Regional Haze and Visibility in the Northeast and Mid-Atlantic States

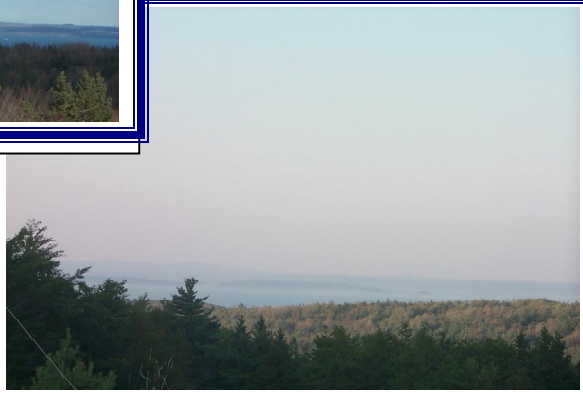
prepared by

Northeast States for Coordinated Air Use Management

for the

Ozone Transport Commission

January 31, 2001



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Appendix A Full Text of the Regional Haze Rule
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Unit, Symbols, Acronyms

Acronyms

ACM – Asymmetric Convective Model
AIRS – Aerometric Information Retrieval System
ATAD – Atmospheric Transport and Diffusion Model
ATDM – Aerosol and Toxics Deposition Model (part of REMSAD)
ANC – acid neutralizing capacity
BACT – Best Available Control Technology
BART – Best Available Retrofit Technology
BLM – Bureau of Land Management
CAA – Clean Air Act
CALMET – California Meteorological model
CALPUFF – California Puff model
CAMNET – Northeast Visibility Camera Network
CAMx-AERO – Comprehensive Air Quality Model with extensions-Aerosol
CASTNet – Clean Air States and Trends Network
CCTM – CMAQ chemical transport model
CenWRAP- Central West Regional Air Partnership
CFR – Code of Federal Regulations
CIRA – Cooperative Institute for Research in the Atmosphere
CMAQ – Community Multi-scale Air Quality Model
CMB – chemical mass balance
CM – coarse mass
CUSTOMER – Customer Use and Survey Techniques for Operations, Management, Evaluations, and Research
CVM – contigent valuation method
EDF – Environmental Defense Fund
EIA – Energy Information Administration
EGU – Electricity Generating Unit
ETS – Emission Tracking System
FAA – Federal Aviation Administration
FDDA – Four-Dimensional Data Assimilation
FEM – Federal Equivalency Monitors
FGD – flue gas desulfurization
FIP – Federal Implementation Plan
FLAG – Federal Land Managers' Air Quality Related Values Workgroup
FLM – Federal Land Manager
FM – fine mass
FRM – Federal Reference Monitors
FWS – Fish and Wildlife Service
GCVTC – Grand Canyon Visibility Transport Commission
GEMAP – Geocoded Modeling and Projection System
GIS – Geographic Information System
IMPROVE – Interagency Monitoring of Protected Visual Environments
HYSPLIT – Hybrid Single-Particle Langrangian Integrated Trajectory model
LADCo – Lake Michigan Air Directors Consortium
LEV – low emission vehicle
MARAMA – Mid Atlantic Region Air Management Association
MEPPS – Model-3 Emissions Processing and Projection System
MM4 – Fourth Generation Mesoscale Model
MM5 – Fifth Generation Mesoscale Model
MOU – Memorandum of Understanding
MRF – Medium Range Forecast model
MT – total mass (PM_{10})
MF – fine mass ($PM_{2.5}$)
NAAQS – National Ambient Air Quality Standards
NADP – National Atmospheric Deposition Program

NAPAP – National Acid Precipitation Assessment Program
NARSTO – North American Research Strategy for Tropospheric Ozone
NASA – National Aeronautics and Space Administration
NEGC/ECP – New England Governors' Conference/ Eastern Canadian Premiers
NEPA – National Environmental Policy Act
NEPART– Northeast Particle Network
NESCAUM – Northeast States for Coordinated Air Use Management
NET – National Emissions Trends (EPA)
NGM – Nested Grid Model
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
NRC – National Research Council
NSPS – New Source Performance Standard
NSR – New Source Review
NSRE – National Survey on Recreation and the Environment
OMC – organic mass from carbon
OTC – Ozone Transport Commission
OTR – Ozone Transport Region
PMF – Positive Matrix Factorization
PSCF – Potential Source Contribution Function
PSD – prevention of significant deterioration
PVAQ – perceived visual air quality
QSSA – Quasi-Steady State Approximation
RACT – Reasonably Available Control Technology
RADM – Regional Acid Deposition Model
RAMS – Regional Atmospheric Modeling System
RCFM – reconstructed particle fine mass
REMSAD – Regulatory Modeling System for Aerosols and Deposition
RPO – regional planning organization
RV – recreational vehicle
SeSARM – Southeast States Air Resource Managers
SIP – State Implementation Plan
SCR – selective catalytic reduction
SMOKE – Sparse Matrix Operator Kernel Emissions model
SMVGEAR – Sparse Matrix Vectorized Gear
SOA – secondary organic aerosol
SNCR – selective non-catalytic reduction
STAPPA/ALAPCO – State and Territorial Air Pollution Program Administrators / Association of Local Air Pollution Control Offices
TEA-21 – Transportation Equity Act for the 21st Century
TIP – Tribal Implementation Plan
UAM-AERO – Urban Airshed Model-Aerosol
UAM-V – Urban Airshed Model – Variable
URM – Urban-to-Regional Multiscale model
USEPA – United States Environmental Protection Agency
USFS – United States Forest Service
WESTAR-Western States Air Resources Council
WRAP-Western Regional Air Partnership
WTP – willingness to pay
WTA – willingness to accept compensation
HC – hydrocarbon

Chemical Species

Al – aluminum
Ca – calcium
CO – carbon monoxide
ElemC, EC – elemental carbon
Fe – iron
HSO_4 – bisulfate
H_2SO_4 – sulfuric acid
HNO_3 – nitric acid
LAC – light absorbing carbon

NOx – oxides of nitrogen (NO_2 and NO)
NO – nitric oxide
NO_2 – nitrogen dioxide
NO_3 – nitrate
NH_3 – ammonia
NH_4 – ammonium
$(NH_4)_3H(SO_4)_2$ – letovicite
NH_4HSO_4 – ammonium bisulfate
$(NH_4)_2SO_4$ – ammmonium sulfate
(NH_4NO_3) – ammonium nitrate
O_3 – ozone
OrgC, OC – organic carbon
$PM_{2.5}$ – particle matter up to 2.5 µm in size
PM_{10} – particle matter up to 10µm in size
Si – silicon
SO_2 – sulfur dioxide
SO_4 – sulfate
Ti – titanium
VOC – volatile organic carbon

Symbols
b_{ext} – light extinction coefficient (Mm^{-1} or km^{-1})
b_{scatt} – light scattering coefficient (Mm^{-1} or km^{-1})
b_{abs} – light absorption coefficient (Mm^{-1} or km^{-1})
f(RH) – relative humidity adjustment factor
[ ] – concentrations

Units
Length
m – meter
nm – nanometer (0.000000001m; 10^{-9}m)
µm – micrometer (0.000001m; 10^{-6}m)
km – kilometer (1000 x m; 10^3 m)
Mm – Megameter (1000000 x m; 10^6 m)

Area
ha – hectare
m^2 – square meter
km^2 – square kilometer

Volume
L – liter
m^3 – cubic meter

Mass
lb – pound
g – gram
ng – nanograms (0.000000001 x g; 10^{-9} g)
µg – micrograms (0.000001 x g; 10^{-6} g)
mg – milligram (0.001 x g; 10^{-3} g)
kg – kilograms (1000 x g; 10^3 g)

Power
W – watt (Joules/sec)
kW – kilowatt (1000 x W; 10^3 W)
MW – megawatt (1000000 x W; 10^6 W)

Energy
Btu – British Thermal Unit (= 1055 Joules)
mmBtu – million Btu
MWh – megawatt hour
kWh – kilowatt hour

Concentration
$\mu g/m^3$ – micrograms per cubic meter
ng/m^3 – nanograms per cubic meter
ppb – parts per billion
ppm – parts per million

Scattering Efficiency
m^2/g – square meters per gram

Visibility
dv – deciview

Executive Summary

In 1977, Congress added the goal of restoring pristine visibility conditions in national parks and wilderness areas to the federal Clean Air Act (CAA). Section 169 of the CAA calls for the prevention of any future, and the remedying of "any" existing, man-made visibility impairment in so-called "Class I" areas.[1] These are ambitious targets given that air pollution now reduces average visual range in the eastern United States to just 15 to 30 miles, about one-third the visual range typical of natural conditions.

Despite the lofty goal adopted in 1977, relatively modest steps were taken over the ensuing two decades to remedy visibility impairment at Class I areas around the country. Control measures undertaken to improve visibility were largely confined to addressing plume blight from specific pollution sources near Class I areas; they did little to address the pervasive, regional nature of haze throughout the eastern U.S. However, emissions reductions were realized through the implementation of other sections of the CAA: most notably the adoption, in 1990, of a national acid rain program aimed at substantially reducing sulfur dioxide emissions, a key contributor to visibility impairment in the East.

On July 1, 1999, the U.S. Environmental Protection Agency (USEPA) issued a new set of regulations aimed at achieving national visibility goals by 2064. Commonly known as the "regional haze rule," these regulations attempt, for the first time, to address the combined visibility effects of numerous pollution sources over a wide geographic region. Significantly, all states – even those without Class I areas – will be required to participate in haze reduction efforts.[2] To facilitate interstate coordination and cooperation, USEPA has designated five regional planning organizations (RPOs) covering all areas of the U.S. The Ozone Transport Commission (OTC), which includes all states along the eastern seaboard from Washington, DC to Maine, was selected to serve as the planning organization for the Northeast and Mid-Atlantic states.[3] The OTC RPO will be coordinating efforts to address visibility impairment at seven Class I areas: Acadia National Park, ME; Brigantine Wilderness, NJ; Great Gulf Wilderness, NH; Lye Brook Wilderness, VT; Moosehorn Wilderness, ME; Presidential Range – Dry River Wilderness, NH; and Roosevelt Campobello International Park, New Brunswick.[4]

This report provides a comprehensive introduction to the problem of visibility impairment and regional haze in the Northeast and Mid-Atlantic. It was undertaken by the Northeast States for Coordinated Air Use Management (NESCAUM) as part of an effort, in partnership with the Mid-Atlantic Region Air Management Association (MARAMA), to assist the OTC in developing a foundation for future haze planning and in identifying research priorities for the next several years.

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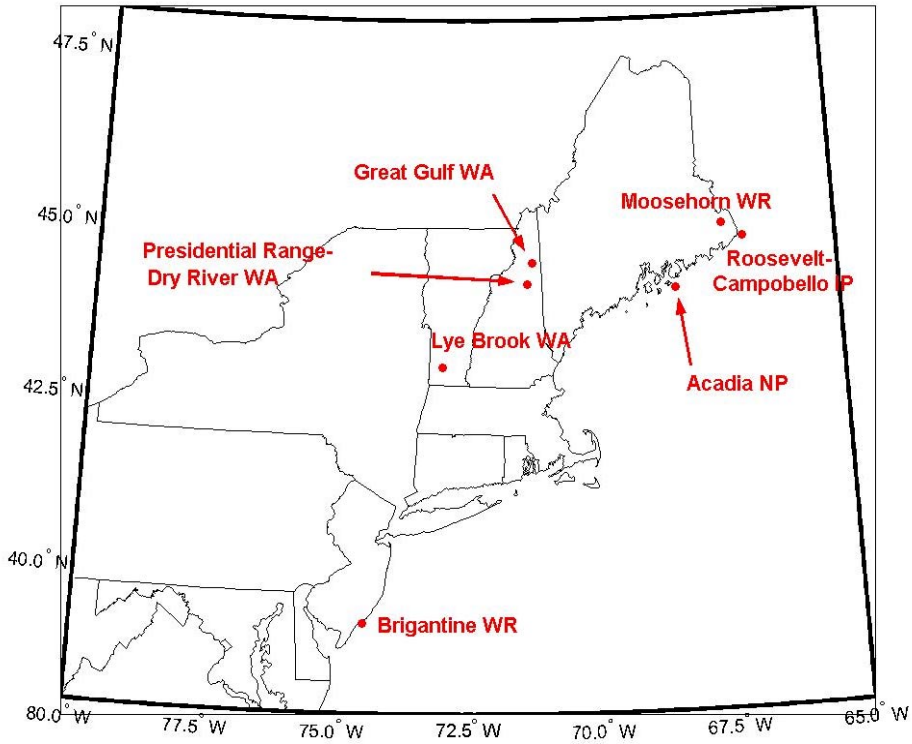
[1] The Class I designation applies to national parks exceeding 6,000 acres; wilderness areas and national memorial parks exceeding 5,000 acres; and all international parks that were in existence prior to 1977.

[2] Tribes may seek approval under 40 CFR 49 to assume the requirements of the regional haze program and be "treated like states," but are not required to do so.

[3] Specifically, the OTC RPO for visibility planning includes the District of Columbia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. Note that the OTC as originally constituted to address ozone transport includes northern Virginia.

[4] Brigantine Wilderness is within the Edwin B. Forsythe National Wildlife Refuge and Moosehorn Wilderness is within the Moosehorn National Wildlife Refuge.

Federal Class I Areas in the Northeast and Mid-Atlantic U.S.



Note: designations are shown with each Class I area. NP = National Park, WA=Wilderness Area, WR = Wilderness Areas located within a Wildlife Refuge, and IP = International Park.

A. The Basics of Haze

Small particles and certain gaseous molecules in the atmosphere cause poor visibility by scattering and absorbing light, thereby reducing the amount of visual information about distant objects that reaches an observer. Some light scattering by air molecules and naturally occurring aerosols occurs even under natural conditions.[5]

The distribution of particles in the atmosphere depends on meteorological conditions and leads to various forms of visibility impairment. When high concentrations of pollutants are well mixed in the atmosphere, they form a uniform haze. When temperature inversions trap pollutants near the surface, the result can be a sharply demarcated layer of haze. Plume blight — a distinct, frequently brownish plume of pollution from a particular emissions source — occurs under stable atmospheric conditions, when pollutants take a long time to disperse.

Visibility impairment can be quantified using three different, but mathematically related measures: light extinction per unit distance (e.g., Mm^{-1});[6] visual range (i.e., how far one can see); and deciviews (dv), a useful metric for measuring increments of visibility change that are just

[5] The fact that air molecules scatter more short wavelength (blue) light accounts for the blue color of the sky. The term "aerosol" is defined as a suspension of particles in a gas. In this report we use the term to refer to particles suspended in the atmosphere.

[6] In units of inverse length. An inverse megameter (Mm^{-1}) is equal to one over one thousand kilometers.

perceptible to the human eye. Each can be estimated from the ambient concentrations of individual particle constituents, taking into account their unique light-scattering (or absorbing) properties and making appropriate adjustments for relative humidity. Assuming natural conditions, visibility in the Northeast and Mid-Atlantic is estimated to be about 23 Mm^{-1}, which corresponds to a visual range of about 106 miles or 8 dv. Under current polluted conditions in the region, average visibility ranges from 103 Mm^{-1} in the south to 55 Mm^{-1} in the north; these values correspond to a visual range of 24 to 44 miles or 23 to 17 dv, respectively. On the worst 20 percent of days, visibility impairment in Northeast and Mid-Atlantic Class I areas ranges from about 25 to 30 dv.

The small particles that commonly cause hazy conditions in the East are primarily composed of sulfate, nitrate, organic carbon, elemental carbon (soot), and crustal material (e.g., soil dust, sea salt, etc.). Of these constituents, only elemental carbon impairs visibility by absorbing visible light; the others scatter light. Sulfate, nitrate, and organic carbon[7] are secondary pollutants that form in the atmosphere from precursor pollutants; primarily sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and volatile organic compounds (VOCs), respectively. By contrast, soot and crustal material and some organic carbon particles (see Footnote 7) are released directly to the atmosphere. Particle constituents also differ in their relative effectiveness at reducing visibility. Sulfates and nitrates, for example, contribute disproportionately to haze due to their chemical affinity for water. This property allows them to grow rapidly, in the presence of moisture, to the optimal particle size for scattering light (i.e., 0.1 to 1 micrometer).

B. Anatomy of Regional Haze

Monitoring data collected over the last decade show that fine particle[8] concentrations, and hence visibility impairment, are generally highest near industrial and highly populated areas of the Northeast and Mid-Atlantic. Particle concentrations are lower, and visibility conditions are better, at the more northerly Class I sites (such as Acadia and Moosehorn) where visibility on the 20 percent best days[9] is close to natural, unpolluted conditions. By contrast, visibility at the more southerly Brigantine site in New Jersey is substantially impaired even on the 20 percent clearest days. On the 20 percent haziest days,[9] visibility impairment is substantial throughout the region.

Sulfate is the dominant contributor to fine particle pollution throughout the eastern U.S. On the haziest 20 percent of days, it accounts for one-half to two-thirds of total fine particle mass and is responsible for about three-quarters of total light extinction at Class I sites in the Northeast and Mid-Atlantic. Even on the clearest 20 percent of days, sulfate typically constitutes 40 percent or more of total fine particle mass in the region. Moreover, sulfate accounts for 60 to 80 percent of the

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[7] The term "organic carbon" encompasses a large number of hydrogen and carbon containing molecules. Light-scattering secondary organic aerosols result from the oxidation of hydrocarbons that are emitted from many different sources, ranging from automobiles and solvents, to natural vegetation. Organic carbon can be emitted as a primary particle from sources such as wood burning, meat cooking, and automobiles and paved road dust.

[8] "Fine particles" refers throughout this study to particles less than or equal to 2.5 micrometers in diameter, consistent with USEPA's recently proposed fine particle NAAQS.

[9] "20 percent best visibility conditions" are defined throughout this report as the simple average of the lower 20th percentile of a cumulative frequency distribution of available data (expressed in deciviews). Similarly, "20 percent worst visibility conditions" represent the average of the upper 20th percentile of the same distribution of available data.

difference in fine particle mass concentrations on hazy versus clear days. Organic carbon consistently accounts for the next largest fraction of total fine particle mass; its contribution typically ranges from 20 to 30 percent on the haziest days. Notably, organic carbon accounts for as much as 40 to 50 percent of total mass on the clearest days, indicating that biogenic hydrocarbon sources (i.e. vegetation) are important at Class I areas in the region. The relative contributions of nitrate, elemental carbon, and fine soil are smaller (typically under 10 percent of total mass) and vary with location. Nitrate plays a considerably larger role at a Washington DC site,[10] pointing to the importance of local NO_x sources in urban settings.

The great majority of 20 percent worst visibility days at northeastern and mid-Atlantic Class I sites occur in the summertime when meteorological conditions are more conducive to the formation of sulfate from SO_2 and to the oxidation of secondary organic aerosols. In addition, winter and summer transport patterns are different, possibly leading to different contributions from upwind pollutant source regions. In contrast to sulfate and organic carbon, the nitrate contribution is typically higher in the winter months (especially at urban sites).[11] The crustal and elemental carbon fractions do not show a clear pattern of seasonal variation.

The basis for USEPA's recent haze regulations is a recognition that visibility impairment is fundamentally a regional phenomenon. Emissions from numerous sources over a broad geographic area commonly create hazy conditions across large portions of the eastern U.S. as a result of the long-range transport of airborne particles and precursor pollutants in the atmosphere. The key sulfate precursor, SO_2, for example, has an atmospheric lifetime of several days and is known to be subject to transport distances of hundreds of miles. NO_x and some organic carbon species are also subject to long-range transport, as are small particles of soot and crustal material.

The importance of transport dynamics is well illustrated by a particularly severe haze episode that occurred in mid-July of 1999. During this episode, unusually hot and humid conditions coincided with the development of a high-pressure system over the Mid-Atlantic region that produced atmospheric stagnation over the heavily urbanized, southern half of the OTC RPO region (i.e., Philadelphia-DC-southern New Jersey). At the same time, wind patterns above the area of stagnation brought a steady flow of air from the Midwest into the New England states. This resulted in several days of unusually high fine particle concentrations throughout the region. At Acadia National Park, ambient sulfate concentrations on July 17, 1999 were 40 percent higher than any previous measurement at that site since the late 1980s; on the same day, visibility at the Burlington, VT airport was limited to just 3 miles. As is often the case, very high ozone levels accompanied these severe haze conditions. This is because haze and ozone – though they are fundamentally different phenomena – tend to form and accumulate under similar meteorological conditions.

C. Federal Regional Haze Requirements

The USEPA's July 1999 rule requires all states that contribute to visibility impairment in a Class I area (whether or not they host a Class I area) to submit implementation plans or "SIPs" for

[10] A Washington DC site is part of the IMPROVE monitoring network and was included for purposes of comparison.
[11] This is largely because the ammonium nitrate bond is more stable at lower temperatures. The role of ammonia in combination with both sulfate and nitrate is discussed further in later sections.

reducing regional haze. Similarly, tribes that choose to participate in the regional haze program (see Footnote 2) would develop tribal implementation plans or "TIPs". Because visibility impairment and haze are directly linked to fine particle pollution, SIP submittal deadlines depend on states' attainment status with respect to a proposed National Ambient Air Quality Standard (NAAQS) for fine particle matter ($PM_{2.5}$) and on whether they choose to participate in regional planning efforts. The fact that the $PM_{2.5}$ NAAQS is currently under review by the Supreme Court creates some uncertainty about the exact timing of future haze requirements. As originally proposed, however, most states (i.e., states that either have a $PM_{2.5}$ non-attainment area and/or are participating in a regional process) are required to submit haze SIPs at the same time that $PM_{2.5}$ attainment SIPs are due – that is, starting in 2007 and no later than the end of 2008. States free of $PM_{2.5}$ non-attainment that do not participate in regional efforts may have to submit haze SIPs as early as 2005-2006. In addition, states planning to participate in regional efforts must indicate their intention to do so in a "committal SIP" that will generally be due within a year of USEPA's first $PM_{2.5}$ attainment designations (i.e. in the 2004-2006 timeframe).

Regional haze SIPs and TIPs must describe states' (or tribes') long-term strategies for monitoring and reducing haze; they must also provide an inventory of relevant emissions and describe plans for applying Best Available Retrofit Technology (BART) requirements to certain point sources.[12] Importantly, states can choose to implement emissions trading or other programs as an alternative to the source-by-source BART approach, if this provides greater visibility benefits. In addition, states with Class I areas must estimate natural visibility impairment and measure baseline conditions for the 20 percent most and least impaired days (in deciviews) using monitoring data collected between 2000-2004. Using this information they must establish reasonable progress goals, taking into account the cost and feasibility of implementing emissions controls. Other requirements include periodic reporting on reasonable progress goals (every five years); comprehensive periodic SIP revisions (every 10 years); adequacy determinations for existing SIPs, and coordination between states and federal land managers. USEPA expects to issue further guidance on many technical aspects of the new rule in 2001.

