determined due to reasons other than weather.
Layered Haze		**Code Description**
0	No layered haze	No layered haze boundary (intensity of coloration edge) is perceptible.
1	Ground-based layered haze only	Only a single-layered haze boundary is perceptible with the haze layer extending to the surface.
2	Elevated layered haze only	An elevated layered haze with two boundaries is perceptible; e.g., horizontal plume.
3	Multiple haze layers	More than a single ground-based or elevated layered haze is perceptible. This can be multiple ground-based layers or a combination of both.
5	Weather concealing scene	Cloud or precipitation are such that determination of the presence of layered hazes is impossible.
9	No observation or cannot be determined	To be used with target code of 9 or if a layered haze value cannot be determined due to reasons other than weather.

- Out-of-focus photographs.

- Photographs taken through a fogged or icy shelter window.

An IBM PC-compatible computer and specific software are used to create digital files. Files are named by site and season and contain site abbreviation, slide number, date, time, and slide condition codes. Digital files are used to prepare qualitative summaries of observed haze types.

5.1.7 Data Reporting and Archive

5.1.7.1 Data Reporting

Data reports should be prepared in a format that generally conforms to the *Guidelines for Preparing Reports for the NPS Air Quality Division* (AH Technical Services, 1987). A separate data report should be prepared for each instrument type; photographic data reports should contain only photographic data. Reporting consists of various text discussions and graphics presentations concerning the instrumentation and collected data. Specific contents of the reports are defined by the contracting agency.

Seasonal photographic reporting should be completed within three months after the end of a monitoring season, and annual reporting within three months after the end of the last reported season. Standard meteorological monitoring seasons are defined as:

Winter	(December, January, and February)
Spring	(March, April, and May)
Summer	(June, July, and August)
Fall	(September, October, and November)

Reports should contain the following major sections:

- Introduction

- Data Collection and Reduction

- Photographic Data Summaries

- References

The introduction should contain a conceptual overview of the purpose of the monitoring program and specific objectives and tasks of the program.

The data collection and reduction section includes discussions of site configuration, camera system components, and basic system operation. Also included should be a map of the United States depicting the location of each monitoring site, and a monitoring history summary table, describing each monitoring site, the type of instrumentation installed, and the historical periods of operation for each instrument. The section briefly describes the slide review and coding process, as well as the compilation of the summary tables, and the quality control and quality assurance procedures applied during the data collection and reduction process.

Photographic data may be presented in various forms depending on contracting agency requirements. Each type of data summary should be accompanied by an explanation. Each report contains a Site and Target Specifications Summary Table listing complete target and site specifications for each scene monitoring site operational during the period, (including site name and abbreviation, latitude, longitude, and elevation of the camera monitoring site; target name, elevation, distance, azimuth, and elevation angle of the site path; number of observations taken per day; and operating period during the reported period). A Qualitative Slide Analysis Summary Table provides a site-by-site accounting of observed haze and target-concealed conditions for each site that operated during the reporting period.

The section also includes a brief discussion of slide and digital file archive, a discussion of the events and circumstances that influenced data recovery, operational summaries for each site including: site name and abbreviation, data collection period, number of total possible observations, collection efficiency (number and percent), a description of the cause or causes of data loss or problem description, and resolutions and/or recommendations relating to the noted operational problems.

The reference section includes technical references (documents that are cited in the report), and related reports and publications (all prior reports pertaining to the monitoring program).

Supplemental data products that may accompany data reports include:

- Slide duplicates or digital images representative of good, medium, and poor visibility conditions for each season that sufficient data are available for qualitative review.
- PC-compatible diskettes of seasonal slide condition code files.
- Optical (nephelometer/transmissometer) data summaries for collocated optical monitoring equipment.

5.1.7.2 Data Archive

All original slides should be stored in non-gassing, polyethylene protector sheets and filed by site, season, and date (roll). All files should be kept alphabetically in standard file cabinets. Even under the most ideal storage conditions, film emulsions will slowly degrade over time.

Supporting hard copy documentation, including status/assessment sheets, slide coding sheets, film tracking logs, and correspondence should be filed in standard file cabinets, in chronological order by site.

Digital data produced from 35 mm photographic slides (containing qualitative condition codes) should be archived on a seasonal basis. ASCII files should be stored in the original format (non-compressed) on diskette. Two copies of each archive should be created.

5.1.8 Quality Assurance

Internal quality assurance of automatic camera equipment is based primarily on visual review of developed visibility monitoring film. Alignment, exposure, and data collection efficiency can all be assessed from developed film. Any noted problems should initiate corrective action. Ongoing review of film and site operator identified problems often initiates corrective actions.

5.1.9 Data Analysis and Interpretation

Photographic data analysis can be qualitative only. Only conditions visually seen in the 35 mm slides can be compiled and interpreted. A more thorough analysis would be to use the slides in conjunction with other forms of data, such as optical or aerosol data. Quantitative analysis of slides has been used in the past, but has been determined to not be an accurate method of air quality or visibility analysis.

5.1.10 Scene Monitoring Standard Operating Procedures and Technical Instructions

The Air Resource Specialists, Inc. document entitled *Standard Operating Procedures and Technical Instructions for 35 mm Scene Monitoring Systems,* includes the following scene monitoring Standard Operating Procedures and Technical Instructions:

SOP 4005	Procurement and Acceptance Testing Procedures for Scene Monitoring Equipment
TI 4005-1000	Procurement and Acceptance Testing Procedures for 35 mm Automatic Camera Systems
SOP 4055	Site Selection for Scene Monitoring Equipment
SOP 4075	Installation and Site Documentation for Scene Monitoring Equipment
SOP 4120	Automatic Camera System Maintenance (IMPROVE Protocol)
TI 4120-3100	Routine Site Operator Maintenance Procedures for 35 mm Automatic Camera System - Canon EOS 630
TI 4120-3110	Routine Site Operator Maintenance Procedures for 35 mm Automatic Camera System - Contax 167MT
TI 4120-3120	Routine Site Operator Maintenance Procedures for 35 mm Automatic Camera System - Contax 137 MA
TI 4120-3130	Routine Site Operator Maintenance Procedures for 35 mm Automatic Camera System - Olympus OM2N
TI 4120-3140	Routine Site Operator Maintenance Procedures for 35 mm Automatic Camera System - Pentax PZ-20

TI 4120-3300	Troubleshooting and Emergency Maintenance Procedures for 35 mm Automatic Camera System - Canon EOS 630
TI 4120-3310	Troubleshooting and Emergency Maintenance Procedures for 35 mm Automatic Camera System - Contax 167MT
TI 4120-3320	Troubleshooting and Emergency Maintenance Procedures for 35 mm Automatic Camera System - Contax 137 MA
TI 4120-3330	Troubleshooting and Emergency Maintenance Procedures for 35 mm Automatic Camera System - Olympus OM2N
TI 4120-3340	Troubleshooting and Emergency Maintenance Procedures for 35 mm Automatic Camera System - Pentax PZ-20
TI 4120-3500	Biannual Laboratory Maintenance Procedures for 35 mm Automatic Camera Systems
SOP 4305	Collection of Scene Monitoring Photographs and Film (IMPROVE Protocol)
TI 4305-4000	Collection, Processing, and Handling of 35 mm Slide Film
SOP 4420	Scene Monitoring Qualitative Data Reduction
TI 4420-5000	Qualitative Scene Coding and Data Reduction of 35 mm Color Slides
SOP 4520	Scene Monitoring Data Reporting
TI 4520-5000	Scene Monitoring Reporting of 35 mm Slides (IMPROVE Protocol)
SOP 4610	Scene Monitoring Archives
TI 4610-5000	35 mm Photographic Slide Archives
TI 4610-5020	Slide Spectrum Archives, (In process)
TI 4610-5030	Photographic-Based Teleradiometric Data Archives

5.2 TIME-LAPSE PHOTOGRAPHY

5.2.1 Measurement Criteria and Instrumentation

Time-lapse images have always been a valuable and convenient tool to document, view, and interpret actual dynamic events in reduced time. Time-lapse images have been used to support scientific studies, document project activities, support legal enforcement, and present important findings to decision-makers and the public.