D. Building a Regional Haze Plan

Quantifying existing visibility conditions, as well as "natural background" conditions, will be central to developing regional haze SIPs. Current methods for making these calculations are somewhat imprecise, particularly with respect to the treatment of humidity effects, although they generally yield results that correspond reasonably well to direct visibility measurements. However, further refinement of available methodologies, particularly in the estimation of "natural background" conditions, may be necessary. For example, it will be essential to develop estimates of both 20 percent best and worst natural background impairment for comparison with baseline conditions[13] in the process of establishing reasonable progress goals.

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[12] BART requirements can be applied to 26 types of stationary sources (including power plants and other industrial facilities), provided they began operation on or between August 7, 1962 and August 7, 1977.

[13] Natural background conditions refer to visibility conditions that would prevail in the absence of any man-made influence. These are contrasted against baseline conditions, or those visibility conditions currently experienced at Class I areas in the region.

Besides quantifying the "gap" between actual and pristine visibility conditions, states will need to consider recent visibility trends and understand the complex atmospheric chemistry of fine particle formation. With the exception of Acadia, less than a decade of monitoring data are available for most Northeast and Mid-Atlantic Class I areas. The available data do not indicate consistent visibility trends over the last few years at most sites (with the possible exception of Acadia, where there appears to have been some modest improvement since the late 1980s). This lack of progress may seem surprising given the SO_2 reductions that occurred during this period under the national Acid Rain Program. Explanations may include the limited years of available data and the difficulty of discerning small visibility changes against relatively polluted background conditions.

The processes by which precursor pollutants such as SO_2, NO_x, and organic compounds form light-scattering particles in the atmosphere are complex. Particle constituents can move between liquid and solid states; condense onto other particles, and react to form different chemical species. Generally, haze does not consist of discrete particles of sulfate, nitrate, or organic carbon; rather various combinations of these constituents adsorb onto existing nuclei moving through the atmosphere, eventually becoming large enough to scatter light. An area of atmospheric chemistry that bears further investigation is the role of ammonia. Implementing sulfate reductions alone may mean that more ammonium ion would be available to bond with nitrate, possibly resulting in less-than-anticipated visibility improvement, especially in the wintertime. Another area for future research concerns the role of naturally occurring biogenic hydrocarbons emissions that may contribute substantially to the organic carbon fraction at rural sites. It is important to note that the biogenic contribution may be indirectly influenced by the presence of elevated levels of ozone, which tends to promote the formation of secondary organic aerosols from all sources. Hence, efforts to reduce regional ozone levels may have a beneficial impact on haze, even at more remote sites in the Northeast and Mid-Atlantic.

E. Emissions Sources

As noted repeatedly in this study, SO_2 is the dominant haze precursor pollutant in the Northeast and Mid-Atlantic. Coal-burning power plants were responsible for two-thirds of total SO_2 emissions nationwide in 1998; other sources of SO_2 include fossil fuel combustion (by both stationary and mobile sources) and certain industrial processes. At present, SO_2 emissions are primarily regulated under the national Acid Rain Program (Title IV of the 1990 CAA Amendments). That program will eventually cut power plant SO_2 emissions by roughly half from 1980 levels, to just under 9 million tons annually.

Volatile organic compounds (VOCs), which contribute to the formation of light-scattering secondary organic aerosols as well as ozone, are emitted primarily by transportation and area sources (such as automobiles, trucks, solvents, architectural coatings, etc.) and to a lesser extent by certain point sources. Substantial VOC reductions have been achieved to date through the regulation of emissions from automobiles and transportation fuels. In addition, a variety of VOC reduction strategies have been implemented in urban areas to address ozone non-attainment. The effects of these programs on visibility conditions at Class I areas (taking into account the indirect impact of ozone reductions on the oxidation of biogenic hydrocarbons) may need to be further investigated.

NO_x emissions are presently regulated primarily for purposes of ozone control and, to a much more limited extent, under the national Acid Rain Program. New federal and California vehicle standards will produce broad-based NO_x reductions from the mobile source sector (including from light and heavy-duty vehicles, construction equipment, marine vessels and locomotives) over the next several years. Substantial additional NO_X reductions from stationary sources are also due to be implemented across much of the eastern U.S. under both the OTC's 1994 NO_x "Memorandum of Understanding" and under the broader and more recent USEPA "NO_x SIP call." These initiatives will reduce NO_x emissions from power plants and large industrial sources by as much as 85 percent from uncontrolled levels in the 2003-2004 timeframe.

Inventory data are generally less robust for elemental carbon (soot) and crustal material. Soot emissions from diesel engines and wood stoves can be effectively reduced using particulate control technologies. Future federal regulations will further limit soot emissions from new diesel engines and states are undertaking a number of initiatives to reduce emissions from existing engines using retrofit technology. While crustal material may be less amenable to control, there is some experience with controlling dust and road-salt in a few areas of the Northeast and Mid-Atlantic that have been in non-attainment of the PM_{10} NAAQS.

F. Review of Analytical Tools

Computer model simulations will play an important role in regional haze planning. A variety of analytical tools are available including source apportionment models, source dispersion models, three-dimensional Eulerian air quality models, and trajectory models. Operating these models can be time and resource intensive and requires detailed inputs including ambient monitoring, emission inventory, and meteorological data. States will need to carefully evaluate and coordinate their modeling efforts, taking into account the strengths of available model platforms (many of which will be refined further in coming years), as well as the availability and resolution of underlying input data. NESCAUM will use USEPA's REMSAD modeling system and the EPA Models-3 Community Multiscale Air Quality (Models-3/CMAQ) modeling system for preliminary regional haze modeling. These two models should provide the flexibility and technical sophistication needed to begin to assess modeling challenges for the regional haze program. Ultimately, a combination of analytical tools and the coordination of individual state efforts will be needed to devise effective visibility improvement strategies.

G. Visibility Monitoring

Visibility monitoring programs will need to incorporate a variety of techniques to adequately characterize haze, including photography, optical monitoring (to measure light scattering and absorption), and aerosol monitoring (to measure particle concentrations and composition). USEPA is currently sponsoring a substantial expansion of existing monitoring networks in support of the proposed $PM_{2.5}$ NAAQS. Eventually over 1,000 fine particle monitoring sites will be deployed nationwide for the purposes of $PM_{2.5}$ non-attainment designations, characterizing background and

transport conditions, and other informational needs. This network will include up to 300 routine chemical speciation sites to assess trends in fine particle composition.

Much of the currently available data on visibility and particle pollution in the eastern U.S. come from the IMPROVE (Interagency Monitoring of Protected Visual Environments) network, which was established in the late 1980s by USEPA and the National Park Service. The IMPROVE program is being expanded and will continue to provide crucial inputs to visibility planning efforts. Visibility is currently monitored at five sites in or near Class I areas in the Northeast and Mid-Atlantic. Four existing, but no longer operative, sites in non-Class I rural areas are to be re-deployed in 2001. In addition, six new sites will be monitored for the first time.

Meanwhile, an initiative known as CAMNET is making real-time pictures of visibility conditions at three sites (Acadia, ME; Boston, MA; and the Great Gulf/Presidential-Dry River area, NH) available on the Internet;[14] additional CAMNET sites are planned for Hartford, CT and New York City. Recommended objectives for future monitoring efforts include extending IMPROVE-type monitoring to other areas, providing specialized data for planning purposes and model verification, expanding public outreach efforts, and tracking relative humidity and ammonia concentrations at existing sites to refine current understanding of particle formation.

H. Social and Economic Considerations

Ultimately, the willingness of policymakers and the public to support effective regional haze abatement strategies will depend, in large part, on the perceived benefits of improved visibility. Class I areas in the Northeast and Mid-Atlantic include: one national park managed by the U.S. National Park Service, three wilderness areas managed by the U.S. Forest Service, two wilderness areas managed by the U.S. Fish and Wildlife Service and one international park managed by the Roosevelt Campobello International Park Commission. While these agencies have somewhat different missions, each promotes the public use and enjoyment of wilderness areas and the protection of ecosystems and natural values (including natural scenery). Outdoor recreation is a multi-billion dollar industry in the U.S. and is often of particular economic importance to communities near protected federal lands.

Various surveys of perceived visual air quality (PVAQ) have been conducted in Class I areas to assess the public's response to different visibility conditions. They indicate that most individuals are more sensitive to incremental changes in visibility when background conditions are relatively clear. In other surveys, visitors have rated "clean, clear air" as among the most important features of national parks and have overwhelmingly ranked scenic views and clean air as "extremely" or "very" important. Although quantifying these inherently subjective value judgments is difficult, techniques such as contingent valuation, in which the public is surveyed about its willingness to pay to protect a resource, are available. Studies of this type have yielded estimates in the billions of dollars for the visibility benefits associated with substantial national pollution reductions.[15]

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[14] http://www.hazecam.net

[15] It should be noted that these results are highly sensitive to the specific survey instrument used.

Federal visibility goals cannot be achieved in the eastern U.S. without broad-based reductions in fine particles and their precursors that will reach far beyond the borders of Class I areas alone. Hence, the benefits of improved visibility are fundamentally intertwined with the benefits of reducing fine particle pollution generally, and ambient sulfate levels in particular. Health benefits are likely to be especially important, since fine particle pollution has been linked to premature morbidity and mortality from respiratory and cardiovascular effects. Because there appears to be no concentration threshold below which fine particles are harmless to human health, actions to improve visibility are likely to produce substantial health benefits, even in areas where a future $PM_{2.5}$ NAAQS is already being attained. Further SO_2 and NO_x reductions would also have multiple ecosystem benefits in terms of addressing continued problems of acid deposition, as well as soil nitrogen saturation and the eutrophication of sensitive aquatic environments. Finally, NO_x and VOC reductions can help alleviate ozone-related health impacts.

I. Summary and Recommendations

This report concludes with a number of recommendations for further research. Sorted into six general categories, these include:

- ***Basic Science***
  - Refining the characterization of natural background conditions to better address natural variability, relative humidity, biogenic emissions, and marine aerosols.
  - Refining the characterization of baseline conditions through sensitivity analyses of methodologies for reconstructing light extinction and further clarification of the role of relative humidity.
  - Further study of the hygroscopicity and composition of secondary organic aerosols and the relative contribution of man-made vs. biogenic sources.
- ***Modeling and Data Analysis***
  - Developing a regional modeling strategy and "in-house" modeling capability by the OTC RPO. Initial modeling goals should include establishing preliminary transport source regions and assessing seasonal variability.
  - Assessing differences in source contributions on best and worst days and evaluating source regions for Class I areas in the OTC RPO based on available data and trajectory analysis techniques.
  - Mapping and displaying data using geographic information systems (GIS).
- ***Air Quality Monitoring and Measurement***
  - Developing methods for dealing with incomplete monitoring data.

- Re-sorting IMPROVE particle mass data using visibility measures
- Compiling, updating, and evaluating additional $PM_{2.5}$ monitoring data for haze planning purposes.
- Updating speciated aerosol and humidity data and translating it to deciviews.
- Quantifying the role of marine aerosols with initial studies at coastal sites.
- Maintaining and expanding the CAMNET program and maximizing the use of these images for planning and outreach purposes.

- ***Emissions Inventories***
  - Developing emission inventories for ammonia.
  - Improving emission inventories for VOC, SO_2, and $PM_{2.5}$, including better spatial and temporal allocation of emissions and more detailed speciation.
  - Evaluating the visibility benefits of diesel and motor vehicle emission reductions, especially with respect to SO_2 and organics, and improving emission inventories for mobile sources.

- ***Communication / Education***
  - Developing programs to educate the public, policymakers and affected industry on regional haze and its links to other important public health and environmental issues.

- ***Regulatory Efforts***
  - Performing a technical analysis of the BART provisions of the regional haze rule as well as USEPA's proposed BART guidance to identify potential emission reduction opportunities for improving visibility in Northeast and Mid-Atlantic Class I areas.

In conclusion, while several years of coordinated research will be needed to better understand visibility problems and develop viable solutions, much is already known about the causes of haze in the eastern U.S. It is clear, for example, from available monitoring data that SO_2 emissions are an obvious target for achieving reasonable progress toward improved visibility in the near term. Another near term priority is for RPOs and states to begin educating policymakers, affected industry, and the public about the adverse impacts of regional haze and its linkages to other important public health and environmental issues. This will be crucial in building the understanding necessary for achieving the aggressive visibility goals of the Clean Air Act.

I. Introduction

In 1977, Congress added the goal of restoring pristine visibility conditions in the nation's most cherished parks and wilderness areas to the federal Clean Air Act. Section 169 of the Act calls for no less than the elimination of "any" man-made visibility impairment in so-called "Class I" areas;[16] an ambitious target given that air pollution now reduces average visual range in the eastern United States to about one-third of that which would be possible under natural conditions.

Despite the lofty goal adopted in 1977, relatively modest steps were taken over the ensuing two decades to address the substantial visibility impairment that was increasingly common at many Class I areas around the country. To be sure, progress was made under other sections of the Clean Air Act: notably the adoption, in 1990, of a national acid rain program aimed at substantially reducing sulfur dioxide emissions, a key contributor to poor visibility in the eastern U.S. However, control measures specifically undertaken to improve visibility were largely confined to addressing "plume blight" from individual pollution sources near Class I areas. These requirements did little to address the pervasive, regional nature of haze throughout the eastern half of the country.

On July 1, 1999, the U.S. Environmental Protection Agency (USEPA) issued new regulations to address poor visibility in federally protected parks and wilderness areas. These regulations mark a dramatic departure from past visibility improvement efforts in that they place a new emphasis on regional strategies to address the cumulative effect of numerous air pollution sources distributed over a wide geographic region. Significantly, the new regulations require even states that do not have a Class I area within their borders to participate in efforts to reduce regional haze. The regional haze rule sets a target date of 2064 for achieving the national visibility goals and requires regular progress reports and implementation plan revisions to ensure reasonable progress toward achieving these goals.

The USEPA has designated five regional planning organizations (RPOs) covering all areas of the U.S to facilitate the development and implementation of cost-effective regional haze abatement strategies and promote effective program coordination among states.[17] The Ozone Transport Commission (OTC) was selected to host the RPO for the Northeast and Mid-Atlantic regions. The OTC RPO includes states along the eastern seaboard from Washington, DC to Maine. Interested tribes in the Northeast and Mid-Atlantic can also join the RPO, giving them a first-ever opportunity to directly participate in regional air quality planning. The OTC RPO will be coordinating efforts to address visibility impairment at seven federal Class I areas within the Northeast/Mid-Atlantic region: Acadia National Park, Maine; Brigantine Wilderness (within the Edwin B. Forsythe National Wildlife Refuge), New Jersey; Great Gulf Wilderness, New Hampshire; Lye Brook Wilderness, Vermont; Moosehorn Wilderness (within the Moosehorn National Wildlife Refuge), Maine; Presidential Range – Dry River Wilderness, New Hampshire; and Roosevelt Campobello International Park, New Brunswick.

The USEPA's 1999 rule will require the submittal of regional haze state implementation plans (SIPs) and tribal implementation plans (TIPs) in the 2006 to 2008 timeframe; deadlines may be earlier for states that choose not to participate in regional efforts. Considerable upfront work will

[16] The Class I designation applies to national parks exceeding 6,000 acres; wilderness areas and national memorial parks exceeding 5,000 acres; and all international parks that were in existence prior to 1977.
[17] A map of the five RPOs is provided in Chapter IV.

be needed to analyze the causes of haze in the Northeast and Mid-Atlantic, characterize the contribution of different emissions sources, and devise effective control strategies that are consistent with other efforts being undertaken under Clean Air Act requirements. Understanding the visibility impacts of existing and future programs to address continuing acid deposition problems, new health-based standards for ambient fine particle pollution, and ozone non-attainment will be of particular relevance to future haze planning efforts.

To assist the OTC RPO in developing a foundation for future haze planning, the Mid-Atlantic Region Air Management Association (MARAMA) and the Northeast States for Coordinated Air Use Management (NESCAUM) are partnering with the OTC to facilitate the needed technical analyses, training and state support functions. NESCAUM has undertaken this study to provide a detailed summary and evaluation of available information on the nature and scope of regional haze in the Northeast and Mid-Atlantic region. It is hoped that this information will provide a comprehensive introduction and common basis for understanding useful to states, tribal officials, applicable federal agencies and others involved in the OTC RPO's planning process. Further, the technical recommendations provided in this report will serve to better define the work agenda of the OTC RPO over the next several years.

This report is organized in two main sections: the first (Chapters II-IV) provides background information necessary to understanding regional haze; the second (Chapters V-IX) introduces technical tools and policy considerations that will be important in developing regional haze plans. In the background section, Chapters II and III describe the phenomenon of haze and its basic causes and characteristics in the Northeast and Mid-Atlantic, noting, in particular, the very important role played by sulfates in determining visibility conditions throughout much of the eastern U.S. Chapter IV provides further detail about the specific provisions of the 1999 regional haze rule, including its planning requirements, key timelines, and Best Available Retrofit Technology (BART) provisions.

The second part of the report shifts to a discussion of topics that will be important in the development of regional haze SIPs. Chapter V provides more technical detail about measuring visibility and identifying baseline conditions; it also provides additional detail about some of the basic atmospheric chemistry involved. Chapter VI discusses major emission sources of haze associated precursor species. Chapters VII and VIII describe available modeling tools and monitoring programs, respectively. Chapter IX describes Class I areas in the RPO region and introduces, in largely qualitative terms, a discussion of the economic costs and benefits associated with the achievement of visibility goals. Finally, Chapter X summarizes the report's findings and recommendations and points toward areas of inquiry for further research in the coming years.

The same fine particles that impair visibility also pose a significant risk to public health and the environment. These pollutants can damage the lungs and exacerbate respiratory problems; they may also contribute to heart attacks in people with existing cardiac problems. Numerous studies have confirmed the relationship between elevated ambient atmospheric fine particle concentrations and increased rates of mortality and morbidity. SO_2 and NO_X are also the primary causes of acid rain, while NO_X is implicated in the widespread eutrophication of sensitive marine bays and estuaries. Thus, these haze precursors pose other, important threats to critical natural resources in the Northeast and Mid-Atlantic region in addition to their visibility impacts. The linkages between haze and other public health and environmental concerns are therefore a recurring theme in this report.

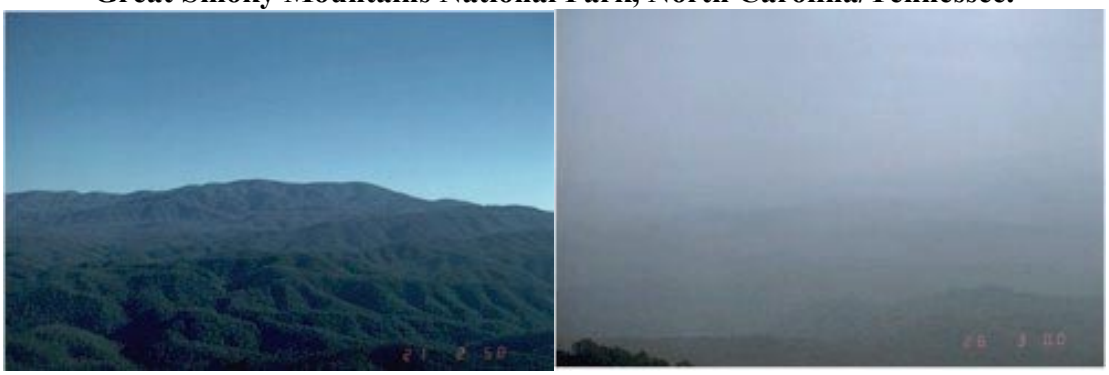
II. The Basics of Haze

Under natural atmospheric conditions, the view in the eastern United States would extend about 60 to 80 miles (100 to 130 kilometers) (Malm, 2000a). Unfortunately, views of such clarity have become a rare occurrence in the East. As a result of man-made pollution, average visual range in the eastern half of the country has diminished to about 15-30 miles, approximately one-third the visual range that would be observed under unpolluted natural conditions. This chapter provides a brief primer on haze in the Northeast and Mid-Atlantic: how haze affects the view, how the resulting visibility impairment is measured, and what causes haze. A more detailed discussion of many of these issues is provided in later Chapters, in particular Chapter V.

A. How Haze Affects the View

In general, the ability to see distant features in a scenic vista is determined less by the amount of light reaching the observer than by the contrast between those features and their surroundings. For example, the illumination of a light bulb in a greenhouse is barely discernible on a sunny day but would be highly visible at night. Similarly, a mountain peak is easily seen if it appears relatively dark against the sunlit sky. If, on the other hand, a milky haze "fills" the space between the observer and the mountain peak, the contrast between the mountain and its background is diminished as both take on a similar hue (Figure II-1).

Figure II-1: View of a good visibility day (left) and a poor visibility day (right) at Great Smoky Mountains National Park, North Carolina/Tennessee.



Source: U.S. EPA Visibility Improvement Program, http://www.epa.gov/oar/vis

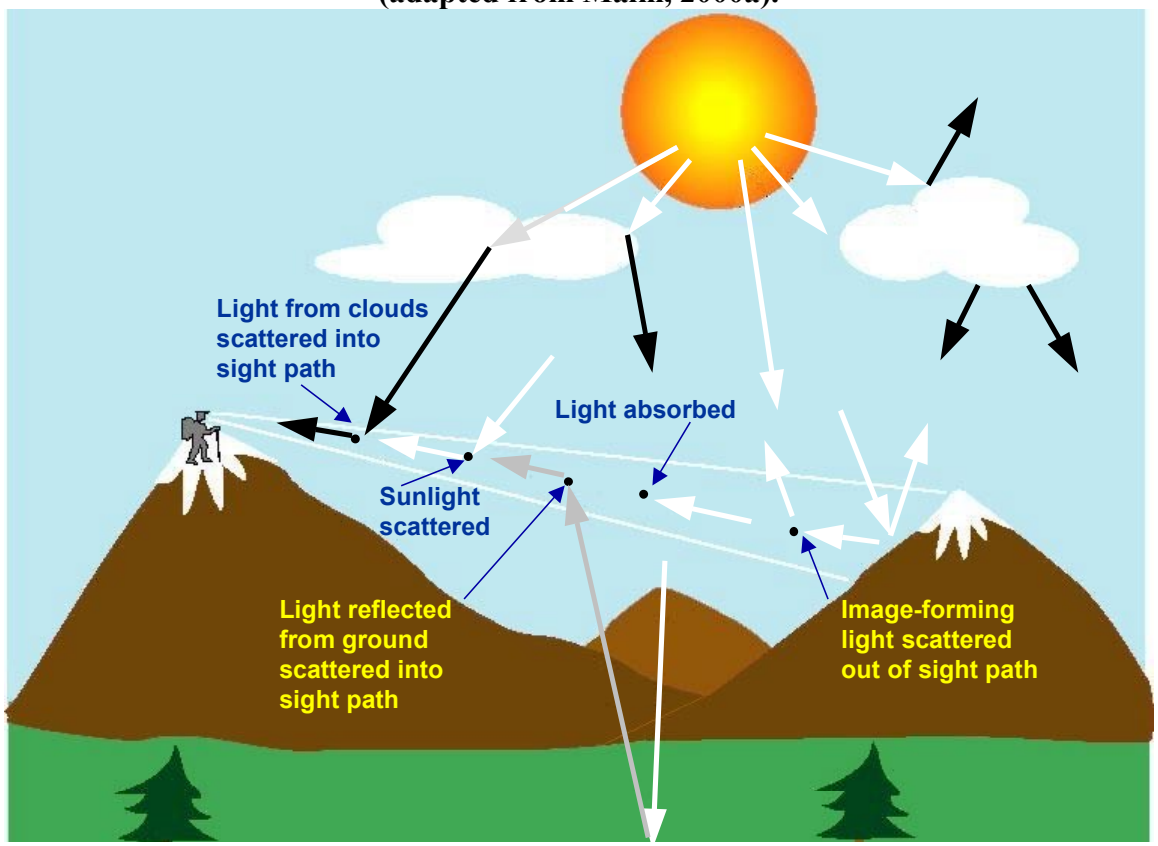
In simple terms, this hazy effect occurs when small particles and certain gaseous molecules in the atmosphere absorb or scatter visible light, thereby reducing the amount of visual information that reaches the observer. This occurs to some extent even under natural conditions, primarily as a result of the light scattering effect of individual air molecules (known as Rayleigh scattering[18]) and of naturally occurring aerosols.[19] The

[18] Because air molecules more effectively scatter light of short wavelengths (i.e. blue light), Rayleigh scattering explains the blue color of the sky.

substantial visibility impairment caused by manmade pollution, however, is almost entirely attributable to the increased presence of very small particles in the atmosphere.[20]

Figure II-2 presents a simplified schematic of the way such small particles interact with packets of light or "photons" as they travel from a distant object to an observer. Along the way, particles suspended in the air can deflect or scatter some of the photons out of the sight path. Intervening particles can also absorb photons, similarly removing them from the total amount of light reaching the observer.