Today, high resolution video systems are replacing film for recording time-lapse images. Advancing video technology provides a wide range of imaging options, and systems can be easily installed and operated. Time-lapse imaging reduces the viewing time of long term dynamic events to practical levels. The understanding and interpretation of certain dynamic patterns can actually be enhanced through the use of time-lapse images. The ability to review high resolution video images at a variety of speeds enhances the interpretive power of the media. Reverse and stop frame functions further aid the interpretive process.

Time-lapse monitoring can be accomplished by 8 mm film or by videotape. The major advantages of videotape over film are that the videotape images are immediately available for viewing (you do not have to wait to develop film) and reproduction costs are minimal as compared to film products. Also, 8 mm cameras and film are becoming obsolete in the camera industry.

Applications of time-lapse monitoring include:

- Air Pollution - Urban and rural haze dynamics, and source-specific emission surveillance (industrial plumes or emissions from hazardous waste remediation projects) can be documented.

- Weather Observations - The day's weather can be documented to support academic studies as well as daily television news summaries.

- Construction Projects - Monitoring may track progress of high-rise construction, as well as monitoring activities and emissions of earth moving projects.

- Traffic Studies - The level of service at busy intersections, and a wide range of traffic count-related applications may be monitored.

- Industrial Processes - Applied engineering practices or equipment performance may be evaluated, and production may be tracked.

- Surveillance - The use of a recreational area may be tracked, or legal investigations may be supported.

Time-lapse images do not provide quantitative information about the cause of visibility impairment. Aerosol and optical properties of the atmosphere must be independently monitored where cause and effect relationships are required.

Time-lapse video systems have two primary components, a camera and a recorder (see Figures 5-3 and 5-4). Systems can be configured to meet a wide range of monitoring requirements. In its simplest configuration, a camera can be positioned to view a selected scene with the recorder programmed for daily on and off recording times. A range of time-lapse intervals can easily be selected on the recorder. More advanced systems can employ options such as programmable, motorized pan/tilt camera housings and zoom lenses that respond to a series of commands throughout the day, each with a different viewing direction, inclination, field of view, and focus setting.

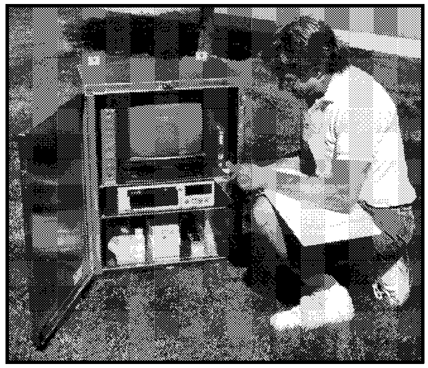

Figure 5-3. Time-Lapse Video Recording Module (Time-Lapse Recorder, Monitor, and Power Systems).

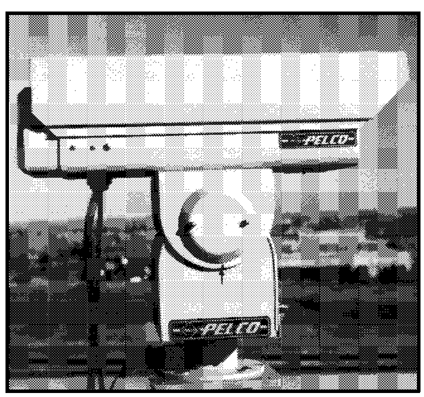

Figure 5-4. Weatherproof Video Camera Enclosure.

The video camera and selected lens can be conveniently housed in a weatherproof, heated and ventilated shelter that can be easily mounted to almost any structure. The recorder must be housed in a clean, dry environment at or near room temperature. Custom heated and cooled shelters can be fabricated for remote locations, but for many installations it is often convenient to use an existing building. The camera and recorder units are connected with signal and power cables. Systems require 115 volt AC service. A broad range of lenses are available for the camera with wide-angle, telephoto, or zoom options. The recorder uses a high resolution S-VHS format that yields extremely high quality images.

The 8 mm camera can be conveniently housed in a weatherproof shelter identical to, or in conjunction with 35 mm cameras (see Figure 5-2).

Detailed information regarding video camera instrumentation or operation can be found in *Standard Operating Procedures and Technical Instructions for 8 mm Time-Lapse Scene Monitoring Systems* (Air Resource Specialists, Inc., 1993-1996).

5.2.2 Siting Criteria

Time-lapse monitoring stations are normally located so that the camera views a recognizable, important vista that highlights the character of the area being monitored. When selecting a site, servicing, installation logistics, aesthetics, and security should also be considered. At many locations, the camera is located with other monitoring equipment such as a transmissometer, a nephelometer, an aerosol sampler or other monitoring systems that support comprehensive air quality evaluations.

To assure consistent, quality data and minimize data loss, selected camera sites should have most or all of the following characteristics:

- Be located to photograph a highly-visited scenic vista or important scenic features of the visibility sensitive area being monitored
- View north or away from direct sun angles to minimize lens flare and overexposure
- Have AC power available (video systems only)
- Be secure from vandalism
- Have available servicing personnel (operator)
- Be reasonably accessible during all months of the year
- Be located considering environmental factors (e.g., snow depth, temperature extremes, precipitation type and amount, relative humidity, etc.) that could affect camera operations or site accessibility
- Be located free of viewing obstructions or interferences
- Have local land manager or land owner cooperation

5.2.3 Installation and Site Documentation

Installation is site-specific, depending on the topography, project goals, and client's needs. Time-lapse systems may be installed on a post, a tower, or attached to a building.

Following the completion of the time-lapse system installation and configuration, operator training should be performed. Site operators should be trained on camera system requirements and routine maintenance procedures. Additional manufacturer's instruction booklets and pertinent maintenance documentation forms should also be provided.

Site documentation for a time-lapse system monitoring station includes completion of site specifications (station name, number of observations per day, elevation, latitude, longitude, map reference, site abbreviation, installation date and name of the installer, site contacts and mailing/shipping address).

5.2.4 System Performance and Maintenance

Videotape and 8 mm time-lapse systems are easy to configure, install, and operate. Videotape recorder programming is done on-screen similar to a home VCR. The recorder can be programmed for record/playback speeds from real time (2 hours per videotape) to various time-lapse intervals up to 480 hours per videotape. Depending on the user-selected record interval and programmed on and off times, the recorder can collect from several days to several weeks of time-lapse images on a single videotape. An operator can be easily trained to perform regular system servicing and tape exchanges. A TV monitor is usually included on-site so that operators can verify system operation. Recorded S-VHS tapes can be played back on the recorder unit or any S-VHS compatible VCR. Tapes can be duplicated to VHS format for more widespread distribution and review on any VCR.

The 8 mm cameras may be programmed to photograph one frame per second to one frame per minute. The film rolls may last several days to weeks, depending on the monitoring schedule.

Operators should perform site servicing visits once a week to once a month, depending on the monitoring schedule. Servicing visits include changing the film or videotape, completing an operations log, identifying film rolls or videotapes, and inspecting all system components for correct operations during each film/tape change. Fresh film or tape is loaded into the cameras, lenses and enclosure windows are cleaned, all batteries are checked, the camera and timer settings are checked, the cameras are aligned, and film/tape and documentation logs are mailed.

5.2.5 Data Collection

Site operators should be trained and provided with an operator's kit that includes a supply of videotape cassettes or film rolls, cassette or film mailers, status/assessment sheets, and system operating instructions.

The time-lapse systems may be programmed to record a full day of tape (client-specified on/off times). The videotape system records on S-VHS tape and is capable of operating unattended for up to 30 days. Site operator(s) should service the site bi-monthly to inspect the system and clean the camera optics.

All videotapes and film should be mailed by the site operator(s) along with site status/assessment sheets. Film rolls should be sent to Kodak for developing. When they arrive back, or when the videotapes arrive, they should be initially reviewed to verify that the system was working properly. Any noted inconsistencies should initiate immediate corrective action. All tapes and rolls should be numbered. The location of each morning and afternoon period should be recorded from the videotapes.

5.2.6 Data Reduction and Validation

5.2.6.1 Data Reduction

Videotapes and film rolls should be reviewed to document observed weather, activity, emissions, visibility, and anomaly events. Tapes should be reviewed in S-VHS format on a high resolution monitor. Qualitative 2-digit (or other) tape/film condition codes are assigned to each morning and afternoon period of tape. The codes identify specific visibility conditions in the following general categories:

- Sky conditions
- Urban activity
- Project-interest related industrial emissions
- Uniform haze intensity
- Layered haze occurrence
- Visual anomalies

Detailed descriptions of the criteria used for coding these categories are presented in Table 5-2. Meteorological conditions are based on visual observations only.

The result of the qualitative coding process is a digital file for each site that contains a 2-digit code for each half-day of tape or film. Final data summary tables and graphic plots can then be made. It is important to note that videotapes or film can only be used to document the presence of observed conditions. The cause of the condition generally must be obtained from supplemental data or from interpretation of other conditions observed in the vista. For example, though videotape or film can document that a white plume emanated from a stack, the chemical constituents of the plume cannot be directly determined from the tape/film.

5.2.6.2 Data Validation

Videotapes/film should be reviewed in conjunction with site documentation and other data if available. Two levels of validation are summarized below:

- Level I: Tapes/film are labeled by site, date, and time (loaded/removed). They are initially reviewed for proper exposure, alignment, and correct operating period.

! Level II: Daily meteorological conditions and patterns are documented, as well as the presence of any anomalies. Tapes/film are reviewed on a high-resolution color monitor or projector. A tape/film condition code is assigned to each morning and afternoon period. Codes for all periods are entered into a digital ASCII file.

Table 5-2

Example Tape/Film Condition Code Key

Sky Conditions		Code Description
0	No clouds	No clouds visible anywhere in the sky.
1	Scattered clouds < half of sky	Less than one-half of the sky has clouds present.
2	Overcast > half of sky	More than one-half of the sky has clouds present.
5	Weather concealing scene	Clouds or precipitation are such that determination of the sky value is impossible.
9	No observation or cannot be determined	To be used with target code of 9 or if sky value cannot be determined due to reasons other than weather.
Layered Haze		**Code Description**
0	No layered haze	No layered haze boundary (intensity of coloration edge) is perceptible.
1	Ground-based layered haze only	Only a single-layered haze boundary is perceptible with the haze layer extending to the surface.
2	Elevated layered haze only	An elevated layered haze with two boundaries is perceptible; e.g., horizontal plume.
3	Multiple haze layers	More than a single ground-based or elevated layered haze is perceptible. This can be multiple ground-based layers or a combination of both.
5	Weather concealing scene	Cloud or precipitation are such that determination of the presence of layered hazes is impossible.
9	No observation or cannot be determined	To be used with target code of 9 or if a layered haze value cannot be determined due to reasons other than weather.

5.2.7 <u>Data Reporting and Archive</u>

5.2.7.1 Data Reporting

Data reports should be prepared in a format that generally conforms to the *guidelines for Preparing Reports for the NPS Air Quality Division* (AH Technical Services, 1987). A separate data report should be prepared for each instrument type; photographic data reports should contain only photographic data. Reporting consists of various text discussions and graphics presentations concerning the instrumentation and collected data. Specific contents of the reports are defined by the contracting agency.

Seasonal photographic reporting should be completed within three months after the end of a monitoring season, and annual reporting within three months after the end of the last reported season. Standard meteorological monitoring seasons are defined as:

Winter	(December, January, and February)
Spring	(March, April, and May)
Summer	(June, July, and August)
Fall	(September, October, and November)

Reports should contain the following major sections:

! Introduction

! Data Collection and Reduction

! Photographic Data Summaries

! References

The introduction should contain a conceptual overview of the purpose of the monitoring program and specific objectives and tasks of the program.

The data collection and reduction section includes discussions of site configuration, camera system components, exposure schedule, and basic system operation. Also included should be a map of the United States depicting the location of each monitoring site, and a monitoring history summary table, describing each monitoring site, the type of instrumentation installed, and the historical periods of operation for each instrument. The section briefly describes the videotape/film review and coding process, as well as the compilation of the summary tables, and the quality control and quality assurance procedures applied during the data collection and reduction process.

Time-lapse data may be presented in various forms depending on contracting agency requirements. Each type of data summary should be accompanied by an explanation. Each report contains a Site and Target Specifications Summary Table listing complete site specifications for each monitoring site operational during the period, (including site name and abbreviation, latitude, longitude, and elevation of the camera monitoring site; number of exposures taken per day; and operating period during the reported period). A Qualitative Slide Analysis Summary Table provides a site-by-site accounting of observed haze and target-concealed conditions for each site that operated during the reporting period. Separate discussions detailing each observed anomaly may also be prepared.

The section also includes a brief discussion of videotape/film and digital file archive, a discussion of the events and circumstances that influenced data recovery, operational summaries for each site including: site name and abbreviation, data collection period, number of total possible observations, collection efficiency (number and percent), a description of the cause or causes of data loss or problem description, and resolutions and/or recommendations relating to the noted operational problems.

The reference section includes technical references (documents that are cited in the report), and related reports and publications (all prior reports pertaining to the monitoring program).

Supplemental data products that may accompany data reports include copies of the videotapes or film.

5.2.7.2 Data Archive

Duplicates of the videotapes or film rolls should be stored in standard storage cabinets, filed by site, season, and date. Supporting hard copy documentation, including operational notes and correspondence, should be appropriately filed in chronological order by site.