Figure II-2: Schematic of visibility impairment due to light scattering and absorption (adapted from Malm, 2000a).



At the same time, particles in the air can scatter light into the sight path, further diminishing the quality of the view. The extraneous light can include direct sunlight and

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[19] Atmospheric aerosol is a more general term for fine particles suspended in the atmosphere that refers to any particle (solid or liquid) which is suspended in the atmosphere. "Fine particles" refers to those aerosol particles with a diameter ≤ 2.5µm.

[20] The only light-absorbing *gaseous* pollutant present in the atmosphere at significant concentrations is nitrogen dioxide (NO_2) (USEPA, 1997a; Seinfeld and Pandis, 1998). However, the contribution of NO_2 to overall visibility impacts in the Northeast is negligible and hence its effects are not generally included in this discussion or in standard calculations of visibility impairment (FLAG, 1999).

light reflected off the ground or from clouds. Because it is not coming directly from the scenic element, this light contains no visual "information" about that element. When the combination of light absorption and light scattering (both in to and out of the sight path) occurs in many directions due to the ubiquitous presence of small particles in the atmosphere, the result is commonly described as "haze."

B. Characterizing and Measuring Haze

The distribution of small particles in the atmosphere under different meteorological conditions can lead to different manifestations of haze. Three common types include uniform haze, layered haze, and plume blight. Table II-1 describes the atmospheric conditions that commonly lead to each type of haze. Uniform haze is characterized by an even degradation of visibility throughout the visible sky. It typically occurs when pollutants from a large number of sources distributed over a broad area are well mixed in the atmosphere. Hence, uniform haze tends to be regional in scope, often extending over large areas of the eastern U.S. As the name implies, layered haze is characterized by a distinct demarcation between clear and hazy air in the visible sky. This type of haze event typically occurs when a temperature inversion or layer of stable air traps pollutants near the earth's surface and prevents them from mixing with air higher in the atmosphere. A third type of haze, referred to as plume blight, is created when the emissions from a particular pollution source are released into stable air. Under these conditions the pollutants take more time to disperse and it is possible to discern a distinct plume emanating from the emissions source. Sometimes the plume will appear brown, an effect caused by the presence of nitrogen dioxide which can absorb significant amounts of light when present in concentrated amounts. Over time, the pollution plumes from multiple individual sources can contribute to layered haze conditions in a stable atmosphere or to uniform haze conditions within a well-mixed atmosphere.

As described in the previous section, small particles in the atmosphere impair visibility and create the effect of haze by attenuating light. Hence visibility impairment is frequently measured as the proportion or fraction of light attenuated per unit distance and is expressed in units of inverse length, typically inverse megameters[21] (Mm^{-1}) or inverse kilometers (km^{-1}) (Trijonis et al., 1990). The degree to which individual particles will scatter or absorb visible light is a function of their geometric size and chemical make-up. The total light extinction caused by a given mix of particles can be estimated by summing the individual scattering and absorption coefficients for each type of particle present. It can also be measured directly using specialized equipment such as transmissometers (to measure light extinction) and nephelometers (to measure light scattering).[22]

While light extinction is the most useful measure of visibility impairment from a scientific perspective, other measures are more intuitively accessible and are commonly used in regulatory and policy contexts. Visual range, for example, is a measure of the furthest distance a large object can be seen against the background sky taking into

[21] One megameter is equal to one million meters or 1000 km.
[22] See further discussion in Chapter V and VIII.

account the minimum or "threshold" level of contrast that is perceptible to the human eye. Visual range is expressed in units of length (e.g., km) and is inversely proportional to light extinction.[23] As light extinction increases and conditions become hazier, visual range decreases.

While visual range is useful in describing a given state of visibility impairment, a different measure is helpful in describing *changes* in visibility. Humans perceive such changes more readily when the view is relatively unimpaired; they are less sensitive to an equivalent change in visibility when conditions are hazier to begin with. In other words, a 10 km reduction in visual range is more noticeable when visual range declines from 60 km to 50 km than when visual range declines from 30 km to 20 km. A unit of measure that accounts for this nuance is the deciview (dv). Like visual range, the deciview measure is directly related to light extinction, though in this case the relationship is logarithmic resulting in a more linear correspondence between the deciview and human perception of visibility change.

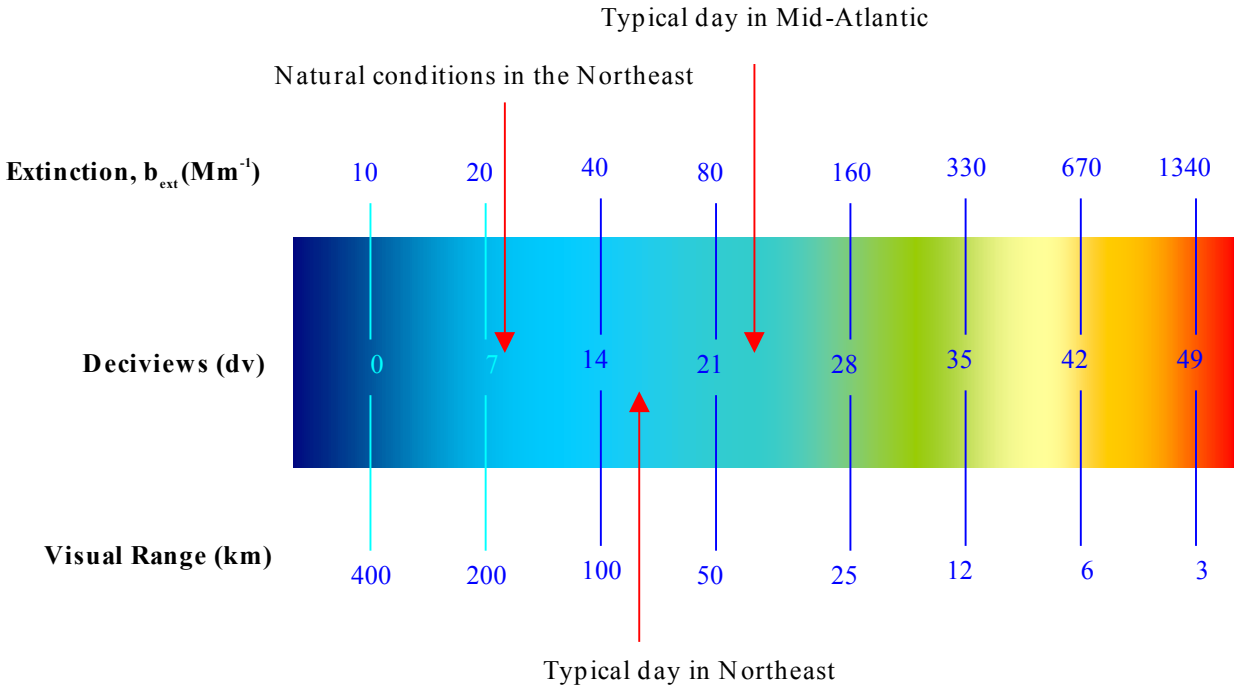
The relationship between all three measures is illustrated by Figure II-3. As the figure indicates, estimated visibility in the northeastern and mid-Atlantic U.S. under natural, unpolluted conditions corresponds to a light extinction coefficient of approximately 23 Mm^{-1} (of which roughly half is attributable to Rayleigh scattering and half to naturally occurring particles). This corresponds to a visual range of approximately 170 km or 8 dv. (Note that estimating "natural, unpolluted" conditions is not straightforward and will produce somewhat different results at different locations. These issues are discussed further in Chapter V.) By comparison, average estimated light extinction coefficients under current, *polluted* conditions range from 55 Mm^{-1} in the Northeast to 103 Mm^{-1} in the Mid-Atlantic states (Malm, 2000b). These values correspond to deciview measures of 17 and 23 dv, respectively and average visual range of just 71 km in the Northeast and 38 km in the Mid-Atlantic.

[23] For a more detailed description of how visual range corresponds to light extinction, see Chapter V.

Table II-1. The environmental elements leading to various haze conditions.

View (provided by IMPROVE)	**Haze**	**Atmospheric Conditions**	**Effects on Emitted Pollutants**
	Clear Day	Atmosphere is well mixed, Generally associated with windy conditions	Pollutants mix vertically and horizontally with some transport away from source
	Plume Blight (viewed as a thin line of haze) local in nature	Stable air and horizontal wind	Pollutants will stretch along horizontal plane from source emission level
	Layered Haze (haze stretching from the surface to a distinct height) generally local in nature	Stable air and no wind (i.e. stagnant conditions, no vertical mixing, may be due to a layer of stable air or an inversion layer)	Accumulation of pollutants at source
	Uniform Haze (stretches from the surface to well above any surrounding vista) can extend across large regional distances	Atmosphere is well mixed	Pollutants are well-mixed around source (vertically and laterally)

Figure II-3. Relationships between various measures of visibility conditions. (adapted from Malm, 2000a).



C. Causes of Haze in the Northeast and Mid-Atlantic

The fine particles that impair visibility and contribute to haze in the eastern U.S. include a variety of pollutants. They are primarily composed of the following constituents:

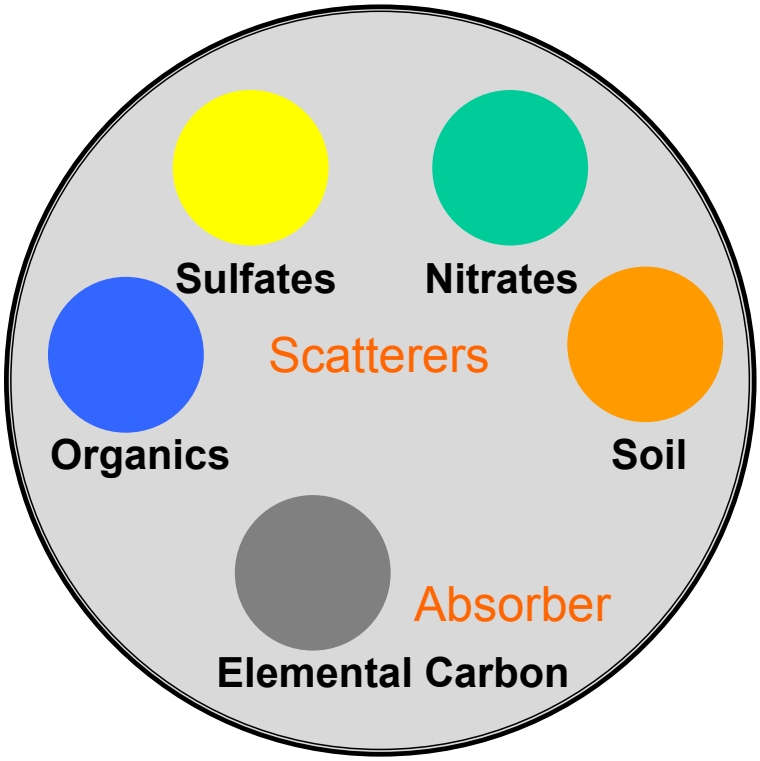
- Sulfates
- Nitrates
- Organic carbon
- Elemental carbon
- Crustal material.

Most of these constituents (i.e., sulfates, nitrates, organic carbon, and crustal particles) affect visibility by scattering light. By contrast, elemental carbon contributes to visibility impairment chiefly by absorbing light (see Figure II-4).[24]

Particles are often characterized as either "primary," meaning that they are directly emitted from a pollution source, or as "secondary," meaning that they are formed in the atmosphere from precursor emissions. Elemental carbon (the main constituent of soot) is emitted directly from diesel combustion and other sources and is an example of a primary particle. Elemental carbon is distinguished from organic carbon by the fact that

[24] As noted previously, nitrogen dioxide is a gaseous, manmade pollutant that can also absorb light. However, its visibility impacts are not generally significant on a regional scale (see Footnote 20).

Figure II-4: Principal components of light impairing particles in the atmosphere. (adapted from Malm, 2000a).



organic carbon is bound to hydrogen and other atoms in the form of more complex molecules. The term organic carbon encompasses literally hundreds to thousands of species of carbon and hydrogen containing molecules. Sulfates and nitrates are formed in the atmosphere from emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X), respectively and are examples of secondary particles. To further complicate matters, particles may exist as liquids or solids and may be composed of a mixture of the different chemical species listed above. The size of particles also varies greatly. Very small or "fine" particles are generally more efficient at scattering light and are hence of primary concern from a regional haze perspective. In fact, per unit mass, particles with diameters in the range of 0.1 to 1.0 micrometer[25] are the most effective at scattering light. This class of particles is within the 2.5 micrometer size designation used to distinguish fine from coarse particles in proposed federal regulations to limit the health impacts of particle pollution (see further discussion in Chapter IV).

Fine particles in the atmosphere come from both man-made and natural sources. Sulfate particles are formed in the atmosphere primarily from SO_2 emissions. The dominant source of SO_2 emissions in the eastern U.S. is fossil fuel combustion, primarily at coal-fired power plants and industrial boilers. Similarly, nitrate particles are formed

[25] One micrometer (µm) is equivalent to one-one millionth of a meter (10^{-6}m), about the size of one hundred molecules laid end-to-end.

from the NO_X emitted by power plants, automobiles, industrial boilers, and other combustion sources. While human sources account for most nitrate precursors in the atmosphere, there are some natural sources, including lightning, biological and abiological processes in soils,[26] and stratospheric intrusion (USEPA, 2000). Organic carbon in the atmosphere is emitted by automobiles, trucks, and industrial processes, as well by many types of vegetation. Elemental carbon (soot) is primarily caused by the combustion of diesel, wood, and other fuels. Crustal material may include soil, salt, rock and other material[27] and has both natural and manmade sources (examples of the latter include soil dust from roads, construction, and agriculture).

Particulate pollution is, as mentioned above and discussed more extensively in later chapters of this report, directly targeted under existing and proposed air quality regulations. To date, however, these regulations provide for the control of ambient particle levels only on the basis of particle size and mass concentration, i.e. without distinguishing between types of particles. When it comes to visibility impairment, however, not all particles are created equal. Depending on their specific size, geometry, chemical composition and – importantly – their ability to absorb water molecules in the atmosphere,[28] different particles will scatter light more or less effectively. Sulfates and nitrates, for example, are highly hygroscopic (meaning they have a strong affinity for water), a characteristic that tends to enhance their light scattering efficiency. As a result these types of particles contribute disproportionately to visibility impairment in the eastern U.S. Table II-2 summarizes the chief constituents of fine particle pollution in the Northeast and Mid-Atlantic, their sources and relative contribution to visibility impairment. Further discussion of the patterns and determinants of fine particle pollution in the East may be found in Chapter III.

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[26] Note that soil processes may be substantially influenced by fertilizer use, thereby creating another potential man-made source of emissions.

[27] A better understanding of crustal material and soil dust, which are likely to vary in composition throughout the U.S., is needed. This class of particles may include silicon, aluminum, iron, calcium, magnesium, sodium, potassium, titanium, manganese, chromium, vanadium, iron and cobalt constituents. Generally, soil dust has lower concentrations of calcium, magnesium and sodium than crustal rock (Seinfeld and Pandis, 1998) and is of greater concern with respect to visibility impacts in the western U.S.

[28] As water condenses onto very small particles in the atmosphere, they grow in size and become more effective at scattering light. This growth rate is directly proportional to the amount of available water (i.e. relative humidity).

Table II-2. Characteristics of Particles Associated with Haze

Particle Species	Effect on Incident Visible Light	Average Contribution to Visibility Impairment in the East[1]	Typical Mass Concentration in the Eastern U.S. ($\mu g/m^3$)		Primary or Secondary Pollutant	Emission Sources		Other Environmental and Health Consequences
			Natural[6]	Natural + Anthro.		Natural	Anthropogenic	
Sulfate	Scatter	60% -80%	0.23	4.8[7]	Secondary pollutant, formed from SO_2	Sea Spray[3], volcanoes[3], wildfires[3], marine plankton[2], bacteria[2]	Fossil-fuel burning[1], notably at coal-fired power plants; and some industrial processes, such as metal smelting[1]	Acid deposition[1,5], respiratory ailments[1,5]
Nitrate	Scatter	5% - 15%	0.1	0.3[7]	Secondary pollutant, formed from NO_X	Wildfires[3], soil[3], lightening[3], stratospheric intrusion[5], home heating	Fossil-fuel burning[3], notably by mobile sources and power plants, aircraft[5]	Acid deposition[1,5], irritant to eyes and lungs[2], eutrophication, ozone precursor[5]
Organic Carbon*	Scatter	10% - 30%	1.5	2.0[7]	Primary and secondary pollutant, formed from hydrocarbons	Wildfires[3], Plants	Meat-cooking[3], dust from roads[3], fireplaces[3], gasoline vehicles[3], diesel vehicles[3], surface coating[3], cigarettes[3], brake lining[3],roofing tar pots[3], tire wear[3], natural gas combust.[3], petroleum processing[3], railroad (diesel oil)[3], refinery gas combust[3]	Enhance formation of ground-level ozone[5], toxic chemicals[2]
Elemental Carbon*	Absorb	5% - 15%	0.02	0.4[7]	Primary Pollutant	Wildfires	Wood combustion[1,4], diesel [4]	Toxic chemicals[5]
Crustal Material	Scatter	5% - 15%	0.5	0.3[7]	Primary Pollutant	Dust[4]	Unpaved roads, agriculture	Respiratory effects
Ammonia (ammonium ion chemically bonds with sulfates and nitrates): animal husbandry[3], fertilizer use[5], sewage[3], mobile sources[3], forest fires[5], combustion[3], industrial processes[3], vegetation[5], wild animals[5]								

Gases listed in blue; Particles in red. *Organic carbon consists of literally thousands of different molecules primarily consisting of carbon and hydrogen in various configurations. Elemental carbon, also termed black, free or graphite carbon, consists of carbon alone.

Sources: [1]USEPA, 2000a; [2]Hill, 1997; [3]USEPA, 1997b; [4]USEPA, 1997a; [5]Seinfeld and Pandis, 1998; [6]Trijonis et al., 1990; [7]approximated from IMPROVE data at five Northeast and Mid-Atlantic Class I sites (Acadia, Maine; Brigantine, NJ; Great Gulf, NH; Lye Brook, VT; Moosehorn, Maine), hence, represents rural concentrations.

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III. Anatomy of Regional Haze in the Northeast and Mid-Atlantic

As described in the previous chapter, visibility impairment and haze in the Northeast and Mid-Atlantic are caused by small, light-scattering and light-absorbing particles in the atmosphere. This chapter begins by describing the geographic distribution of fine particle pollution in the Northeast and Mid-Atlantic and the relative contribution of different particle species to light extinction on the best and worst visibility days in the region. A short section also describes particle concentrations and composition at a few Class I sites just south and west of the Northeast/Mid-Atlantic region. The chapter then goes on to describe seasonal variation in particle pollution and visibility impairment, the link between regional haze and other air quality concerns, and the regional nature of haze. Finally, the chapter concludes with a description of a particularly extreme regional haze episode that occurred between July 15 and July 20 of 1999 in the eastern U.S. A review of this episode helps to illustrate many of the factors that contribute to severe visibility impairment in the eastern U.S.

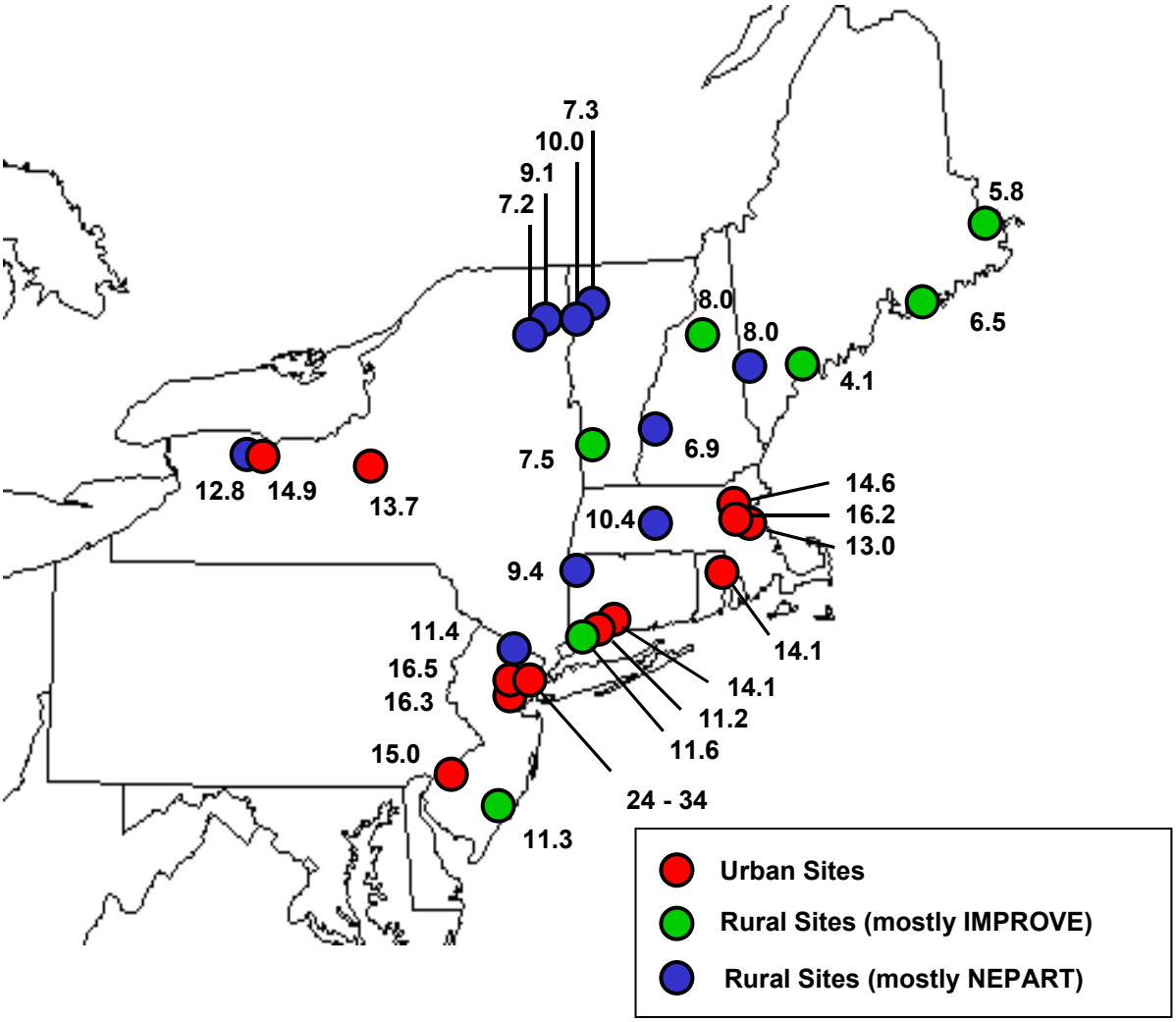
A. Fine Particle Concentrations in the Northeast and Mid-Atlantic

Data on fine particle concentrations (in micrograms per cubic meter or $\mu g/m^3$) in the Northeast and Mid-Atlantic are available from a network of monitors that have operated under various programs in the region since the late 1980s.[29] Figure III-1a shows average annual fine particle concentrations, while Figure III-1b exhibits average daily high values[30] for the period from 1991-98. Note that "fine particles" are defined throughout this discussion as particles with a diameter less than or equal to 2.5 µm ($PM_{2.5}$) for consistency with current monitoring programs and proposed federal regulations.

The geographic distribution of fine particle concentrations shown in Figures III-1a and III-1b is consistent with the geographic distribution of pollutant sources in the East, and with the movement of prevailing weather systems, which tend to flow from west and south toward the north and east. Both annual average and maximum daily fine particle concentrations are highest near heavily industrialized areas and population centers. Not surprisingly, given the direct connection between fine particle pollution and haze, the same pattern emerges when one compares measures of light extinction on the most and least visibility impaired days at parks and wilderness areas subject to federal haze regulations in the Northeast and Mid-Atlantic (see Figures III-2a and III-2b). Light extinction from particles on the 20 percent most visibility impaired days[31] ranges from 178 Mm^{-1} at Brigantine, NJ (the southernmost Class I site in the region) to 133.6 Mm^{-1} at Lye Brook, VT to 86.2 Mm^{-1}at Moosehorn, ME (the northernmost Class I site in the

[29] Monitoring programs and technologies are discussed further in Chapter VIII.
[30] Defined as the 98th percentile mass concentration measured over a 24-hour period in the course of a year.
[31] See Footnote 9 for definition of twenty percent most/least visibility impaired days. See Figure III-2a and 2b for total light extinction (particle extinction plus rayleigh extinction) on the worst/best days.

Figure III-1a: Annual average fine particle concentrations in the northeastern U.S.

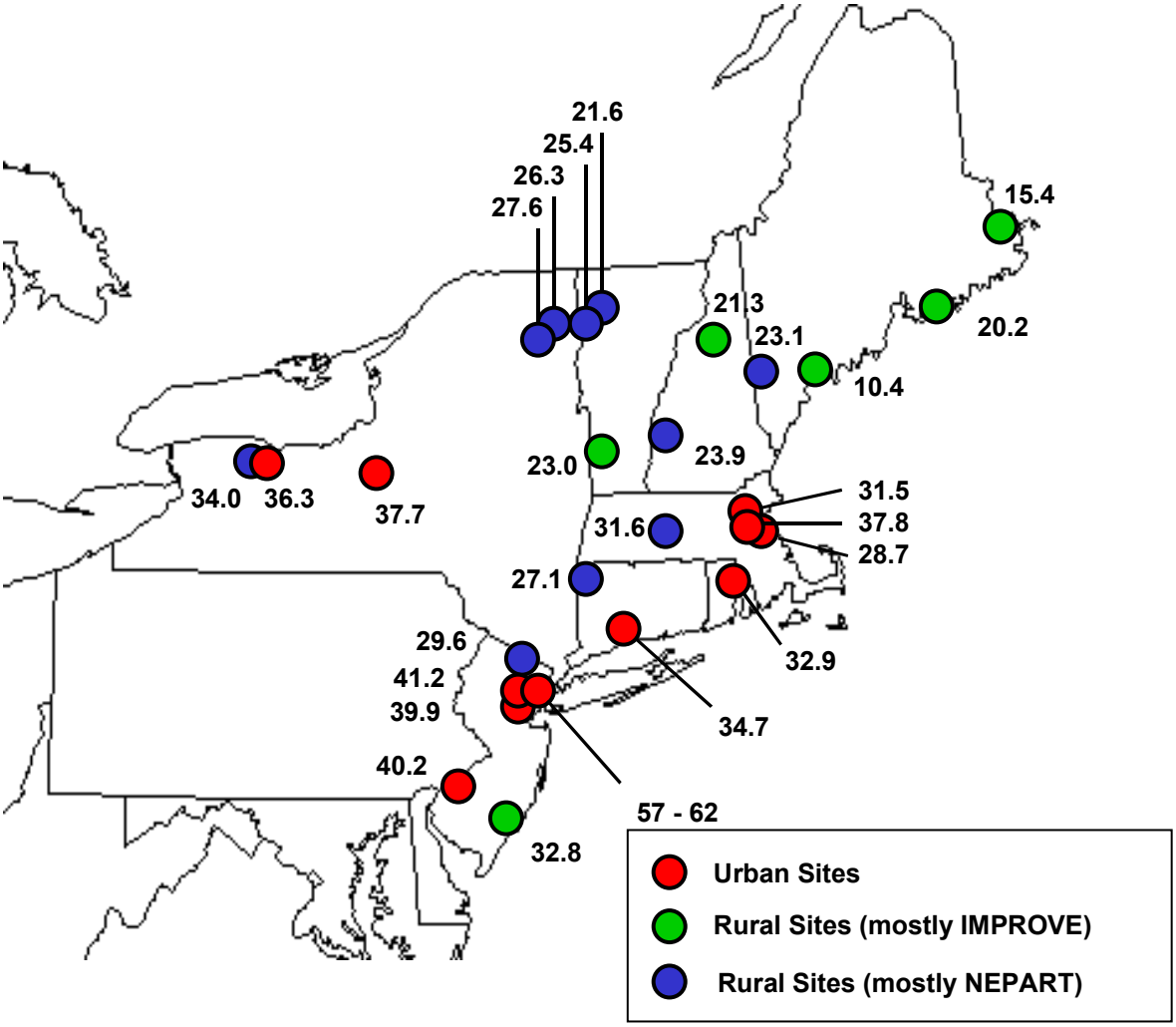


Note: Data are listed in $\mu g/m^3$ and were obtained from a variety of sources including: the IMPROVE Program, the NEPART network (see Chapter VIII), various state agencies, and other field studies (NESCAUM, 1999).

region). The corresponding figures for the 20 percent least visibility impaired days[31] at these sites range from 41.5 Mm^{-1} at Brigantine to 16-17 Mm^{-1} at Lye Brook and Moosehorn.

Notably, visibility values on the 20 percent least impaired days at the more remote northeastern and mid-Atlantic Class I areas are comparable to estimates of visibility for the region under natural, unpolluted conditions (on the order of 20 Mm^{-1}, as noted in the previous chapter). At the more southerly Brigantine site, by contrast, light extinction on even the 20 percent least impaired days is well above that associated with natural conditions. Equally striking, however, is the fact that substantial visibility impairment occurs as frequently as every one day out of five at even the most remote sites in the region. Measured light extinction of 96 Mm^{-1} at Moosehorn on the 20 percent most

Figure III-1b: 98th percentile fine particle concentrations in the northeastern U.S.

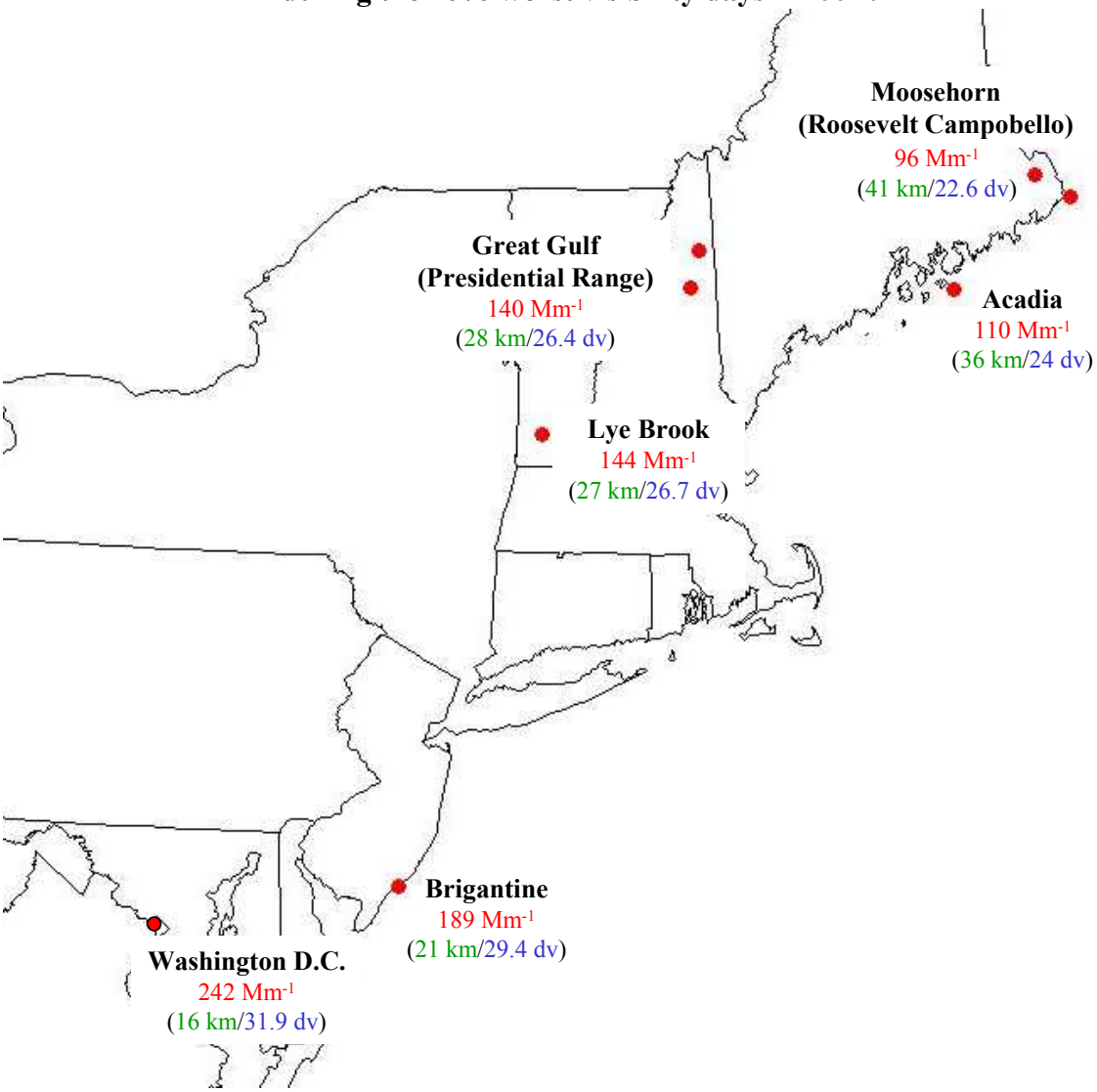


Note: Data are listed in $\mu g/m^3$ and were obtained from a variety of sources including: the IMPROVE Program, the NEPART network (see Chapter VIII), various state agencies, and other field studies (NESCAUM, 1999).

impaired days corresponds to a visual range of only 41 km; this is less than a quarter of the visual range of 170 km estimated for natural conditions.

In sum, the spatial distribution of fine particle concentrations and particle-related light extinction in the Northeast and Mid-Atlantic points to the role played by anthropogenic (manmade) sources of pollution, and more particularly to the atmospheric transport of pollutants from regions to the south and west toward the north and east. It also points to the fact that substantial visibility impairment is a frequent occurrence in even the most remote and pristine areas of the Northeast and Mid-Atlantic.

Figure III-2a: Extinction near Class I areas in the Northeast and Mid-Atlantic States during the 20% worst visibility days in 1997.

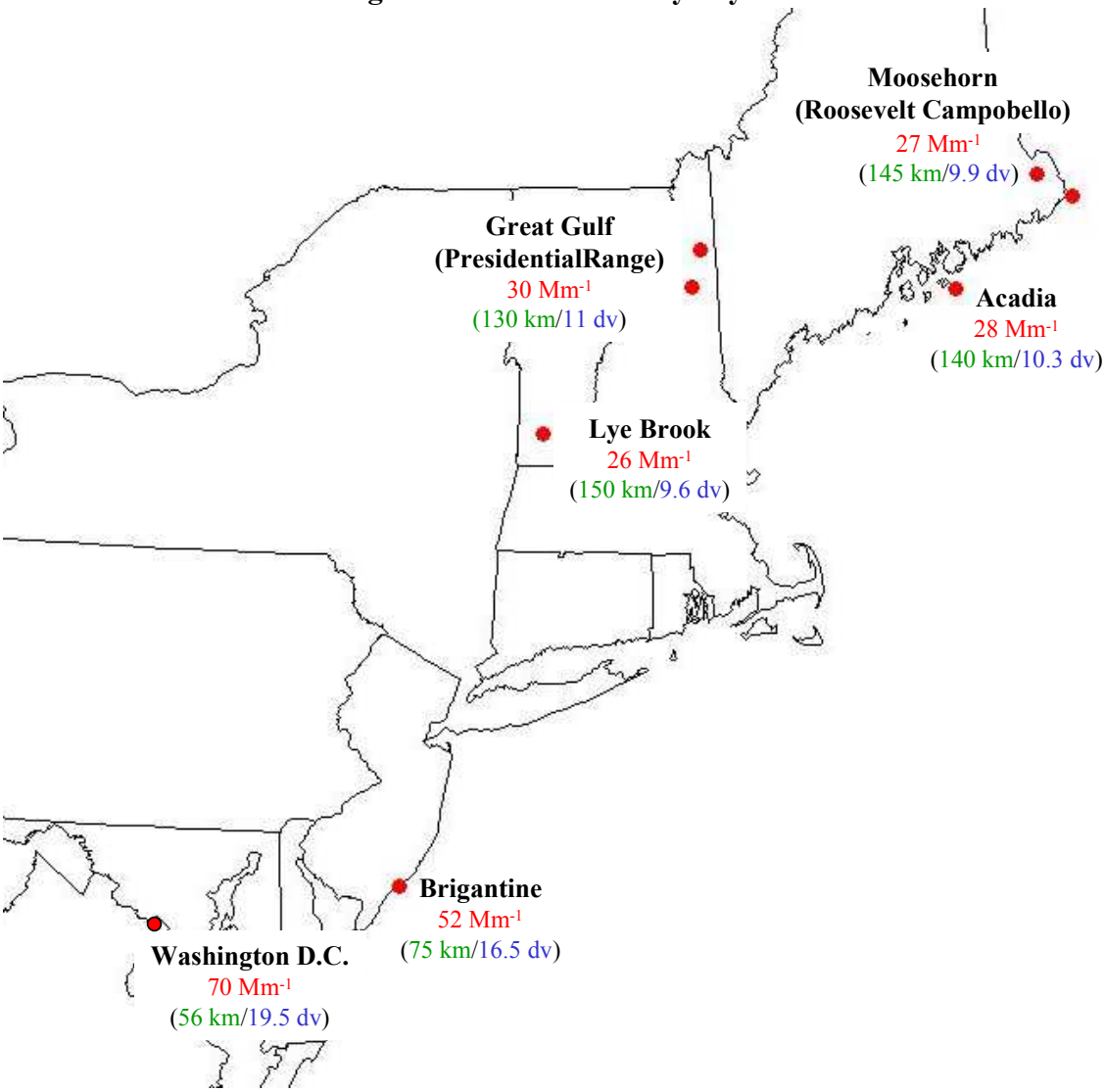


B. Fine Particle Composition in the Northeast and Mid-Atlantic

The chief constituents of fine particle pollution in the Northeast and Mid-Atlantic, and hence the pollutants that are largely responsible for haze, were introduced in the previous chapter. They include sulfates, nitrates, organic carbon, elemental carbon, and material from the earth's crust (e.g. soil, dust, sea salt, etc.). Figures III-3a and III-3b provide more detail on the relative contribution of these constituents to fine particle mass concentrations at northeastern and mid-Atlantic Class I sites on the 20 percent most and least visibility impaired days in 1997.[32] Data from Washington D.C. are included for purposes of comparison with a more southern, urban site.

[32] Fine particle mass concentrations were derived from monitoring data collected by the IMPROVE monitoring network. IMPROVE stands for Interagency Monitoring of Protected Visual Environments. It

Figure III-2b: Extinction near Class I areas in the Northeast and Mid-Atlantic States during the 20% best visibility days in 1997.



The most striking observation to emerge from Figures III-3a and III-3b concerns the dominant role of sulfate. Sulfate alone accounts for anywhere from one-half to two-thirds of total fine particle mass on the 20 percent haziest days at all of the sites shown. Even on the 20 percent clearest days, sulfate generally accounts for the largest fraction (40 percent or more) of total fine particle mass at all the sites except Great Gulf, NH.[33]

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and other monitoring programs are described in greater detail in Chapter VIII. Appendix B of this report details IMPROVE sampling techniques and data analysis; Appendix C presents more complete sampling data from each IMPROVE site. The methodology used to analyze IMPROVE data for purposes of this report is described in Chapter V. Note that mass concentrations derived for Figures III-3a and III-3b differ slightly from those presented in Appendix C due to different sorting methodologies (i.e. particle extinction vs. gravimetric fine mass). The year 1997 was selected because it was characterized by representative meteorological conditions.

[33] It is worth pointing out that there are no complete years of monitoring data for Great Gulf, which may explain its divergence from the other IMPROVE sites. Data for this site only span the summer months of

After sulfate, organic carbon consistently accounts for the next largest fraction of total fine particle mass. Its contribution typically ranges from 20 to 30 percent on the haziest days. On the 20 percent clearest days in 1997, the contribution from organic carbon was as high as 40 percent at the more rural sites (and even reached as much as 50 percent at Great Gulf[34]); this is likely to be indicative of the role played by organic emissions from vegetation (so-called "biogenic hydrocarbons"). Relative contributions from nitrate, elemental carbon, and fine soil are all smaller (typically under 10 percent), but the relative ordering among the three species varies with location. Nitrate plays a noticeably more important role at the Washington, DC site compared to northeastern and mid-Atlantic Class I locations, perhaps reflecting a greater contribution from vehicles and other urban pollution sources.

Sulfate is not only the dominant contributor to fine particle mass in the region, it accounts for anywhere from 60 to almost 80 percent of the *difference* between fine particle concentrations on the clearest and haziest days at northeastern and mid-Atlantic Class I sites. Notably, the exception is Washington DC, where sulfate accounted for only 41 percent of the difference in average fine particle concentrations for the 20 percent most vs. least visibility impaired days in 1997.

As noted at the conclusion of the previous chapter, all particles are not created equal when it comes to their effect on visibility. Because of the hygroscopic (water attracting) properties of sulfate and nitrate, their relative contributions to total light extinction are found to be disproportionately larger than their relative contributions to total particle mass. By comparison, the light-scattering contribution of organic carbon, which is assumed to be non-hygroscopic, becomes smaller. Figures III-4a and III-4b present the same speciated monitoring data from 1997, this time in terms of contribution to estimated light extinction. Note that these contributions are shown relative to total *particle-related* light extinction, which does not include the background contribution from Rayleigh scattering. These figures also group coarse particles (i.e., particles with a diameter between 2.5 and 10 μm) with fine soil under the "crustal" category. Figures III-3a and III-3b do not include coarse particles as their mass is not considered a contribution to fine particle mass.

May or June through September, and hence miss some of the hazy days that can occur during the cooler months of the year in the Northeast. Moosehorn, ME is the only other site where the sulfate contribution was matched by the organic carbon contribution (with each accounting for 40 percent of total mass) on the 20 percent clearest days in 1997. However, 1997 may have been slightly anomalous in this respect. As at other Class I sites, in 1995, 1996, and 1998 the organic carbon contribution at Moosehorn was somewhat below the sulfate contribution on even the 20 percent least impaired days.

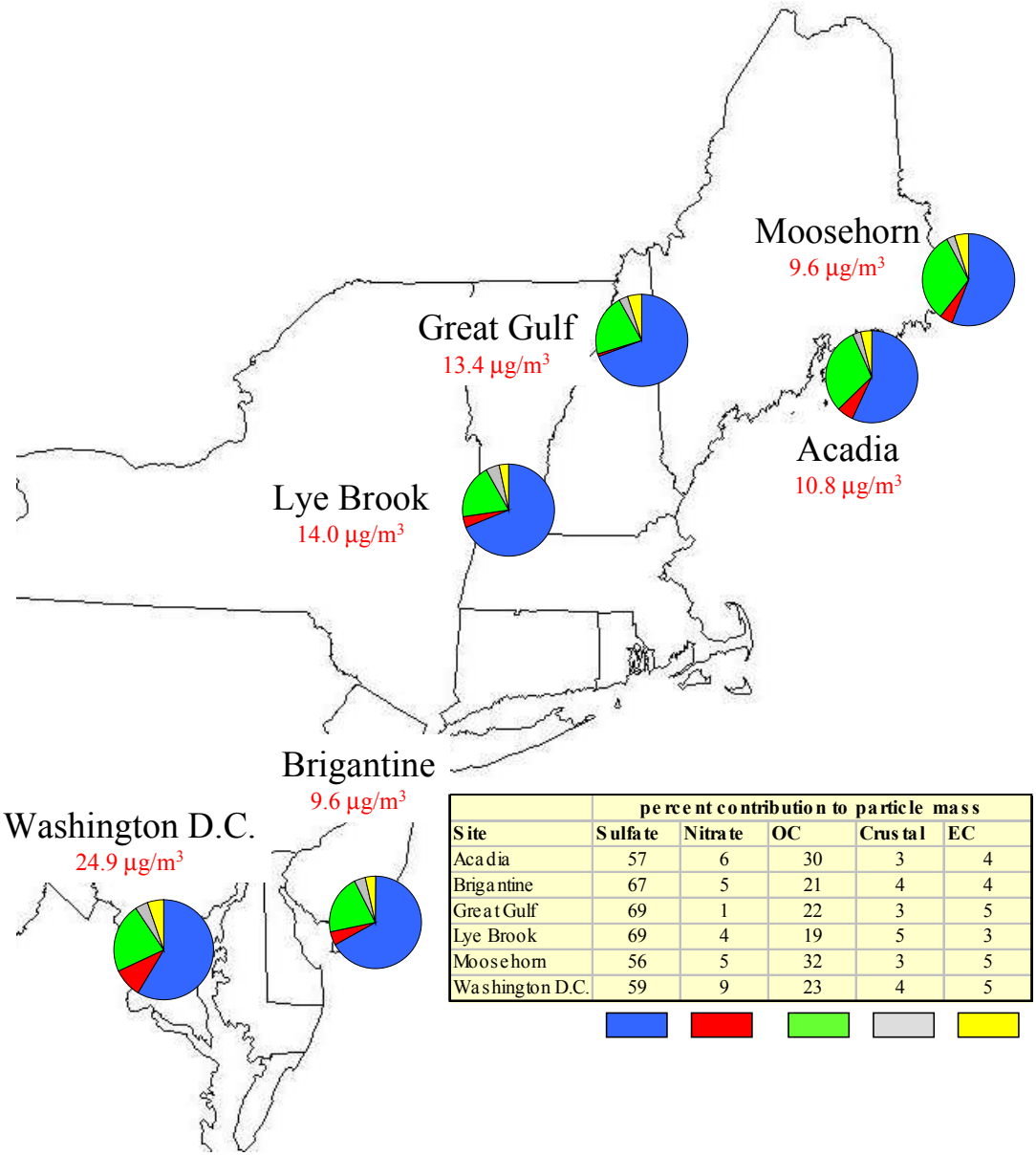
[34] As noted in Footnote 33, data for the Great Gulf site are limited to the summer months when natural organic emissions from trees are likely to be highest. (Another factor in the summertime may be the presence of higher ozone levels, which contribute to enhanced oxidation of organics regardless of origin.) This may explain the especially high organic carbon contribution documented at this site. A comparison to summer data from the nearby Lye Brook site tends to confirm this hypothesis. On the 20 percent least impaired summer days at Lye Brook, relative mass concentrations for organic carbons were almost identical to those found at Great Gulf, suggesting that hydrocarbons (a substantial portion of which may be biogenic in origin) do contribute up to half of fine particle mass at rural sites on clear summer days in the region.