5.2.8 Quality Assurance

Internal quality assurance of time-lapse camera equipment is based primarily on visual review of developed visibility monitoring film. Alignment, exposure, and data collection efficiency can all be assessed from videotape or developed film. Any noted problems should initiate corrective action. Ongoing review of film and site operator identified problems often initiates corrective actions.

5.2.9 Data Analysis and Interpretation

Time-lapse data analysis can be qualitative only. Only conditions visually seen in the videotapes/film can be compiled and interpreted. A more thorough analysis would be to use the videotapes/film in conjunction with other forms of data, such as optical or aerosol data. All noted anomalies should be evaluated. Any coding or comment inconsistencies should be resolved and the digital code files updated if appropriate.

5.2.10 8 mm Time-Lapse Scene Monitoring Systems Standard Operating Procedures and Technical Instructions

The Air Resource Specialists, Inc. document entitled *Standard Operating Procedures and Technical Instructions for 8 mm Time-Lapse Scene Monitoring Systems*, includes the following 8 mm time-lapse-related Standard Operating Procedures and Technical Instructions:

SOP 4005	Procurement and Acceptance Testing Procedures for Scene Monitoring Equipment

TI 4005-1001	Procurement and Acceptance Testing Procedures for 8 mm Automatic Camera Systems
SOP 4055	Site Selection for Scene Monitoring Equipment
SOP 4075	Installation and Site Documentation for Scene Monitoring Equipment
SOP 4120	Automatic Camera System Maintenance (IMPROVE Protocol)
TI 4120-3200	Routine Site Operator Maintenance Procedures for 8 mm Automatic Camera System - Minolta XL 401/601
TI 4120-3210	Routine Site Operator Maintenance Procedures for 8 mm Automatic Camera System - Minolta D12
TI 4120-3400	Troubleshooting and Emergency Maintenance Procedures for 8 mm Automatic Camera System - Minolta XL 401/601
TI 4120-3410	Troubleshooting and Emergency Maintenance Procedures for 8 mm Automatic Camera System - Minolta D12
TI 4120-3520	Biannual Laboratory Maintenance Procedures for 8 mm Automatic Time-Lapse Camera Systems
SOP 4305	Collection of Scene Monitoring Photographs and Film (IMPROVE Protocol)
TI 4305-4003	Collection, Processing, and Handling of 8 mm Time-Lapse Movie Film
SOP 4420	Scene Monitoring Qualitative Data Reduction
TI 4420-5010	Qualitative 8 mm Time-Lapse Movie Film Review
SOP 4520	Scene Monitoring Data Reporting
TI 4520-5010	Scene Monitoring Reporting of 8 mm Time-Lapse Movie Film
SOP 4610	Scene Monitoring Archives
TI 4610-5010	8 mm Time-Lapse Film Archives

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7.0 VISIBILITY MONITORING-RELATED GLOSSARY AND ABBREVIATIONS

Abrasion mode	A size range of particles, typically larger than about 3 micrometers in diameter, primarily generated by abrasion of solids.
Absorption	Capture of incident light by particles or gases in the atmosphere.
Absorption coefficient	Proportion of incident light absorbed per unit distance. Typical units are inverse megameters (Mm^{-1}).
Accumulation mode	A size range of particles, from about 0.1 to 3 micrometers, formed largely by accumulation of gases and particles upon smaller particles. They are very effective in scattering light.
Acid deposition	Wet and/or dry deposition of acidic materials to water or land surfaces. The chemicals found in acidic deposition include nitrate, sulfate, and ammonium.
Acid rain (or acid precipitation)	The deposition of acid chemicals (incorporated into rain, snow, fog, or mist) from the atmosphere to water or land surfaces. The pH of rain is considered acid when it is below about 5.2 pH.
Adverse impact	A determination that an air-quality related value is likely to be degraded within a Class I area.
Aerometric Information Retrieval System (AIRS)	A computer-based repository of US air pollution information administered by the EPA Office of Air Quality Planning and Standards.
Aerosol	A suspension of microscopic solid or liquid particles in air. Atmospheric aerosols govern variations in light extinction and, therefore, visibility reduction.
Aerosol extinction	See reconstructed light extinction.
Aethalometer	An aerosol monitoring instrument that continuously measures particle light absorption (aerosol black carbon) on a quartz fiber filter.
Agglomeration	The process of collisions of particles that stick together to become larger particles.
Air light	Light scattered by air (molecules or particles) toward an observer, reducing the contrast of observed images.
Air pollutant	An unwanted chemical or other material found in the air.
Air pollution	Degradation of air quality resulting from unwanted chemicals or other materials occurring in the air.

Air quality	(In context of the national parks): The properties and degree of purity of air to which people and natural and heritage resources are exposed.
Air quality related values (AQRVs)	Values including visibility, flora, fauna, cultural and historical resources, odor, soil, water, and virtually all resources that are dependent upon and affected by air quality. "These values include visibility and those scenic, cultural, biological, and recreation resources of an area that are affected by air quality" (43 Fed. Reg. 15016).
AIRWeb	Air Resources Web, an air quality information retrieval system for US parks and wildlife refuges developed by the Air Resources Division of the National Park Service and the Air Quality Branch of the US Fish and Wildlife Service.
Albedo	Ratio of the light reflected by a surface to the incident light.
Ambient air	Air that is accessible to the public.
Anion	A negative ion, such as sulfate, nitrate, or chloride.
Anthropogenic	Caused by human activities (i.e., man-made).
Apparent contrast	Contrast at the observer of a target with respect to some background, usually an element of horizon sky directly above the target.
Apportionment	The act of assessing the degree to which specific components contribute to light extinction or aerosol mass.
Artifact	Any component of a signal or measurement that is extraneous to the variable represented by the signal or measurement.
AT	Ambient Temperature
Atomic absorption spectroscopy	A method of chemical analysis based on the absorption of light of specific wavelengths of light by disassociated atoms in a flame or high temperature furnace. It is sensitive only to elements.
Atmospheric clarity	An optical property related to the visual quality of the landscape viewed from a distance (see optical depth and turbidity).
Attainment area	A geographic area in which levels of a criteria air pollutant meet the health-based National Ambient Air Quality Standard for that specific pollutant.
Audit	An investigation of the ability of a system of procedures and activities to produce data of a specified quality.
b_{abs}	Absorption coefficient. A measure of light absorption in the atmosphere by particles and gases. Standard reporting units are inverse megameters (Mm^{-1}).