The sulfate contribution, already dominant in terms of total fine particle mass, becomes even larger when the differential visibility impacts of different particle species are considered. Figure III-4a shows that in 1997, sulfate accounted for 70 to 82 percent of estimated particle light extinction at northeastern and mid-Atlantic Class I sites, as well as in Washington, DC. Organic carbon continues to be the second most important contributor to particle light extinction at rural sites on the most impaired days, but slips to third behind nitrate in Washington, DC.[35]

Figure III-4b indicates that on the 20 percent least impaired days, sulfate accounts for over half of total particle light extinction at rural sites, followed in most cases by organic carbon. Notably, crustal material plays a relatively more significant role on the clearest days (especially at the Brigantine and Acadia sites), a result that may be due in part to the inclusion of coarse particles in this category. The relative contribution of elemental carbon and nitrate on the 20 percent clearest days is generally smaller at the rural sites, but varies from location to location.

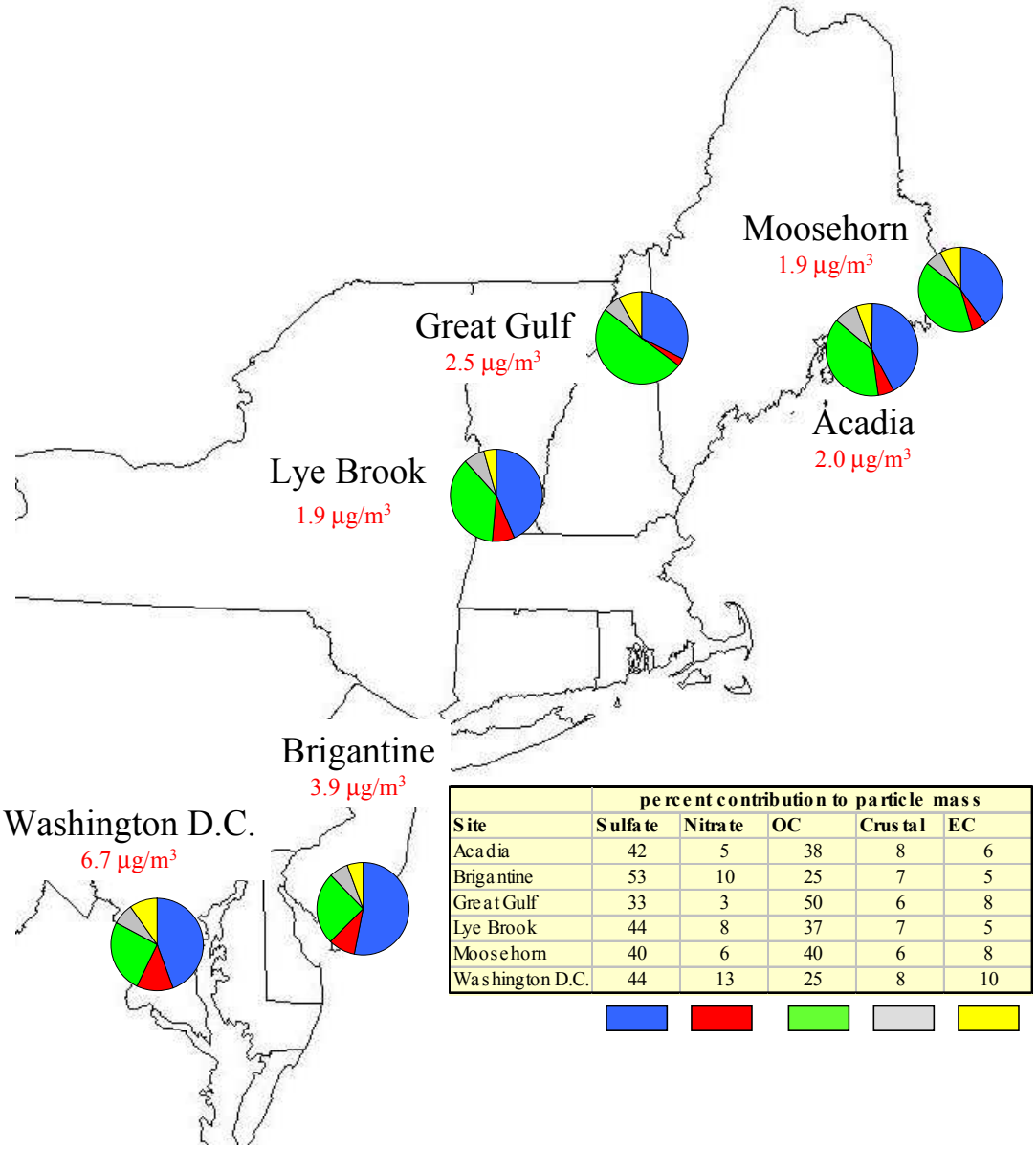
[35] The monitoring data presented in Appendix C indicate that nitrate was often, though not always, the second highest contributor to particle light extinction at the DC site over the sampling period from 1989 to 1998. It should be noted that the speciated data for 1997 in DC, when sorted by calendar year and light extinction, depart from the relative ordering shown in Appendix C, although they are directionally consistent with the data for previous years. Despite these discrepancies, the general finding that nitrate plays a greater role in overall light extinction at the DC site appears robust when all sampling years are taken into account.

Figure III-3a: Mass characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in the Northeast and Mid-Atlantic States during the 20% worst visibility days in 1997.



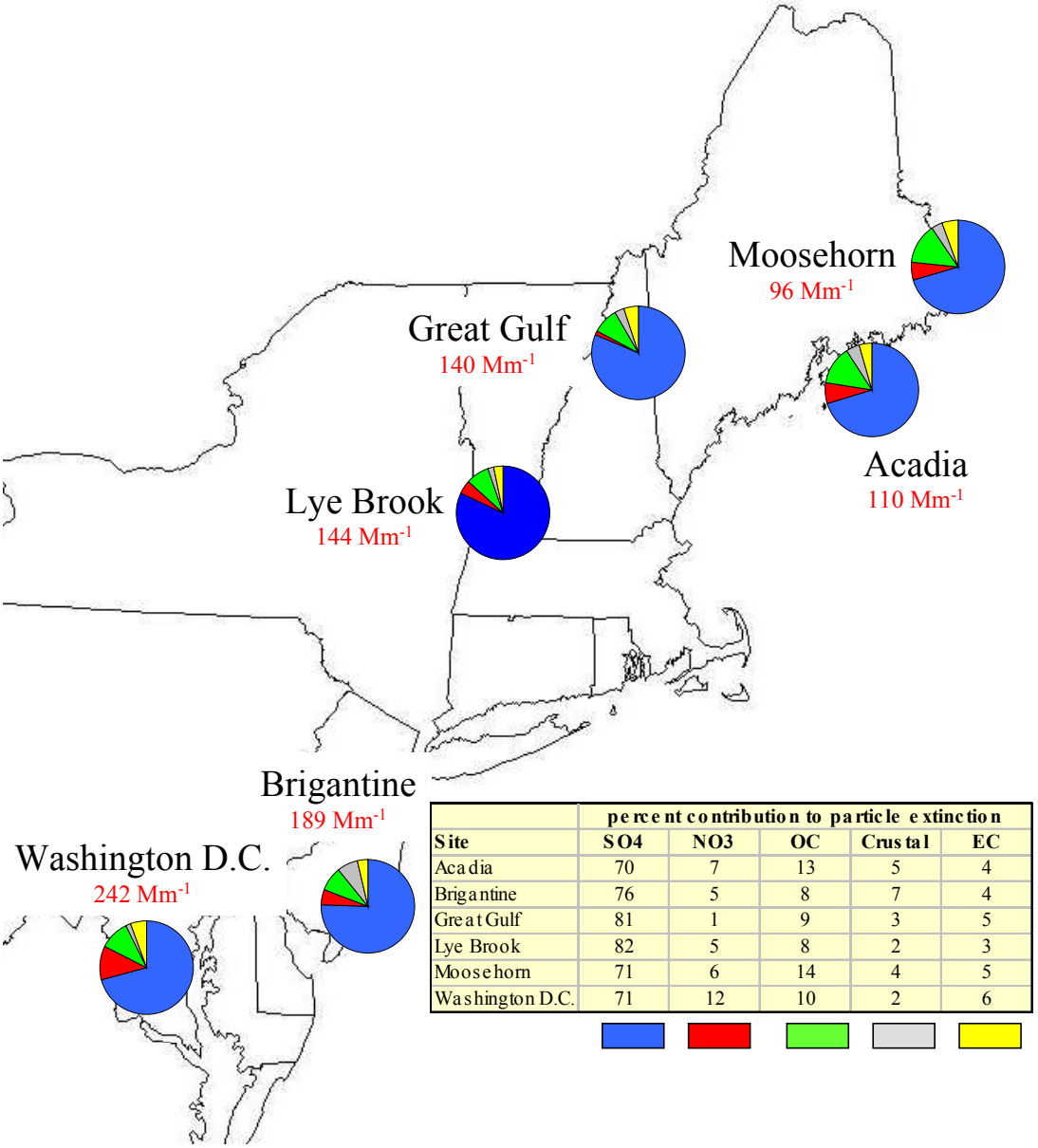
	percent contribution to particle mass				
Site	Sulfate	Nitrate	OC	Crustal	EC
Acadia	57	6	30	3	4
Brigantine	67	5	21	4	4
Great Gulf	69	1	22	3	5
Lye Brook	69	4	19	5	3
Moosehorn	56	5	32	3	5
Washington D.C.	59	9	23	4	5

Figure III-3b: Mass characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in the Northeast and Mid-Atlantic States during the 20% best visibility days in 1997.



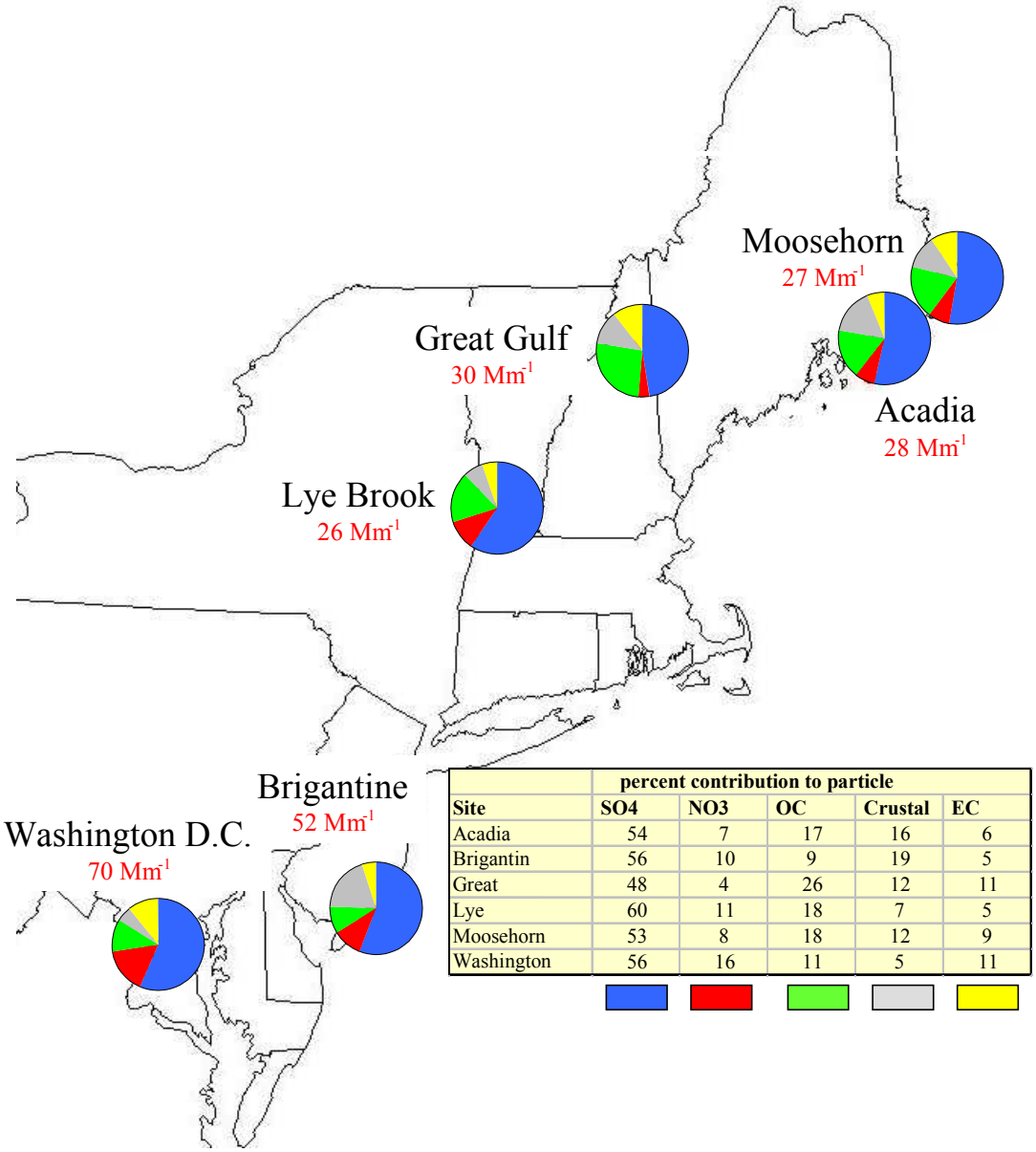
	percent contribution to particle mass				
Site	Sulfate	Nitrate	OC	Crustal	EC
Acadia	42	5	38	8	6
Brigantine	53	10	25	7	5
Great Gulf	33	3	50	6	8
Lye Brook	44	8	37	7	5
Moosehorn	40	6	40	6	8
Washington D.C.	44	13	25	8	10

Figure III-4a: Particle extinction characteristics in or near Class I areas in the Northeast and Mid-Atlantic States during the 20% worst visibility days in 1997.



	percent contribution to particle extinction				
Site	SO4	NO3	OC	Crustal	EC
Acadia	70	7	13	5	4
Brigantine	76	5	8	7	4
Great Gulf	81	1	9	3	5
Lye Brook	82	5	8	2	3
Moosehorn	71	6	14	4	5
Washington D.C.	71	12	10	2	6

Figure III-4b: Particle extinction characteristics in or near Class I areas in the Northeast and Mid-Atlantic States during the 20% best visibility days in 1997.



	percent contribution to particle				
Site	**SO4**	**NO3**	**OC**	**Crustal**	**EC**
Acadia	54	7	17	16	6
Brigantin	56	10	9	19	5
Great	48	4	26	12	11
Lye	60	11	18	7	5
Moosehorn	53	8	18	12	9
Washington	56	16	11	5	11

C. Haze Characteristics at Nearby Class I Areas

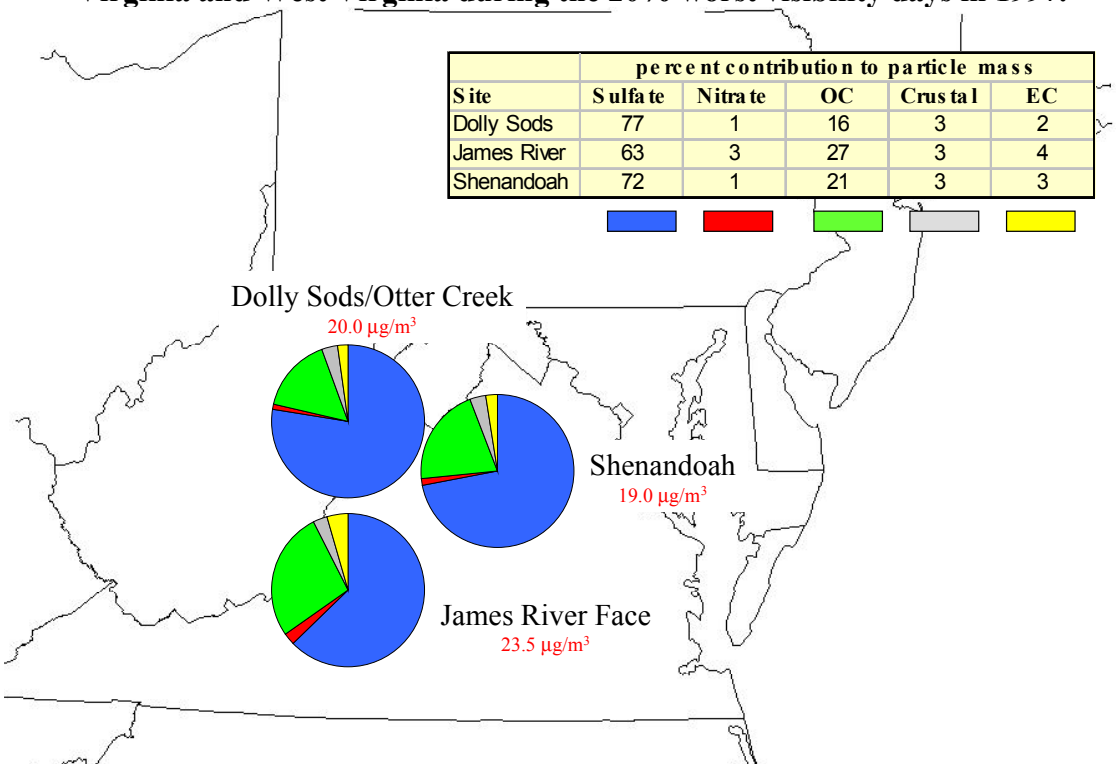
As noted earlier in this report (and discussed in later sections of this chapter), haze is a fundamentally regional problem and often affects large swaths of the eastern U.S. at the same time. Hence, it is interesting to compare particle concentrations and visibility impairment inside the Northeast/Mid-Atlantic region to values measured at Class I areas just outside the region. Figures III-5a and III-5b show fine particle concentrations and mass composition at Class I areas just to the south and west of the OTC RPO, including Shenandoah National Park and James River Face Wilderness Area in Virginia and the Dolly Sods and Otter Creek Wilderness Areas in West Virginia.[36] (Note that there are no Class I areas to the immediate west in Ohio, Michigan, or Indiana.) Figures III-6a and III-6b show the corresponding values in terms of light extinction.

As these figures show, fine particle concentrations and visibility impairment at Class I areas just to the south and west of the OTC RPO region are significantly higher than concentrations at Class I areas within the region. The relative contribution of different particle constituents is similar, though sulfate contributes an even larger fraction of total particle extinction (from 65 to 85 percent on the best and worst visibility days respectively). By contrast, nitrate plays a somewhat lesser role in overall light extinction at these more southern sites relative to sites in the OTC RPO region.

Finally it should be noted that the Class I areas shown in Figures III-5 and III-6, while not within the OTC RPO region, may be affected by emissions sources which are within the region. As such these areas may need to be included in the regional haze planning efforts of some OTC RPO states, especially those in the more southern portion of the region.

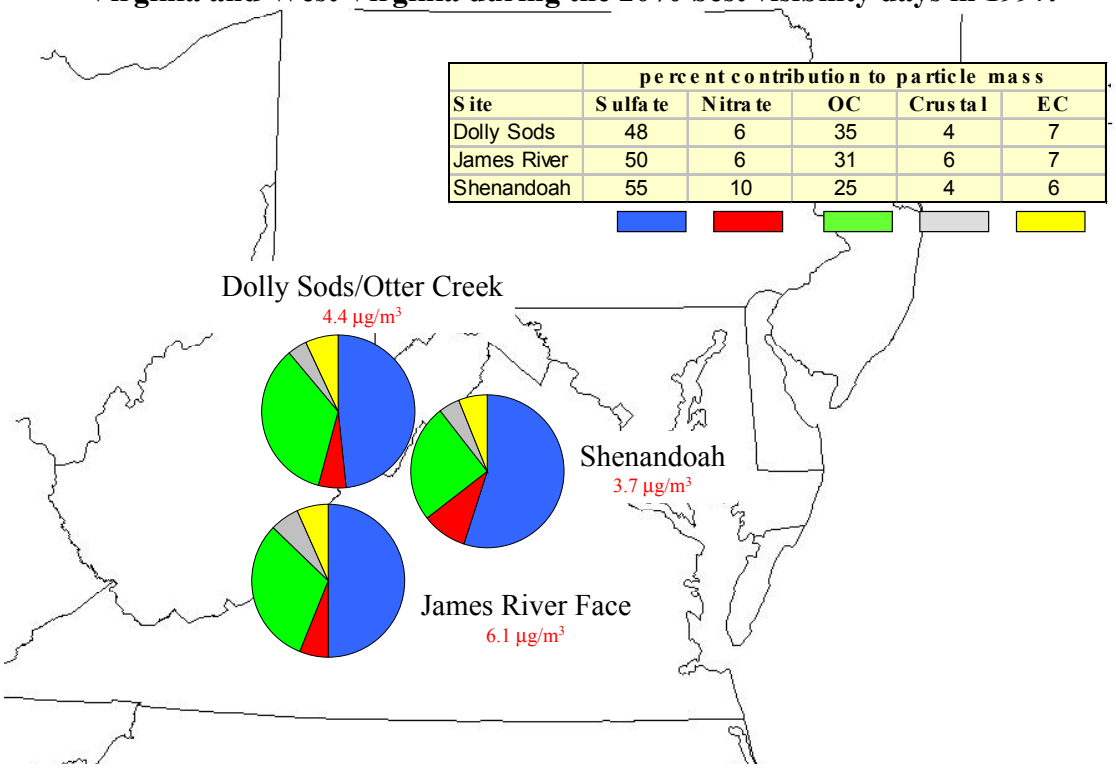
[36] Note that the maps are based on monitoring data from three IMPROVE sites and were generated using the same methodology (described in detail in Chapter V) used to generate Figures III-3 and III-4.

Figure III-5a: Mass characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in Virginia and West Virginia during the 20% worst visibility days in 1997.



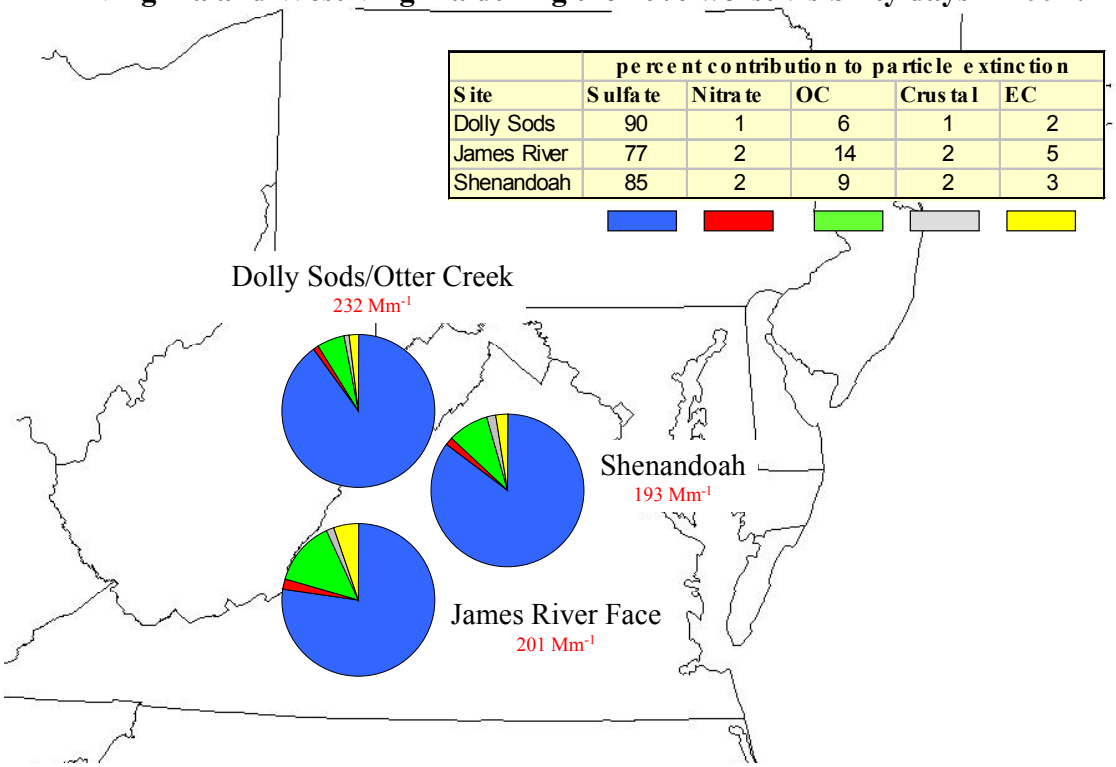
	percent contribution to particle mass				
Site	Sulfate	Nitrate	OC	Crustal	EC
Dolly Sods	77	1	16	3	2
James River	63	3	27	3	4
Shenandoah	72	1	21	3	3

Figure III-5b: Mass characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in Virginia and West Virginia during the 20% best visibility days in 1997.



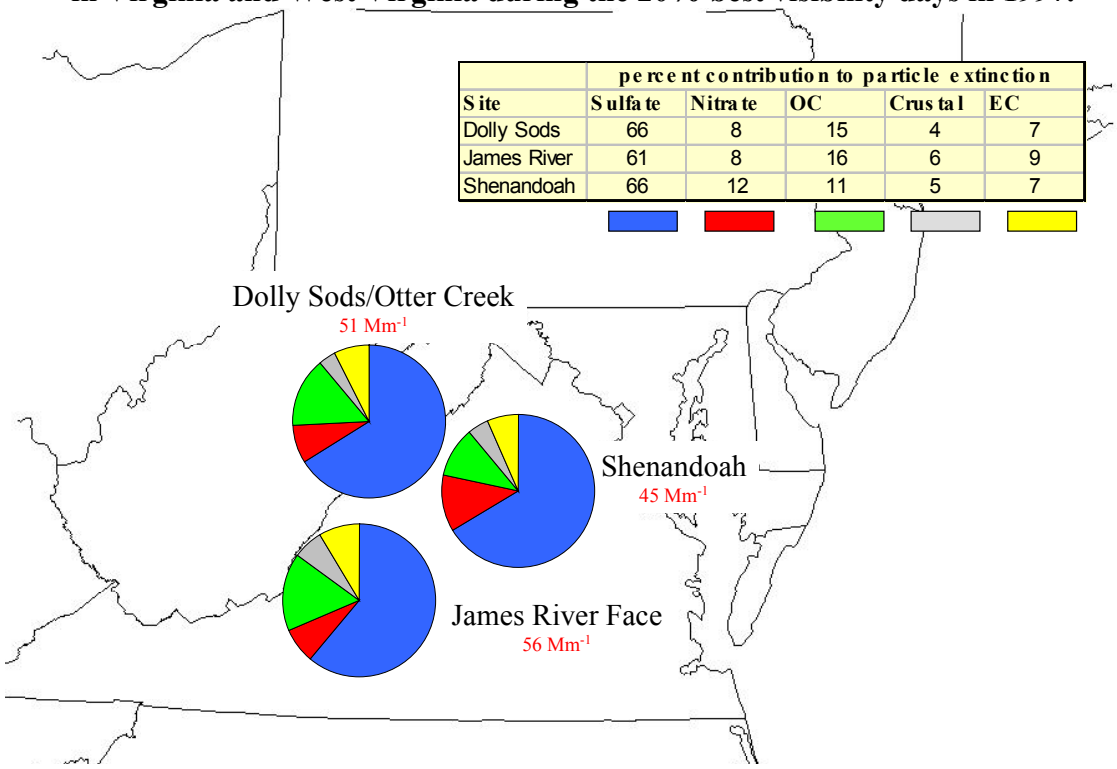
	percent contribution to particle mass				
Site	Sulfate	Nitrate	OC	Crustal	EC
Dolly Sods	48	6	35	4	7
James River	50	6	31	6	7
Shenandoah	55	10	25	4	6

Figure III-6a: Extinction characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in Virginia and West Virginia during the 20% worst visibility days in 1997.



	percent contribution to particle extinction				
Site	Sulfate	Nitrate	OC	Crustal	EC
Dolly Sods	90	1	6	1	2
James River	77	2	14	2	5
Shenandoah	85	2	9	2	3

Figure III-6b: Extinction characteristics of fine particles ($PM_{2.5}$) in or near Class I areas in Virginia and West Virginia during the 20% best visibility days in 1997.



	percent contribution to particle extinction				
Site	Sulfate	Nitrate	OC	Crustal	EC
Dolly Sods	66	8	15	4	7
James River	61	8	16	6	9
Shenandoah	66	12	11	5	7

D. Seasonal Variations in Particle Concentration and Light Extinction

The two digital camera views of the Boston city skyline shown in Figures III-7a and III-7b on the opposing page suggest that hazy days in the summer and winter can have significantly different visual characteristics in the Northeast. Indeed, the milky, uniform visibility impairment shown in Figure III-7a is typical of summertime regional haze events in the Northeast. During the winter, by comparison, reduced convection and the frequent occurrence of shallow inversion layers often creates a layered haze with a brownish tinge, as shown in Figure III-7b. This visual difference suggests seasonal variation in the relative contribution of different gaseous[37] and particle constituents during the summer vs. winter months.

Figures III-8a through III-8e show seasonal variation in the relative contribution of different particle species to estimated light extinction during the 20 percent most impaired days from 1997 to 1998 at several northeastern and mid-Atlantic sites.[38] Mass concentrations (in $\mu g/m^3$) are indicated by the numbers at the top of each column. To generate these figures, those days which were among the 20 percent most impaired days and occurred in the summer (June, July, and August) were grouped together as were those which occurred in the winter (December, January, and February). Because some poor visibility days occurred outside these months, 1998 data were included to increase the sample size for each season.

Monitoring data from the Virginia and West Virginia sites discussed in the previous section were also examined with respect to seasonal variation. However, the results suggest that almost none of the 20 percent worst visibility days in 1997 and 1998 occurred in the wintertime in these areas, indicating that the most severe visibility degradation occurs in the summer at these sites. Hence, similar seasonal figures for these areas are not included here.

As the figures on the subsequent pages show, only a handful of the 20 percent most visibility impaired days at each of the OTC RPO sites occurred between December and February during the two-year period. In addition, total light extinction on the haziest winter days was generally well below total light extinction during the haziest summer days.

Figures III-8a through III-8e indicate that the overall difference in summer vs. winter particle mass concentrations and light extinction is largely driven by seasonal variation in sulfate mass concentrations. This is because winter meteorological conditions are less conducive to the oxidation of sulfate from SO_2. In addition, seasonal differences in long-range transport patterns from upwind SO_2 source regions may be a factor.

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[37] The brownish tinge in Figure III-7b is caused by gas phase nitrogen dioxide which can accumulate to high enough levels to contribute to light absorption in urban locations, especially when trapped by a shallow inversion layer.

[38] The Great Gulf site is excluded as only summer data are available from that site.

Figure III-7a: Hazy day in Boston, MA during the summer (July 16, 1999)

Figure III-7b: Hazy day in Boston, MA during the winter (January 21, 1999)

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Figure III-8a: Summer/winter particle species contribution to reconstructed light extinction during the 20 percent most impaired days at Acadia, ME.

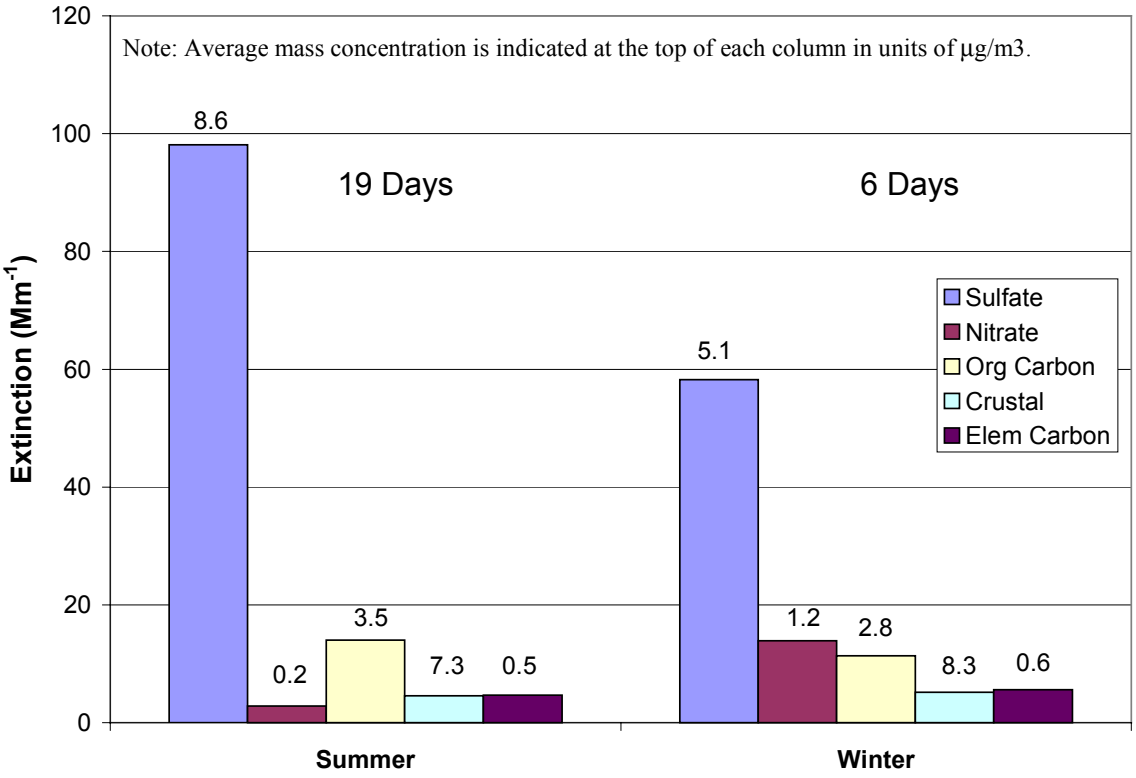


Figure III-8b: Summer/winter particle species contribution to reconstructed light extinction during the 20 percent most impaired days at Brigantine, NJ.

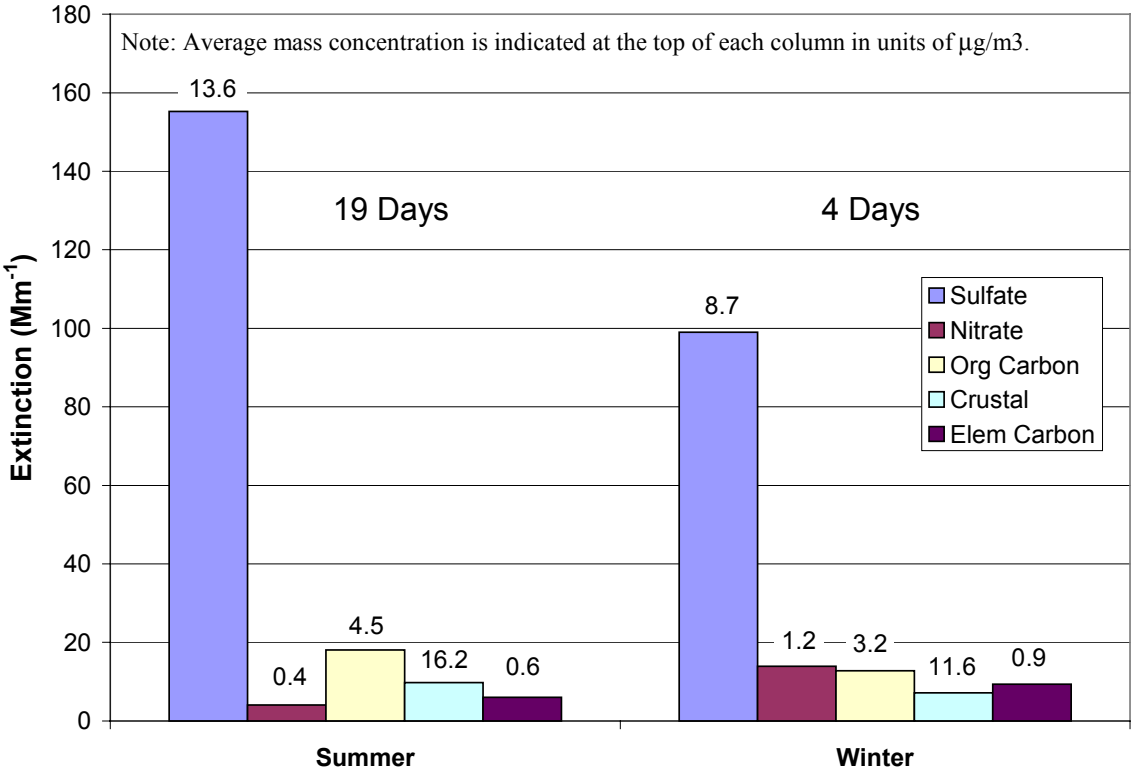


Figure III-8c: Summer/winter particle species contribution to reconstructed light extinction during the 20 percent most impaired days at Lye Brook, VT.

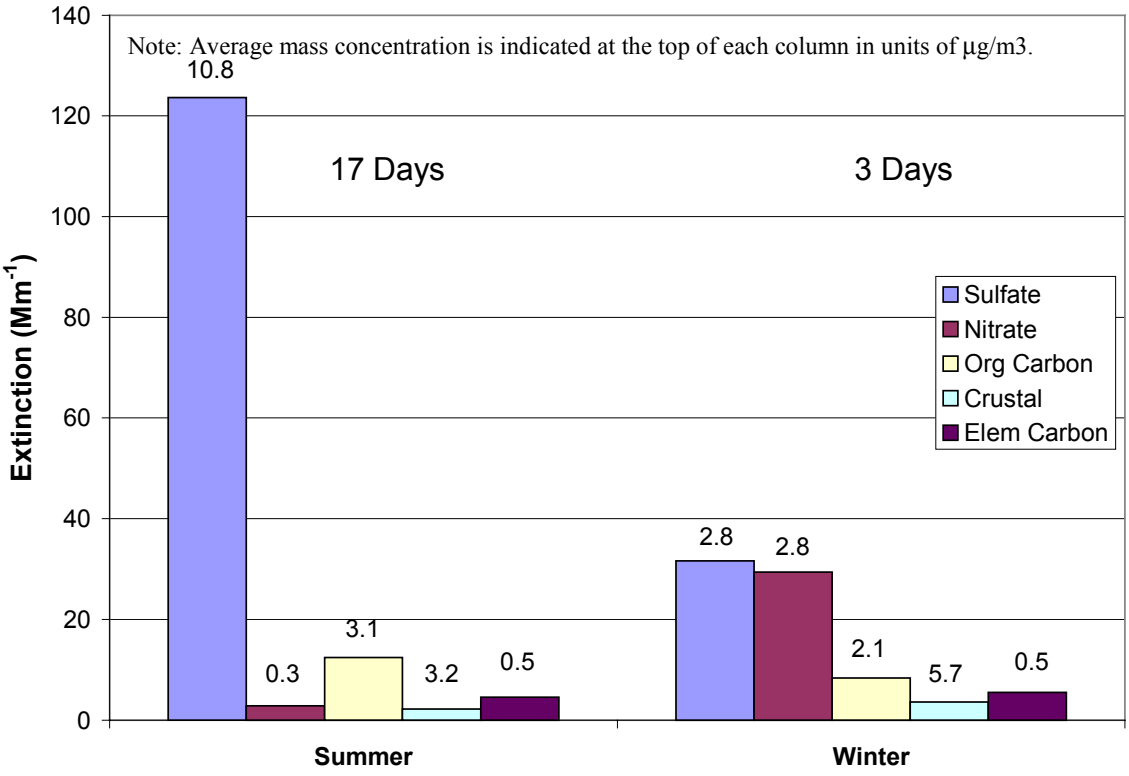


Figure III-8d: Summer/winter particle species contribution to reconstructed light extinction during the 20 percent most impaired days at Moosehorn, ME.

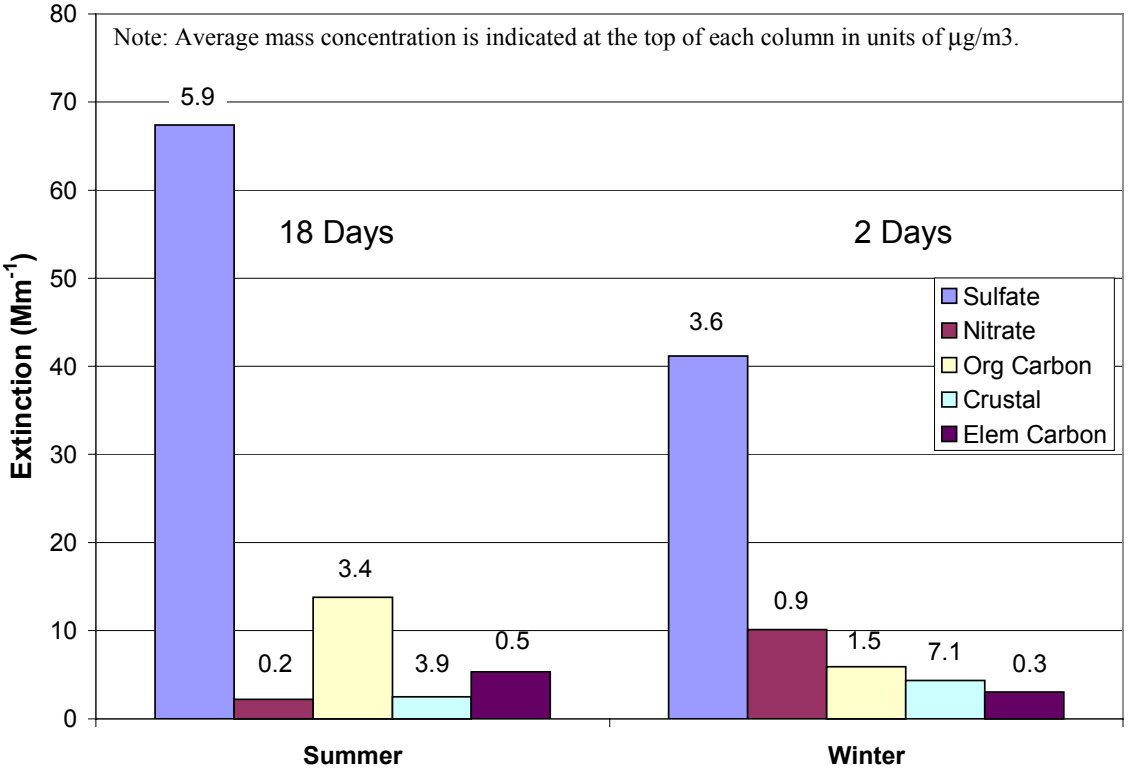
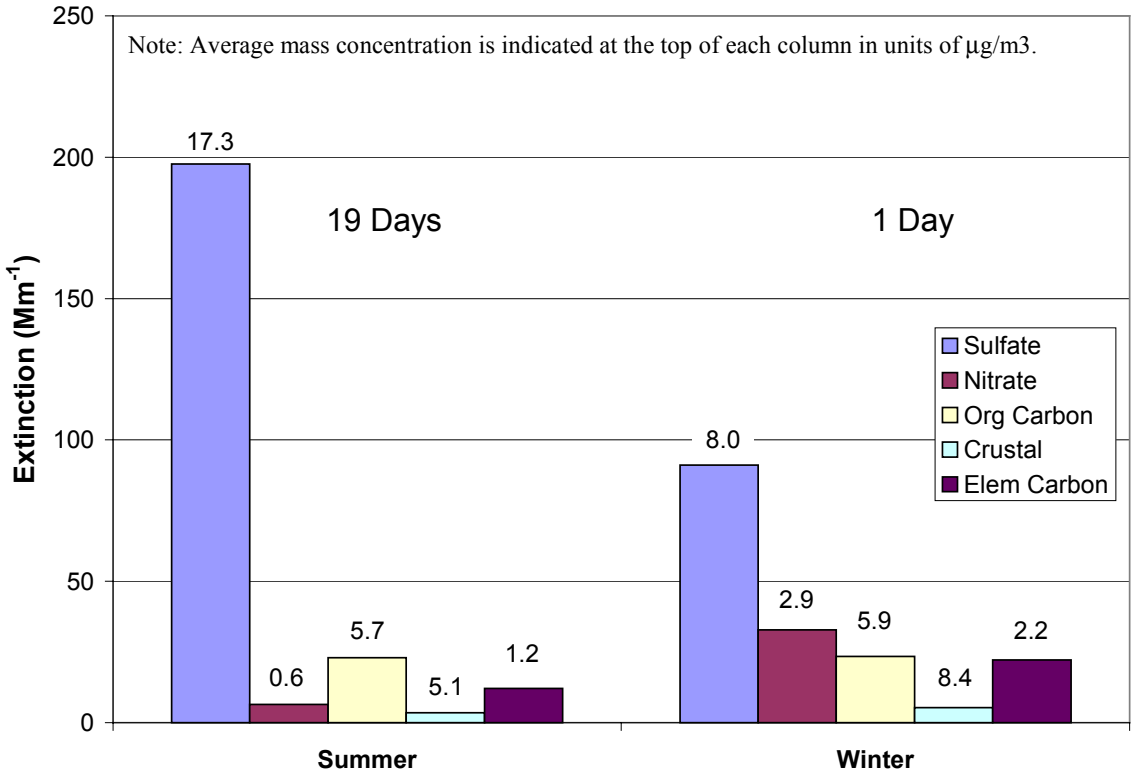


Figure III-8e: Summer/winter particle species contribution to reconstructed light extinction during the 20 percent most impaired days at Washington, DC.