b_{ext}	Extinction coefficient. Measured directly by a transmissometer. Can be reconstructed from nephelometer and aerosol data. It is equal to the sum of b_{scat} and b_{abs}. Represents the proportion of radiation reduced by scattering and absorption per unit distance. Standard reporting units are inverse megameters (Mm^{-1}).
b_{scat}	Scattering coefficient. Measured directly by a nephelometer, the scattering coefficient includes scattering due to particles and atmospheric gases (Rayleigh scattering). Standard reporting units are inverse megameters (Mm^{-1}).
BAPMON	Background Air Pollution Monitoring Network
BART	Best Available Retrofit Technology
Best Available Control Technology (BACT)	A source emission limitation, based on the maximum degree of reduction for each pollutant, that must be applied by sources subject to the Prevention of Significant Deterioration program.
Bias	An unfair influence, inclination, or partiality of opinion.
Bimodal distribution	A distribution containing much of its elements in two distinct ranges of values. The size distributions of aerosols often show two peaks corresponding to about 1 and 10 micrometers in diameter.
Biological effects	Ecological studies to determine the nature or extent of air pollution injury to biological systems.
BLM	Bureau of Land Management
Brightness	A measure of the light received from an object, adjusted for the wavelength response of the human eye, so as to correspond to the subjective sensation of brightness. For visually large objects, the brightness does not depend on the distance from the observer.
Brightness contrast	The ratio of the difference in brightness between two objects to the brightness of the brighter of the two. It varies from 0 to -1.
CAA	Clean Air Act (including all of its amendments).
Calibration	The process of submitting samples of known value to an instrument, in order to establish the relationship of value to instrumental output.
Camera	Device for recording visual range on film.
CARB	California Air Resources Board

Cascade impactor — An instrument that samples particles by impacting on solid surfaces via jets of air. After passing the first surface, the air is accelerated toward the next surface by a higher speed jet, in order to capture smaller particles than could be captured by the previous one.

Charge neutralization — A process of removing static electric charges. This is done to particle-sampling filters in order to prevent electrostatic forces from distorting the apparent weight of the sample.

CIE — Commission International de l'Eclairage

CIRA — Cooperative Institute for Research in the Atmosphere

Clarity — Relative distinctness or sharpness of perceived scene elements.

Class I areas — National parks and wilderness areas managed by the National Park Service, U.S. Fish and Wildlife Service, and the USDA Forest Service and defined by the Clean Air Act Amendments of 1977 as having "special protection" from effects of air pollution. These federal lands have been defined as having "air-quality related values" (AQRVs), such as water quality, native vegetation, ecosystem integrity, and visibility, that need protection from air pollution. National Parks larger than 6,000 acres, National Memorial Parks and National Wilderness Areas larger than 5,000 acres, and International Parks.

Class II areas — Areas of the country protected under the Clean Air Act, but identified for somewhat less stringent protection from air pollution damage than Class I, except in specified cases.

Clean Air Act — Originally passed in 1963, the current national air pollution control program is based on the 1970 version of the law. Substantial revisions were made by the 1990 Clean Air Act Amendments.

Clean fuels — Low-pollution fuels that can replace ordinary gasoline, including gasohol, natural gas, and propane.

CMB — Chemical Mass Balance

Coarse mode — A size range of particles between 2.5 microns and 10 microns. Coarse particles are mostly composed of soils. The sum of the masses of coarse and fine particles (all particles smaller than 10 microns) is called PM_{10}.

Color — A qualitative sensation described by hue, brightness, and saturation.

Color contrast or difference — Contrast between two adjacent scene element colors. Any difference in color hue, saturation, or brightness, between two perceived objects.

Colorimetric analysis — Chemical analysis based on the colors of dyes formed by the reaction of the analyte with reagents.

Condensation counternuclei	An instrument that counts nucleation mode particles by causing them to grow in a humid atmosphere, and observing light reflections from the individual enlarged particles.
Continuous sampling device	An air analyzer that measures air quality components continuously. (See also monitoring, integrated sampling device).
Contrast	Relative difference in light coming from a target compared to the surrounding background, usually the horizon sky. Any difference in the optical quality of two adjacent images.
Contrast change threshold	Minimum change in contrast perceptible to an observer.
Contrast threshold	Minimum apparent contrast at which a target is just perceptible.
Contrast transmittance	Ratio of apparent contrast to inherent contrast. The ability of an atmosphere to transmit an image without loss of contrast. It varies from 0% to 100% and depends on the length of the viewing path. When the object is darker than its background, it has a value between 0 and -1. For objects brighter than their background the value varies from 0 to infinity. When the contrast transmittance is equal to 0, the object cannot be seen.
Current conditions	Contemporary, or modern, atmospheric conditions affected by human activity.
Datalogger	An electronic device for measuring analog or digital signals and recording the results on a storage media. Many of them can record inputs on a number of separate locations, reporting them as separate "channels."
Deciview (dv)	A haziness index designed to be linear with respect to human perception of visibility. A 1-2 dv change in haziness corresponds to a small, visibly perceptible change in scene appearance. Higher deciview values indicate more extinction and a corresponding decrease in visual range.
Deliquescence	The process that occurs when the vapor pressure of the saturated aqueous solution of a substance is less than the vapor pressure of water in the ambient air. Water vapor is collected until the substance is dissolved and is in equilibrium with its environment.
Dew point	The temperature at which humidity in the air will condense upon a solid surface.
Dichotomous	Any particle sampler that separately collects coarse and fine particles samplerfrom one atmosphere. Often refers to virtual impactor instruments.
Discoloration	Any change in the apparent color of an image. Often refers to the loss of blue sky color due to air pollution.
DMB	Differential Mass Balance

Dose-response	The relationship between the dose of a pollutant and its effect on a biological system.
DRUM	Davis Rotating-drum Universal-size-cut Monitor
Dry deposition	Also known as dryfall, includes gases and particles deposited from the atmosphere to water and land surfaces. This dryfall can include acidifying compounds such as nitric acid vapor, nitrate and sulfate particles, and acidic gases.
Edge sharpness	Describes a characteristic of landscape features. Landscape features with sharp edges contain scenic features with abrupt changes in brightness.
Electrical aerosol	A particle sampler that puts electrical charges on particles and sorts analyzerthem by their different drift rates in an electric field.
Elevated layer	A pollution distribution that is not in contact with the ground.
Emissions	Release of pollutants into the air from a source.
EMSL	Environmental Monitoring Systems Laboratory
EOF	Empirical Orthogonal Function
EPA	United Stated Environmental Protection Agency
Equilibration	A balancing or counter balancing to create stability, often with a standard measure or constant.
Externally mixed	Particulate species that co-exist as separate particles without co-mingling or combining.
Extinction	Process of reducing radiation transfer by scattering and absorption.
Extinction budget	Apportioning the extinction coefficient to atmospheric constituents to analysisestimate the change in visibility caused by a change in constituent concentrations.
Extinction coefficient	Proportion of radiation reduced by scattering and absorption per unit distance. Standard units are inverse megameters (Mm^{-1}). The atmospheric extinction coefficient, loosely referred to as "extinction," represents the ability of the atmosphere to absorb and scatter light. It equals the sum of the scattering and absorption coefficients.
Fine particles	Particulate matter with an aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$). Fine particles are responsible for most atmospheric particle-induced extinction. Ambient fine particulate matter consists basically of five species: sulfates, ammonium nitrate, organics, elemental carbon, and soil dust.
FIPS	Federal Implementation Plans