Although sulfate accounts for a relatively smaller fraction of total light extinction during the winter months, it nevertheless remains the dominant constituent species during both seasons. The absolute contribution from organic carbon declines somewhat during the winter, but generally not by a tremendous amount. Similarly, there does not appear to be a consistent seasonal difference in the contribution from elemental carbon and crustal material, although their average concentrations tend to be highest in summer.

Nitrate, by contrast, clearly contributes more in absolute and relative terms to particle light extinction in the winter months. Indeed, the winter nitrate contribution to light extinction almost equaled the winter sulfate contribution at Lye Brook during the 1997-98 period. The greater presence of nitrate during the cold season is a consequence of the chemical properties of ammonium nitrate. Ammonia bonds more weakly to nitrate than it does to sulfate and ammonium nitrate tends to dissociate at higher temperatures. Consequently, ammonium nitrate becomes more stable at lower temperatures and hence contributes more to overall light extinction during the winter months.

E. The Link Between Haze and Other Air Quality Problems

As should be evident from the discussion in Chapter II and subsequent sections of this report, haze and visibility impairment are very directly linked to fine particle pollution. In fact, haze *is* particle pollution, though it is measured and regulated in different ways and for different reasons. Particulate matter (PM) is among the so-called "criteria pollutants" for which USEPA has established National Ambient Air Quality Standards (NAAQS) to protect human health. At present, a NAAQS exists for particles up to 10 micrometers in diameter (PM_{10}); more recently, recognizing that smaller particles pose particular health risks because they may be inhaled more deeply in the lungs, USEPA promulgated separate NAAQS for particles up to 2.5 micrometers in diameter ($PM_{2.5}$). The new standards would limit annual average $PM_{2.5}$ concentrations to 15 $\mu g/m^3$ and peak (98th percentile) 24-hour concentrations to 65 $\mu g/m^3$, based on epidemiological evidence pointing to a number of health risks associated with both chronic and short-term fine particle exposure. These risks include increased risk of respiratory and cardiovascular illness (including chronic bronchitis and asthma) and increased risk of premature death. The new PM standards (together with a new 8-hour ozone standard) are currently under review by the U.S. Supreme Court; meanwhile USEPA is reviewing possible future revisions to the $PM_{2.5}$ NAAQS on the basis of new epidemiological evidence.

The connection of haze to another prominent criteria pollutant, ozone, is more complicated. Haze and ozone are fundamentally different phenomena: ozone, itself a colorless pollutant, does not directly impair visibility and is formed from a different set of chemical reactions. Thus, it is possible for fine particle levels, and hence visibility impairment, to be high on days that are relatively free of ground-level ozone pollution. On the other hand, ozone formation involves many of the same precursor pollutants (notably NO_x and VOCs) [39] and is enhanced by the same meteorological conditions conducive to the formation of fine particles, including the presence of sunlight and humidity. Consequently, researchers have found that high ozone levels are often associated with hazy air masses in the summertime (Husar et al., 1976; Samson and Ragland, 1977; Gillani and Wilson, 1980) and weather forecasters are most likely to issue smog alerts on days described as "hazy, hot, and humid."[40] In addition, there is an important, indirect link between ozone and haze. Ozone is an atmospheric oxidant and therefore promotes the formation of secondary particles – including sulfate, nitrate, and organic aerosols – from precursor emissions of SO_2, NO_x, and VOCs, respectively.

Finally, to the extent that haze is caused, in part, by precursor emissions of SO_2 and NO_x, efforts to reduce haze and improve visibility will have an important, if indirect

[39] Note that optimal conditions for the formation of particles and ozone differ in terms of the relative concentrations of precursor pollutants; in addition, NO_X, is probably more important in ozone formation than as a particle constituent in the eastern U.S. Conversely, SO_2, which plays an important role in particle formation, does not play a role in ozone formation.

[40] Note that the combination of heat and humidity alone cannot cause "hazy" conditions and poor visibility, absent the addition of particle-forming pollutants.

link to concerns in many eastern states about the ongoing ecosystem impacts of acid deposition and nitrogen saturation/eutrophication. These ecosystem impacts affect critical natural resources in the Northeast and Mid-Atlantic states; impacts that are not confined to Class I areas.

F. The Regional Nature of Haze in the Eastern U. S.

The recent regulations promulgated by USEPA to address visibility impairment throughout the nation are premised on the recognition that haze is a fundamentally regional problem. Because pollutants can travel in the atmosphere, numerous emissions sources dispersed over a broad geographic region often contribute to haze conditions over large areas of the country. For example, the primary precursor pollutant for sulfate – a key constituent of fine particle mass throughout the eastern U.S. – is SO_2, a pollutant that has an atmospheric lifetime of several days and is known to be capable of traveling hundreds of miles before leaving the atmosphere.[41] Other particle constituents and precursors including NO_X,[42] organic compounds,[43] and primary particles such as crustal[44] and elemental carbon, are also subject to long-range transport under certain meteorological conditions.

The conditions that tend to create widespread haze and visibility impairment in the OTC RPO region often start with high-pressure systems that bring pollutants from the Midwest and Southeast (including ozone precursors, sulfates, and other secondary pollutants) into the Northeast and Mid-Atlantic states, where they mix with pollutants from major urban centers. Warm temperatures, abundant sunlight, and lack of ventilation within the stable boundary layer of these high-pressure systems promote the production and accumulation of ozone and visibility reducing particles as the systems slowly sweep eastward and northward. The result can be a large-scale airmass, often blanketing major portions of the eastern half of the country, with elevated concentrations of ozone and fine particles.

Just such conditions occurred during the summer of 1999 between Thursday, July 15 and Tuesday, July 20. The result was one of the most severe regional haze events recorded over the last decade in the eastern U.S. The final section of this chapter concludes with a description of that event as a way of illustrating the various factors that combine to create persistent problems of low visibility and regional haze in the Northeast and Mid-Atlantic states.

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[41] Modeling by USEPA indicates that about two-thirds of total sulfur deposition from large power plants in the Ohio River Valley occurs within 500 km to 700 km downwind (300-400 miles), with the remaining third depositing at even greater distances from the emissions source (USEPA, 1995).

[42] While NO_X itself has a relatively short lifetime in the atmosphere, it has been shown that NO_X can quickly form peroxyacetyl nitrate (PAN) which is stable with respect to transport over large distances after which the reverse reaction can occur, releasing NO_X far downwind of its source (Seinfeld and Pandis, 1998).

[43] Organic compounds, as discussed earlier, encompass a wide variety of molecular families with a range of reactivities and thus can be transported over a correspondingly wide range of distances.

[44] In fact, dust storms over the Sahara Desert in northern Africa commonly result in deposition of Saharan dust over broad regions of the southeastern U.S. (Prospero and Nees, 1986).

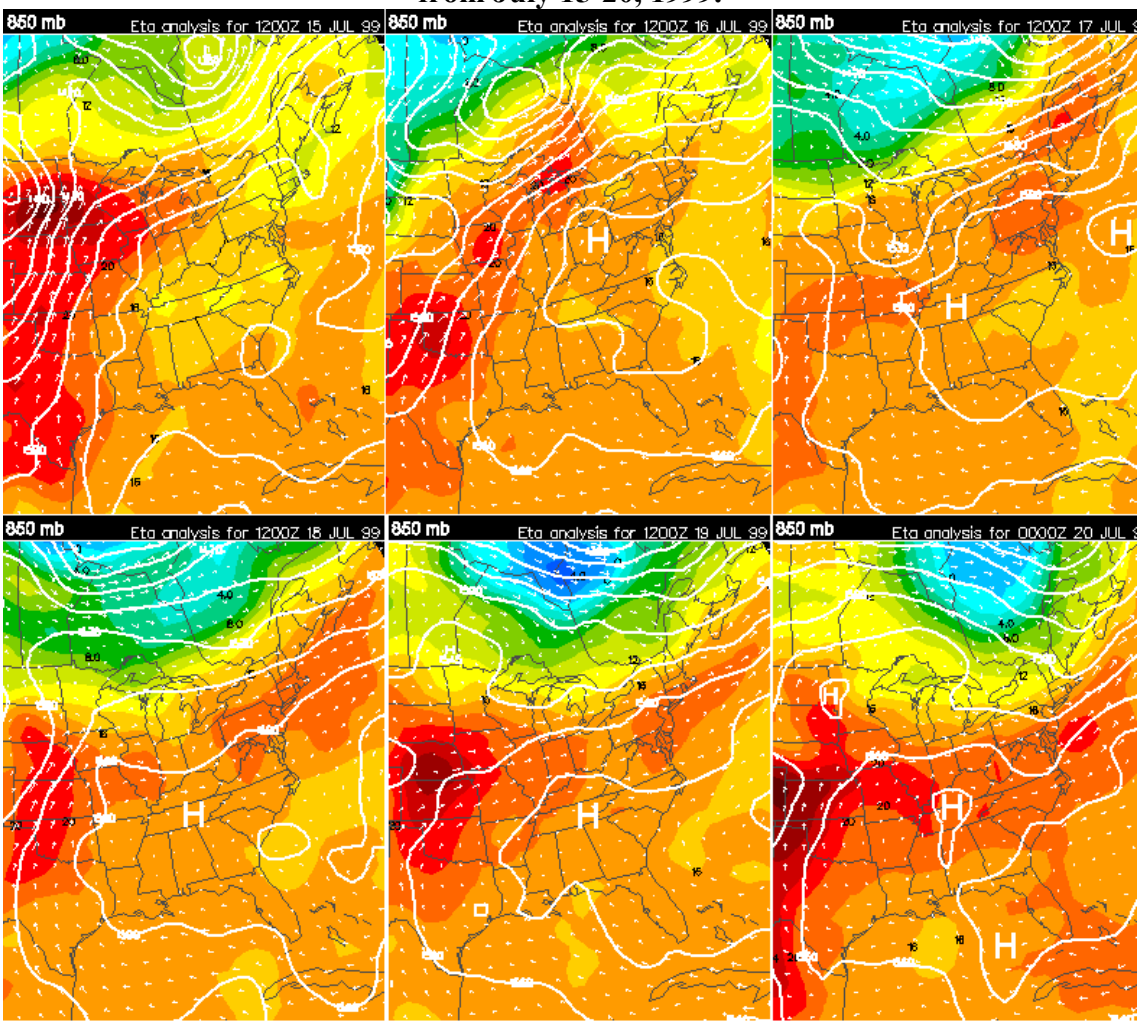
G. Anatomy of a Severe Haze Event

It should be stressed at the outset of this section that the haze event that occurred in mid-July of 1999 in the eastern U.S. was only unusual in its severity, not in its underlying causes. Moreover, it bears emphasizing that regional haze is not necessarily episodic in nature. Rather the conditions that create high haze levels in the East are common, especially in the summertime, and often persist for long periods of time.

July of 1999 was unusually hot; indeed it was the ninth warmest July since 1895 for the Northeast and Mid-Atlantic as a whole. The stage was set for a major pollution event when a high-pressure system began to build over the southeastern U.S on July 14-15.[45] Over the next several days, this area of high pressure began to move over the Mid-Atlantic region. As it built, a pool of cooler air lifted quickly to the Northeast, which is a typical feature prior to the onset of a pollution transport event for the Northeast (NESCAUM, 1998). Winds rotating clockwise around the high-pressure zone began bringing air pollutants from source regions to the west into the Northeast. On Sunday, July 18, an advancing cold front in the Great Lakes region began to distort the northern edge of the high pressure ridge; over the next two days this shallow cold front pushed the high pressure system southward and out of the Northeast (See Figure III-9).

[45] The meteorological development of this episode has been extensively documented by Dr. William Ryan at the University of Maryland (Ryan, 2000). This summary draws heavily from Dr. Ryan's work.

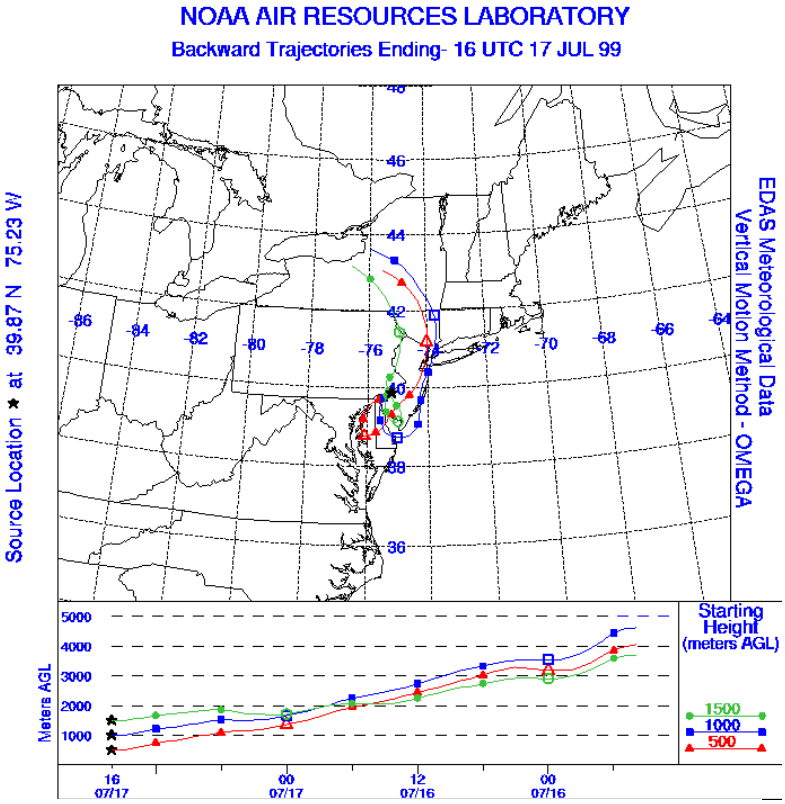
Figure III-9: Upper air map of the evolution of a high pressure ridge from July 15-20, 1999.



Colors correspond to upper air temperatures with blue shading indicating coolest and red shading warmest. Note the relatively cooler air mass over the mid-Atlantic region on July 15 that moved to the Northeast. This feature typically signals an incipient pollution transport episode for the Northeast region.

Wind flows associated with the July 15-20 high pressure system exhibited a complex pattern in parts of the Northeast. Back trajectory analysis of the air arriving over Philadelphia on July 17 and 18 shows a circular pattern in which easterly air flow near the surface cancelled the usual westerly trajectory of winds over the lower (southern) parts of the Ozone Transport Region (Figure III-10). This area of recirculation, which also appears in wind field maps from July 15-19 (Figure III-11), allowed for the build-up of particle and ozone-forming pollutants over the heavily urbanized areas of Washington DC, Baltimore, Philadelphia, and southern New Jersey.

Figure III-10: 48-hour back trajectories for Philadelphia, PA (HYSPLIT, 2000).



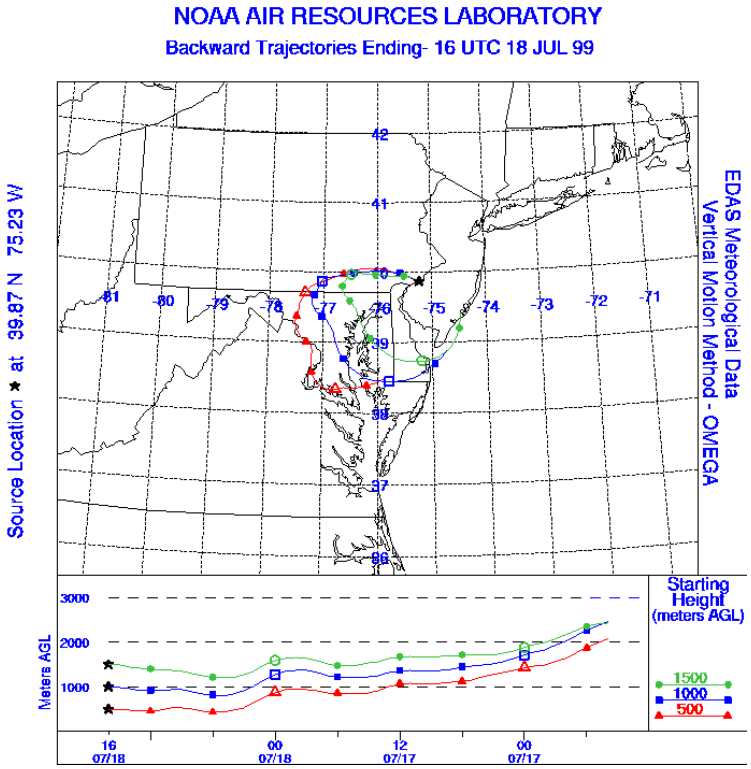
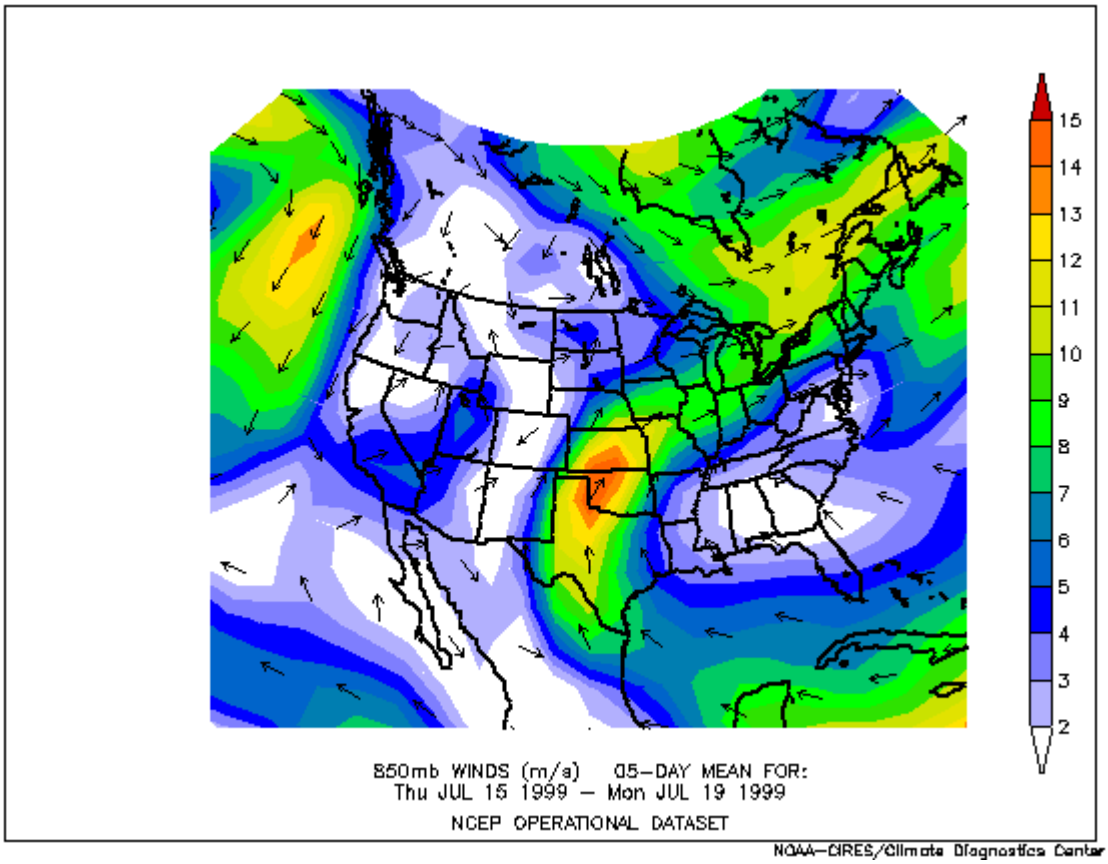


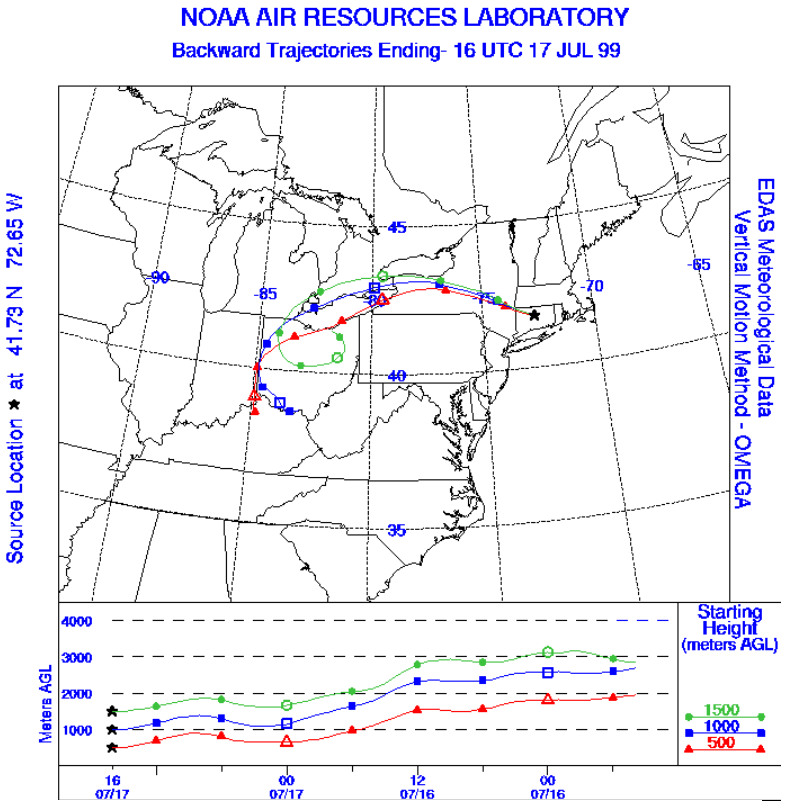
Figure III-11: Average mean vector wind field map from July 15 through July 19, 1999.