FLM	Federal Land Manager
FTP	File Transfer Protocol
FWS	United States Fish and Wildlife Service
GC	Gas Chromatography
Hazardous air pollutants	Airborne chemicals that cause serious health and environmental effects. (HAP)
Haze (hazy)	A visual phenomenon resulting from scattering of light in a volume of aerosols. Condition of the atmosphere in which particles obscure a significant part of the vista.
High volume (HI-VOL)	A simple particle sampler consisting of a filter holder and a vacuum sampler cleaner blower, in a simple rain shelter. Some units have flow measuring or controlling features.
Hue	Attribute of color that determines whether it is red, yellow, green, blue, or other color. It is most strongly related to wavelength of light.
Humidity	Water in air, as a gas. Often measured as a percentage, compared to the maximum amount of water vapor the air can contain at that temperature.
Hydrophobic	Lacking affinity for water, or failing to adsorb or absorb water.
Hygroscopic	Characteristic of substances (e.g., particles in the atmosphere) having the property of absorbing water vapor from air. Also pertains to a substance (e.g., aerosols) that have an affinity for water and whose physical characteristics are appreciably altered by the effects of water.
Illumination	Application of visible radiation to an object.
Impairment	The degree to which a scenic view or distance of clear visibility is degraded by man-made pollutants.
IMPROVE	Interagency Monitoring of Protected Visual Environments, a collaborative monitoring program established in the mid-1980's as a part of the Federal Implementation Plans. IMPROVE objectives are to provide data needed to assess the impacts of new emission sources, identify existing man-made visibility impairment, and assess progress toward the national visibility goals that define protection of 156 Class I areas.
IN	Ice Nuclei
INAA	Instrumental Neutron Activation Analysis
Indirect effects	Non-optical atmospheric effects of aerosols on cloud albedo and formation (e.g., as condensation nuclei for cloud droplets).

Inhalable particulate matter	Particles smaller than about 12 micrometers in diameter, capable of being drawn into the human bronchial system. Larger particles tend to be filtered out in the upper respiratory tract.
Inherent contrast	Contrast of the target against the horizon sky background when viewed at the target. Same as intrinsic contrast. The contrast that would be seen between two adjacent scenic elements if there were no intervening atmosphere.
Integral vistas	Scenic views which extend beyond Class I boundaries, that are critical to the enjoyment of the area.
Integrated sampling	An air sampling device that allows estimation of air quality components device over a period of time (e.g., 24 hours to two weeks) through laboratory analysis of the sampler's medium.
Integrating nephelometer	Instrument that measures the light scattered from a light beam by an enclosed air sample through scattering angles between 5° and 175°.
Internally mixed	Refers to the situation where individual particles contain one or more species. For example, water is internally mixed with its hygroscopic hosts.
Ion	A charged molecular group or atom.
Ion chromatography	A method of separating ions by their different speeds of passage through an ion-exchange resin. The ions are usually detected by their conductivity.
IP	Inhalable Particle network
Just noticeable change (JNC)	A variation of just noticeable difference that relates directly to human visual perception. A JNC corresponds to the amount of optical change in the atmosphere required to evoke human recognition of a change in a given landscape (scenic) appearance. The change in atmospheric optical properties may be expressed as the number of JNC's between views of a given scene at different intervals of time.
Just noticeable difference (JND)	A measure of change in image appearance that affects image sharpness. Counting the number of JND's (detectable changes) in scene appearance is regarded as an alternative method of quantifying visibility reduction (light extinction).
Koschmeider constant	The constant in the reciprocal relationship between standard visual range and the extinction coefficient (see standard visual range).
Layered haze	Haze that obscures a horizontal layer of a vista.
Light extinction	The absorption and scattering of light. The attenuation of light per unit distance due to absorption and scattering by the gases and particles in the atmosphere.
LIPM	Laser Integrating Plate Method

LOD	Limit of Detection
LQL	Lower Quantifiable Limit
Magnehelic gauge	A differential pressure gauge suitable for measuring pressure differences as small as 0.1 inches of water.
Major source	A stationary facility that emits a regulated pollutant in an amount exceeding the threshold level (100 or 250 tons per year, depending on the type of facility).
Matrix filter	A filter that is formed of a mat or matrix of fibers. It is physically thick, and particles are trapped deep in its structure.
MDL	Minimum Detectable Limit
Membrane filter	A thin filter, usually made of a synthetic polymer, with microscopic holes in it. Particles are collected only on the surface facing the air flow.
Mie scattering	Scattering by particles whose size is comparable to the wavelength of radiation. The attenuation of light in the atmosphere by scattering due to particles of a size comparable to the wavelength of the incident light. This is the phenomenon largely responsible for the reduction of atmospheric visibility. Visible solar radiation falls into the range from 0.4 to 0.8 µm, roughly, with a maximum intensity around 0.52 µm.
Mixing layer	An unstable layer of air that has turbulent mixing, usually due to solar heating of the ground. It is often capped by a stable layer of air.
Mm^{-1}	Inverse megameter. A unit of extinction related to SVR and dv. Higher extinction coefficients correspond to lower SVR values and higher deciview values.
Mobile sources	Moving objects that release regulated air pollutants, (e.g., cars, trucks, buses, airplanes, trains, motorcycles, and gas-powered lawn mowers). See also source; stationary source.
MOHAVE	Measurement of Haze and Visual Effects
Monitoring	Measurement of air pollution and related atmospheric parameters. See also continuous sampling device, integrated sampling device.
MPP	Mohave Power Project
MTF	Modulation Transfer Function
NAMS	National Air Monitoring Stations
NAS	National Academy of Sciences

National Acid Precipitation Assessment (NAPAP)	The 10-year (1980-1990) interagency research program designed to investigate acid deposition and its effects nationwide. The products of this program are the series of State of the Science and Technology Program documents that summarize what we know about the severity of acid deposition and the resources it affects.
National Ambient Air Quality Standards (NAAQS)	Permissible levels of criteria air pollutants established to protect public health and welfare. Established and maintained by EPA under authority of the Clean Air Act.
National Atmospheric Program	A national network of about 200 sites where wet deposition is collected weekly and sent to the Central Analytical Laboratory in Illinois for Deposition chemical analysis. This network has operated since 1977 and is funded (NADP) by seven federal agencies, and numerous cooperators in agencies, universities, and industry. This network of predominately rural sites is designed to represent broad, regional patterns of deposition.
Natural conditions	Prehistoric and pristine atmospheric states (i.e., atmospheric conditions that are not affected by human activities).
Nephelometer	An optical instrument that measures the scattering coefficient (b_{scat}) of ambient air by directly measuring the light scattered by aerosols and gases in a sampled air volume. See also integrating nephelometer.
NESCAUM	Northeast States for Coordinated Air Use Management
Neutron activation	A method of chemical analysis in which the sample is bombarded with analysis neutrons in a nuclear reactor. The nuclei of various elements in the sample are modified to radioactive forms, and the concentrations of the elements are then determined by the intensities and wavelengths of the radiation emitted.
NGS	Navajo Generating Station
NOAA	National Oceanic and Atmospheric Administration
Nonattainment area	A geographic area in which the level of a criteria air pollutant is higher than the level allowed by the federal standards. For NAAQS, where the pattern of "violations of standard" is sufficient to require remedial action; a boundary is determined around the location of the violations. the area within that boundary is designated to be in non-attainment of the particular NAAQS standard and an enforceable plan is developed to prevent additional violations.
NPS	National Park Service
NSR	New Source Review
Nuclei mode	A size range of particles below about 0.1 micrometer in diameter. These particles are the nuclei around which larger particles grow.

OAQPS	EPA Office of Air Quality Planning and Standards
Optical depth	The degree to which a cloud or haze prevents light from passing through it. It is a function of physical composition, size distribution, and particle concentration. Often used interchangeably with "turbidity."
Optical monitoring	Optical monitoring refers to directly measuring the behavior of light in the ambient atmosphere.
Optical particle	An instrument which measures the size of individual particles by the counteramount of reflected light from a microscopic illuminated volume.
Organic compounds	Chemicals that contain the element carbon.
Orifice audit device	A device which measures air flow based on the known relationship of air flow through and orifice to the pressure drop across it.
Origins	Particle origins can be anthropogenic (man-made) or natural. Another origin classification is primary (particles that are emitted into the atmosphere as particles, such as organic and soot particles in smoke plumes or soil dust particles), and secondary (those formed from gas-to-particle conversion in the atmosphere, such as sulfates, nitrates, and secondary organics).
PESA	Proton Elastic Scattering Analysis
PIXE	Particle Induced X-ray Emission
Particle sampler	An instrument to measure particulate matter in ambient air.
Particle scattering coefficient	Proportion of incident light scattered by particles per unit distance (Mm^{-1}).
Particulate matter	Dust, soot, other tiny bits of solid materials that are released into and move around in the air.
Path function	Radiance per unit path length from a specified point along the path radiated towards the observer.
Path radiance	Radiance of path directed towards the observer. Or "airlight," is a radiometric property of the air resulting from light scattering processes along the sight line, or path, between a viewer and the object (target).
Perceptible	Capable of being seen.
Phase function	Relationship of scattered to incident light as a function of scattering angle; volume scattering function.
Photochemical	Any chemical reaction which is initiated by light. Such processes are processimportant in the production of ozone and sulfates in smog.

Photometer	Instrument for measuring photometric quantities such as luminance, illuminance, luminous intensity, and luminous flux. An instrument for measuring the brightness of an object. It has been suggested that this name be reserved for those instruments which have been adjusted to match the wavelength response of the human eye, but established usage is not yet this consistent, and radiometers are sometimes called photometers.
Photometry	Study of photometric quantities of light.
Photopic	Vision or wavelength response of the cones of a normal eye when exposed to a luminance of at least 3.4 candelas per square meter.
Plume	Airborne emissions from a specified source and the path through the atmosphere of these emissions.
PM	The acronym for airborne "particulate matter," an air quality parameter for which standards are maintained within NAAQS.
$PM_{2.5}$	The acronym for that portion of PM that has an aerodynamic diameter of 2.5 microns or less.
PM_{10}	The acronym for that portion of PM that has an aerodynamic diameter of 10 microns or less.
Polarization	A property of light. Light can be linearly polarized in any direction perpendicular to the direction of travel, circularly polarized (clockwise or counterclockwise), unpolarized, or mixtures of the above.
Precursor	A substance or condition whose presence generally precedes the formation of another, more notable, condition or substance.
Prescribed burn	A wildland fire whose progress has been controlled by a combination of strategies, including: construction of artificial fire breaks, selection of natural firebreaks and burnout of vulnerable fuels within the fire control line. A wildfire may be declared a controlled burn if ignition occurs within an area for which an approved burning plan exists and weather conditions fall within the acceptable range. While a forest management burn is referred to as a prescribed burn in the planning stage, the same project may be referred to as a controlled burn in the implementation stage.
Prevention of Significant Deterioration (PSD)	A program established by the Clean Air Act that limits the amount of additional air pollution that is allowed in Class I and Class II areas.
Primary particles	Suspended in the atmosphere as particles from the time of emission (e.g., dust and soot).
PSD	Prevention of Significant Deterioration

Psychrometer	An instrument for measuring humidity based on the temperature drop of a thermometer with a wet wick on the bulb.
Pyanometer	An instrument that measures directly the loss of total solar radiance under clear sky conditions.
QDM	Quadratic Detection Model
Quality assurance	An overall plan undertaken to quantify, control, and perhaps improve the quality of data acquired by a system.
Quality control (QC)	Actions routinely taken to maintain a specified level of quality of acquired data.
R-MAP	Resource Management Assessment Program.
Radiometer	A name for light-measuring instruments which do not match the wavelength response of the human eye.
RAPS	Regional Air Pollution Study
RASS	Radio Acoustic Sounding Systems
Rayleigh scattering	Scattering by gas molecules, whose size is small compared to the wavelength of radiation. Light scattering (principally blue light) by atmospheric gases. Perfectly clean air (100 percent Rayleigh scattering) would correspond to an SVR of 391 km at an elevation of 5,000 feet, which is the theoretical maximum for an SVR. Rayleigh scattering also corresponds to $b_{ext} = 10\ Mm^{-1}$, and is defined as 0 deciview.
Reconstructed light extinction	The relationship between atmospheric aerosols and the light extinction coefficient. Can usually be approximated as the sum of the products of the concentrations of individual species and their respective light extinction efficiencies.
Reflectance	Ratio of reflected to incident light.
Reflection	Return of radiation by a surface without a change of frequency.
Regional haze	A cloud of aerosols extending up to hundreds of miles across a region and promoting noticeably hazy conditions. Condition of the atmosphere in which uniformly distributed aerosol obscures the entire vista irrespective of direction or point of observation. Is not easily traced visually to a single source.
RH	Relative Humidity
Saturation	One part of the description of color, it qualitatively corresponds to the purity of color: the lack of mixed black or white.

Scattering	Changing the direction of radiation at collisions with particles and gas molecules. The diversion of light from its original path. It can be caused by molecules or particles.
Scattering coefficient	Proportion of incident light scattered per unit distance. Standard units are inverse megameters (Mm^{-1}).
Scattering efficiency	The relative ability of aerosols and gases to scatter light. A higher scattering efficiency means more light scattering per unit mass or number of particles, this in turn means poorer visibility. In general, fine particles (diameter less than 2.5 microns) are efficient scatterers of visible light.
Scene element	Discrete segment of a landscape scene.
Scene monitoring	Scene monitoring is the monitoring of a specific vista or target. Optical and aerosol monitoring measure an abstract, but easily quantifiable parameter of the atmosphere. Scene monitoring captures the effects of all atmospheric parameters simultaneously, but in an inherently difficult manner to quantify. It is, for example, difficult to determine quantitatively which of two photographs represent "better" visibility conditions. Scene monitoring is generally done to help relate quantitative data in a "user-friendly" format.
Secondary particles	Formed in the atmosphere by a gas-to-particle conversion process.
Sight path	The straight line between the observation point and the target.
SLAMS	State and Local Air Monitoring Stations
Smog	A mixture of air pollutants, principally ground-level ozone, produced by chemical reactions involving smog-forming chemicals. See also haze.
Soot	Black particles with high concentrations of carbon in graphitic and amorphous elemental forms. It is a product of incomplete combustion of organic compounds.
Source	Any place or object from which air pollutants are released. Sources that are fixed in space are stationary sources; sources that move are mobile sources. (See also major source).
Southern Appalachian Mountain Initiative (SAMI)	A consortium of government agencies, industry, and environmental groups, formed to investigate the status of air quality and its effects in the highland regions of the southeastern United States. The objective of this regional cooperative is to determine the current and future impacts of regional air pollutants, such as ozone and acid deposition, and to recommend regional air management strategies to control the formation of these pollutants.
SRP	Salt River Project

Standard visual range (SVR)	Visual range is the furthest distance that a human observer can resolve range a large dark target under the prevalent atmospheric conditions. Standard visual range is visual range standardized to Rayleigh scattering at an elevation of 5,000 feet (10 Mm^{-1}). The distance under daylight and uniform lighting conditions at which the apparent contrast between a specified target and its background becomes just equal to the threshold contrast of an observer, assumed to be 0.02.
STAPPA/ALAPCO	State and Territorial Air Pollution Program Association/Administrators and the Association of Local Air Pollution Control Officials
State Implementation Plan (SIP)	A collection of regulations used by the state to carry out its Implementation responsibilities under the Clean Air Act.
Stationary source	A fixed source of regulated air pollutants (e.g., industrial facility). See also source; mobile sources.
Stratification data)	The process of separating a database into different groups according to (of some detail of their origin, for the purposes of improving statistical sensitivity.
Strip chart recorder	A device for making a time record of some signal, usually an applied voltage. The signal drives a pen in one direction, while paper is moved under the pen in the perpendicular direction at a uniform rate.
Sun radiometer	A device for measuring the intensity of sunlight falling on the ground. If the sky is cloudless and the angle of the sun is known, then a measure of the clarity of the air can be had by this measurement.
Surface layer	A concentration of air pollution that extends from the ground to an elevation where the top edge of a pollution layer is visible.
S-VHS	Super-VHS, an high definition video format which is capable of achieving horizontal resolution of over 400 lines. A tape recorded in S-VHS format cannot be played on a recorder which is designed to accommodate only the VHS format. See also VHS.
Target	Object in the distance observed by a person or instrument for visibility measurements.
Temperature	Weather condition in which warm air sits atop cooler air, promoting inversionstagnation and increased concentrations of air pollutants. A condition of a layer of atmosphere in which temperature increases with altitude. Such a layer is stable, and pollutants migrate through it very slowly. Also known as an inversion layer.
Texture	Roughness of the landscape.

Threshold contrast	A measure of human eye sensitivity to contrast. It is the smallest increment of contrast perceptible by the human eye.
TMBR	Tracer Mass Balance Regression
Total light extinction	The sum of scattering (including Rayleigh scattering) and absorption coefficients. See also extinction coefficient.
Total suspended particulates (TSP)	Total particulate matter in a sample of ambient air.
Toxic air pollutants	See hazardous air pollutants.
Tracer elements	An element which is emitted most strongly by a specific source or class of sources, and can therefore be used as evidence for an impact by such a source when the element is detected in an air pollution sample.
Transmission gauge	A device for determining the amount of particles collected on a filter by the attenuation of light passing through the filter. Beta rays are sometimes used in place of visible light, and the resulting instrument is called a beta gauge.
Transmissometer	A device for assessing visibility conditions by measuring the amount of light received from a distant light source. Total light extinction is measured by integrating light scattering and absorption properties of the atmosphere.
Transmittance	The ratio of the light transmitted through a medium to the incident light. Light is attenuated by scattering and adsorption from gases and particles.
Tribal Implementation Plan (TIP)	A collection of regulations used by the indian tribes to carry out its responsibilities under the Clean Air Act.
TRPA	Tahoe Regional Planning Agency
TSP	The acronym for total suspended particulates, that portion of PM that is captured by a PM sampler which does not attempt to discriminate according to particle size.
Turbidity	A condition that reduces atmospheric transparency to radiation, especially light. The degree of cloudiness, or haziness, caused by the presence of aerosols, gases, and dust.
UCD	University of California-Davis
Uniform haze	Pollutants that are uniformly distributed both horizontally and vertically from the ground to a height well above the highest terrain.
USFS	United States Forest Service

USFWS	United States Fish and Wildlife Service
VHS	Video Home System, a video tape format commonly used on video recorder/players.
VIEW	Visibility Intensive Experiment in the West, a project of the US EPA, with cooperation of the National Park Service, to measure visibility at many stations throughout the western United States to document current visibility and examine trends.
Violation of standard	A regulatory situation, (i.e., NAAQS), where the pattern of "exceedences of standard" is greater than the frequency allowable under that standard.
Virtual impactor	A type of dichotomous sampler which separates large particles from an air stream by impacting them on the "virtual surface" of a slowly moving column of air.
Visibility	The ability to see an object or scene as affected by distance and atmospheric conditions; to perceive form, color and texture.
Visibility indexes	Aerosol indexes include the physical properties of the ambient atmospheric particles (particle origin, size, shape, chemical composition, concentration, temporal and spatial distribution, and other physical properties). Optical indexes include coefficients for scattering, extinction, and absorption, plus an angular dependence of the scattering known as the normalized scattering phase function. Scenic indexes comprise visual range, contrast, color, texture, clarity, and other descriptive terms.
Visibility Metric	A statistical summary of a set of visibility data including the median (or mean) of the cleanest 20% of the samples, the median (or mean) of all samples, and the median (or mean) or the dirtiest 20% of the samples.
Visibility reduction	The impairment or degradation of atmospheric clarity. It becomes significant when the color and contrast values of a scene to the horizon are altered or distorted by airborne impurities.
Visual air quality	Air quality evaluated in terms of pollutant particles and gases that affect how well one can see through the atmosphere.
Visual image	The digitizing, calibration, modeling, and display of the effects of processingatmospheric optical parameters on a scene. The process starts with a photograph of landscape features viewed in clean atmospheric conditions and models the effects of changes in atmospheric composition.
Visual range (VR)	An expression of visibility; the maximum distance at which a large black object just disappears against the horizon.
Washout	The process by which particles are removed from air by capture by raindrops.
WESTAR	Western States Air Resources Council

Wet deposition	The deposit of atmospheric gases and particles (incorporated into rain, snow, fog, or mist) to water or land surfaces.
Wildfire	Any wildland fire that requires a suppression response. A controlled burn may be declared a wildfire if part of it escapes from the control line or if weather conditions deteriorate and become unacceptable, as described in the burning plan.
XRF	X-Ray Fluorescence

TECHNICAL REPORT DATA
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1. REPORT NO. EPA-454/R-99-003	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE VISIBILITY MONITORING GUIDANCE DOCUMENT		5. REPORT DATE 5 February 1999
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Environmental Protection Agency Emissions Monitoring and Analysis Division Monitoring and Quality Assurance Group (MD-14) Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This EPA Visibility Monitoring Guidance Document was prepared to provide assistance to those organizations responsible for collecting visibility and particulate matter data for regulatory and planning purposes. The information in this document includes: background on visibility protection requirements from the Clean Air Act and related regulations; a summary of visibility monitoring goals and objectives set forth in the Clean Air Act and related EPA regulations; considerations and recommendations for developing effective visibility monitoring sites and networks, particularly for implementation of the monitoring requirements for the $PM_{2.5}$ and regional haze regulatory programs. These considerations and recommendations address visibility definitions and theory, monitoring goals and objectives, data quality objectives, monitoring methods, data archive and data applications, and network design. Descriptions of current visibility measurement methods and monitoring protocols are also provided, particularly those used under the Interagency Monitoring of Protected Visual Environments (IMPROVE) program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Visibility Monitoring, PM 2.5, aerosol, regional haze, IMPROVE		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
	20. SECURITY CLASS (This page)	22. PRICE

EPA Form 2220-1 (9-73)