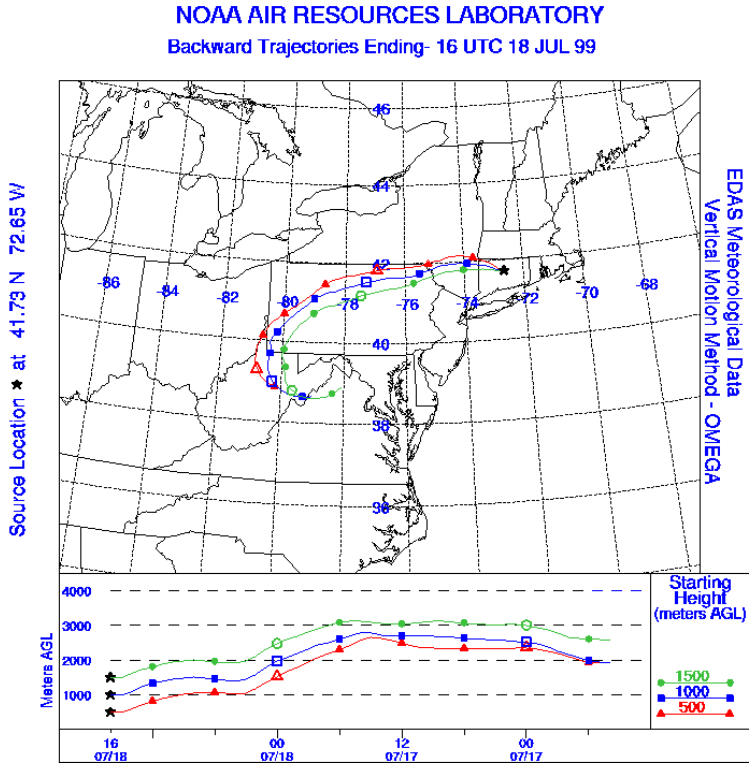


Note the small white area near Washington, DC, indicating very low average wind speed vectors. Recirculation around this area within the larger high pressure region over the southeastern United States created a complex flow pattern in the lower Northeast.

Meanwhile, wind patterns above the area of recirculation produced a consistent westerly flow of air into the more northern parts of the Ozone Transport Region on July 17 and 18. Back trajectory analysis for Hartford, CT during this period shows that the air entering the New England states came from areas substantially to the west, including Ohio, western Pennsylvania, and West Virginia (see Figure III-12). Having just stagnated (as indicated by the looping structure at the back end of the trajectories) over an area characterized by numerous large SO_2 and NO_X sources, the air reaching Hartford – like the air recirculating in the Philadelphia-DC area –was likely to have higher than normal concentrations of ozone and fine particle precursors. In sum, the July 1999 episode exhibited both local transport (in the southern part of the Ozone Transport Region) and long-range transport (in the more northern part of the region).

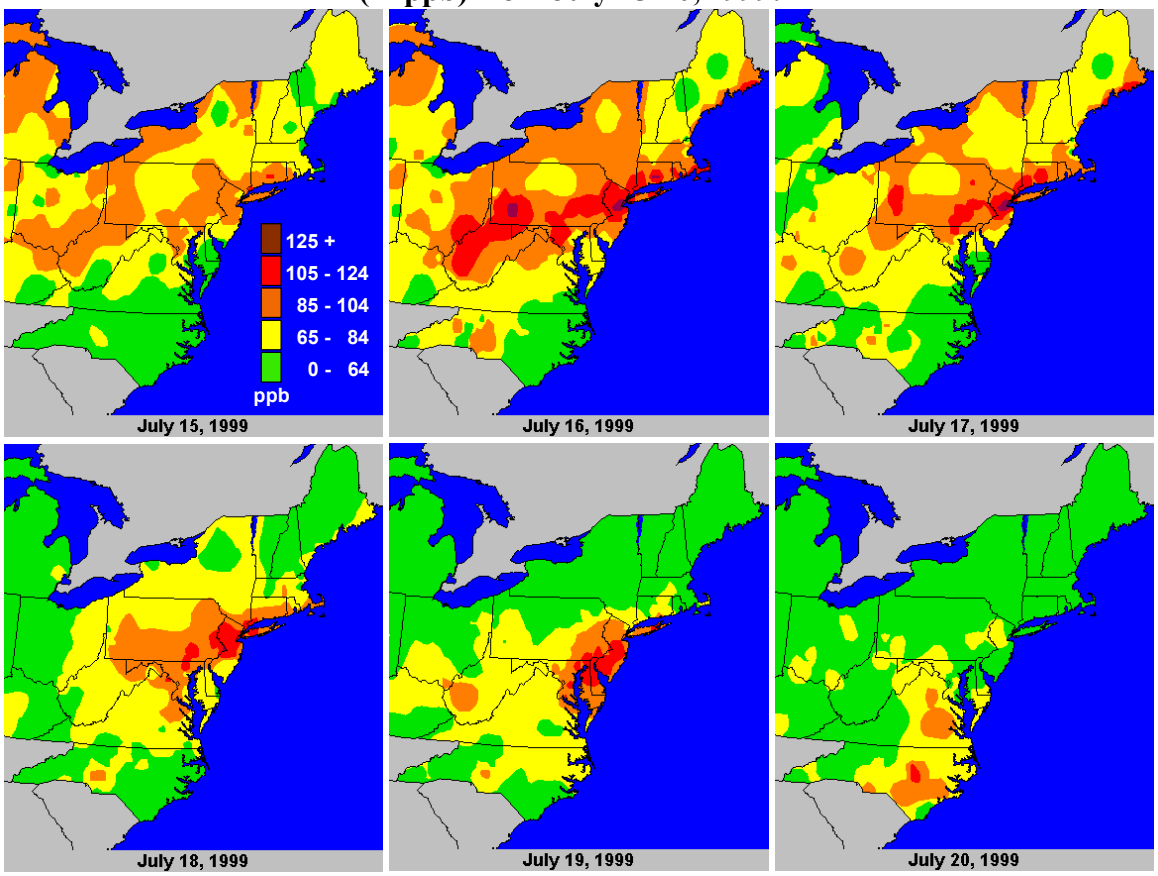
Figure III-12: 48-hour back trajectories for Hartford, CT (HYSPLIT, 2000).





This complex pattern of intermittent transport and recirculation in the southern portions of the OTC RPO region, combined with consistent westerly transport of air from the industrial Midwest to the northern parts of the region resulted in some of the highest ozone and fine particle concentrations recorded over the past decade. Figure III-13 shows daily maximum 8-hour ozone concentrations over the region from July 15 to July 20. The highest concentrations generally coincided with the development and movement of the high pressure system: they occurred in the middle to northern portions of the Northeast early in the episode, peaked across a large area spanning West Virginia to Connecticut on July 18, and then began to shift south as the cold front pushed the high pressure system out of the region toward the end of the episode. Notably, ozone concentrations were already relatively high (greater than 85 parts per billion) in parts of the Northeast and in areas to the west at the start of the episode on July 15. This reservoir of ozone to the west set the stage for transport into the Northeast during the upcoming days.

Figure III-13: Daily maps of maximum 8-hour averaged ozone concentrations (in ppb) from July 15-20, 1999.



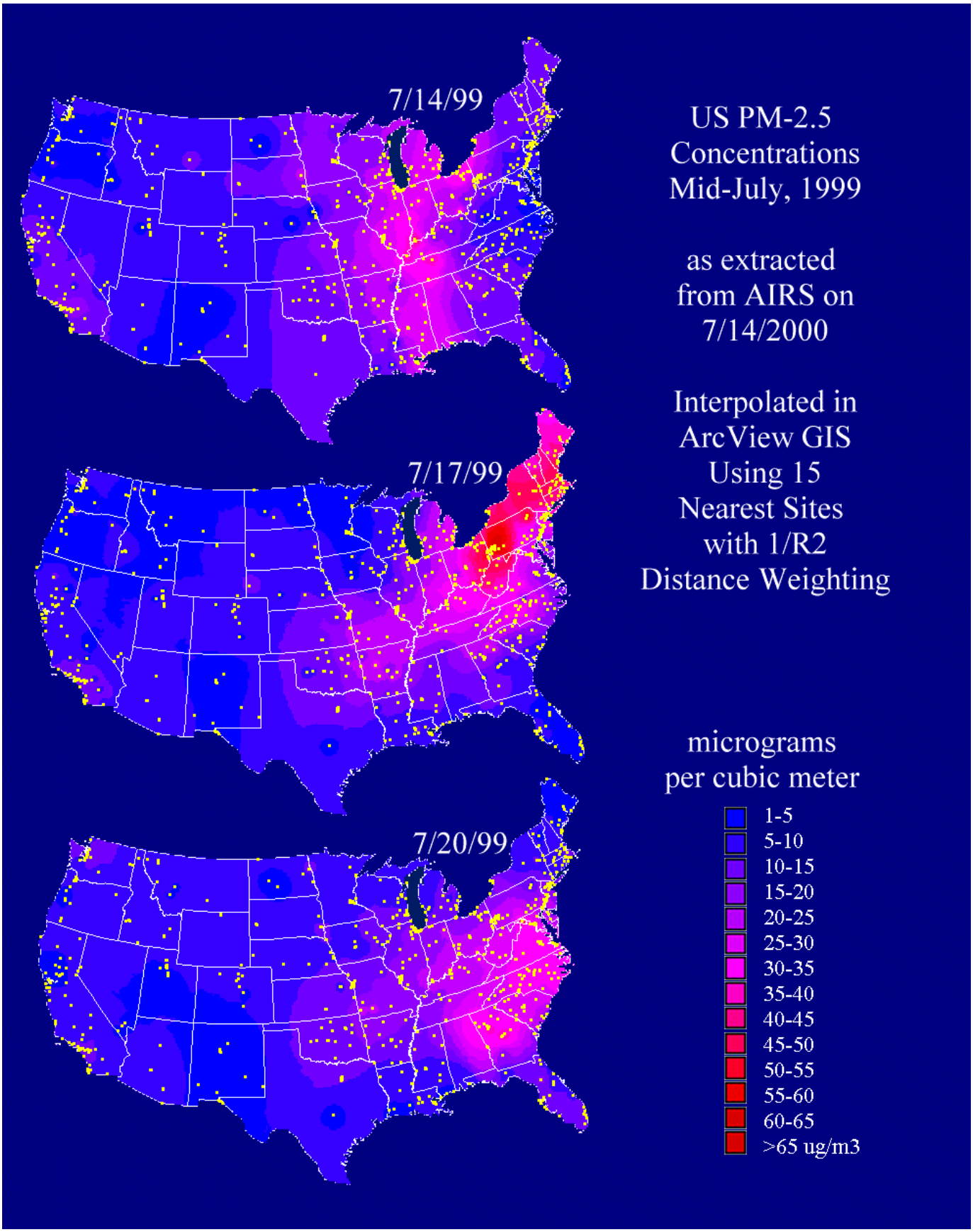
Note: Ozone maps are from U.S. EPA AIRNow (http://www.epa.gov/airnow/maparch.html). The maps are based on spatial interpolations and may not represent actual measured values at some locations (e.g. the Pittsburgh monitor only registered 121 ppb maximum concentrations on the 16th).

A similar pattern characterizes $PM_{2.5}$ monitoring data collected over this period (see Figure III-14).[46] As with ozone concentrations on July 17, the northernmost areas of the Ozone Transport Region experienced higher fine particle concentrations than the southern portions of the region (Poirot, 1999). Maximum 24-hour $PM_{2.5}$ concentrations on July 17 ranged from 46 $\mu g/m^3$ in Acadia National Park and 50 $\mu g/m^3$ in Bennington, VT[47] to just 18 $\mu g/m^3$ in southern New Jersey's Brigantine Wilderness and 29 $\mu g/m^3$ in Washington, DC.

[46] Because fine particle concentrations were being measured on an every three day basis during 1999, figures are only available for July 14, July 17, and July 20.

[47] Data may be preliminary in some cases and subject to change. The consistency of the high concentrations across the region, however, suggests that the preliminary data are reasonable indicators of high concentrations during this time period.

Figure III-14 Fine particle mass concentrations during July, 1999 (Poirot, 2000a).



These unusually high fine particle concentrations resulted in extremely poor visibility conditions across the Northeast and Mid-Atlantic, even at the most remote and northerly sites. On July 17, visibility at the Burlington, VT airport was just 5 km (3 miles); at Acadia National Park it was just 13-16 km (8-10 miles). Figure III-15 shows visibility conditions at Boston and Acadia on July 16 relative to clear conditions at both sites. As the high pressure system shifted south, poor visibility conditions continued, with airports from Washington to Philadelphia reporting visibility restricted to just a few miles for several days.

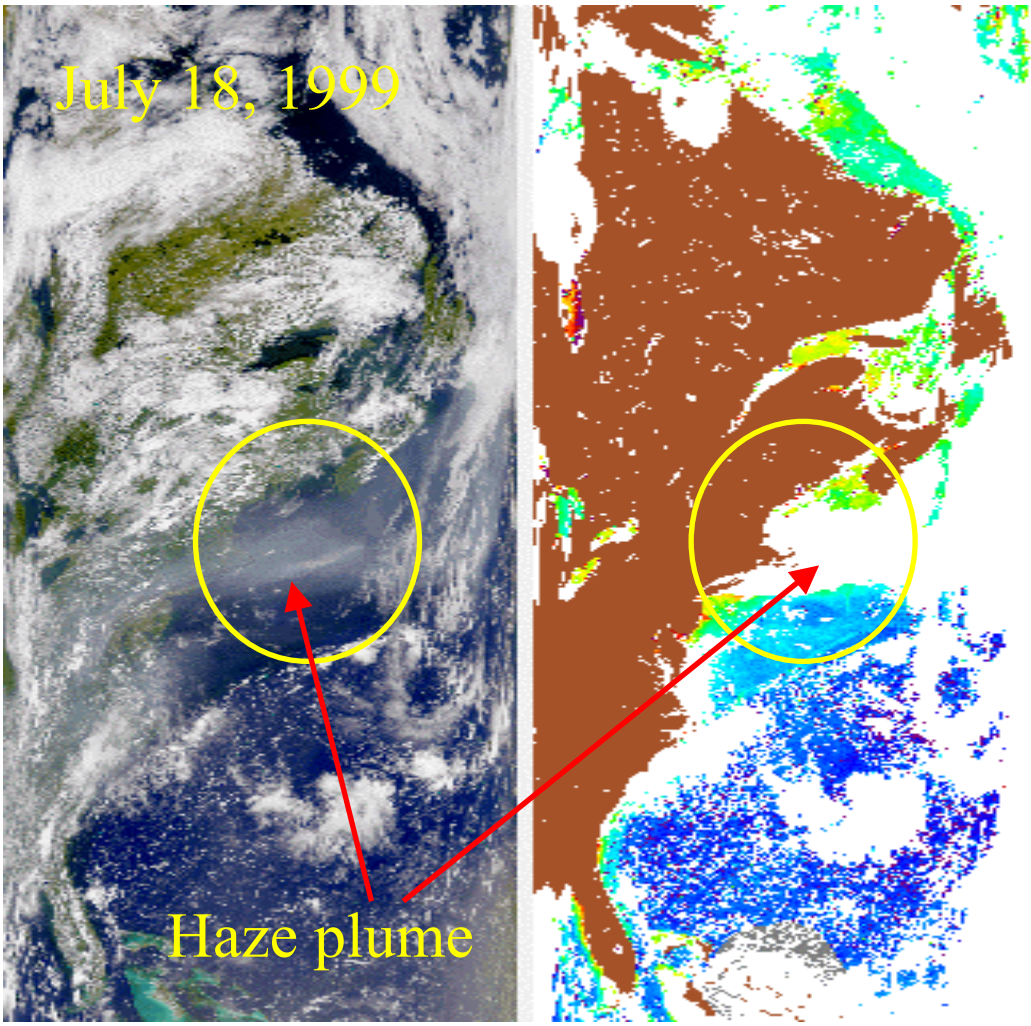
Figure III-15: Digital camera views of Acadia National Park, Maine (upper row) and the Boston, Massachusetts skyline (lower row).

The pictures on the left are examples of "good" visibility days at both locations. The pictures at the right show poor visibility conditions at each site at 6:00 p.m. (eastern daylight time) on July 16, 1999.

The high levels of particulate pollution recorded in the Northeast and Mid-Atlantic during the 1999 mid-July episode provided stark images of haze that could even be seen from outer space. Images from a satellite orbiting about 440 miles overhead recorded a large trail of haze extending off the northeastern U.S. coast from Long Island Sound to well off Cape Cod, MA on July 18, 1999 (Figure III-16).[48] (Note that the false color image on the right side of the figure helps identify the location of the haze plume, which is circled in both images, relative to the coastline.)

[48] Images came from a satellite in the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project, http://seawifs.gsfc.nasa.gov/SEAWIFS.html. Figure III-16 is an adapted image from Westphal, 1999.

Figure III-16: Satellite image from SeaWiFS on July 18, 1999.



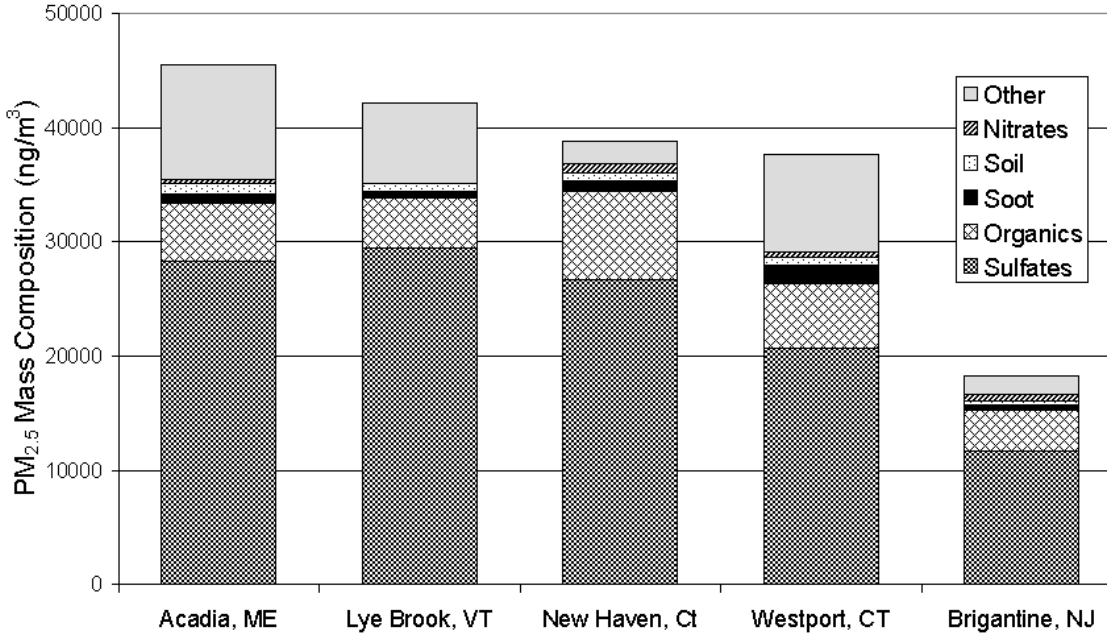
Similar images were captured by a weather satellite in a geosynchronous orbit 22,000 miles above the Earth on that day.[49] Researchers have since analyzed these satellite images to identify plume features across large portions of the Northeast and out over the Atlantic Ocean, including a particularly thick haze patch near the islands of Martha's Vineyard and Nantucket on the evening of July 16 (Husar, 1999; Westphal, 1999).

During the mid-July 1999 haze event, as during most poor visibility days in the Northeast and Mid-Atlantic, sulfate accounted for a very large fraction of overall fine particle mass. Figure III-17 shows speciated data for fine particle mass concentrations at several northeastern and mid-Atlantic sites on July 17, 1999. The fact that sulfate levels were higher at Acadia National Park on this occasion than at Brigantine in New Jersey is reflective of the unique transport conditions that characterized this haze event. In fact, the 24-hour ammonium sulfate concentrations measured at Acadia on July 17 were 40

[49] A description of the Geostationary Operational Environmental Satellite program is on the internet at http://goes1.gsfc.nasa.gov/.

percent higher than any other previous measurement at that site since monitoring began in 1988. Monitoring data from Rye, NH during this period bear out the unusual "spike" in sulfate concentrations that occurred on July 16 and 17 in the Northeast (see Figure III-18).

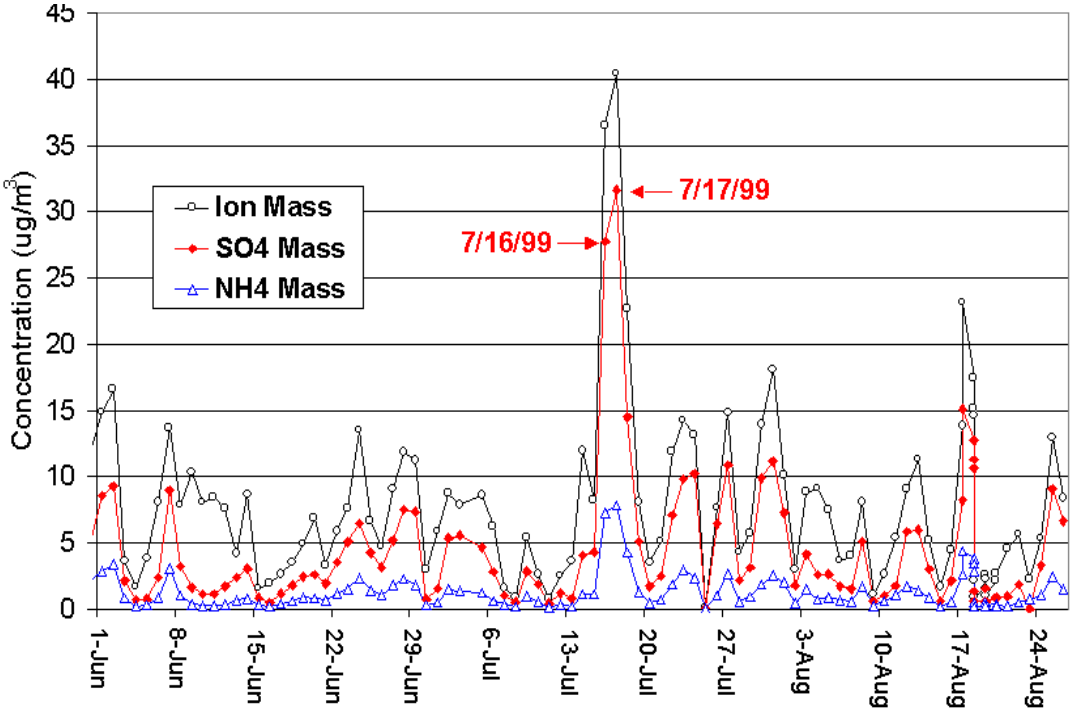
Figure III-17: Average 24 hour total fine particle ($PM_{2.5}$) mass concentrations in the Northeast on July 17, 1999.



Concentrations are in nanograms per cubic meter (ng/m^3).[50] Results are from IMPROVE monitors at Acadia, Lye Brook, and Brigantine and from IMPROVE-type monitors operated by the State of Connecticut at New Haven and Westport in 1999.

[50] 1000 ng/m^3 is equivalent to 1 $\mu g/m^3$. These units are customarily used by the IMPROVE program from which the figure was obtained.

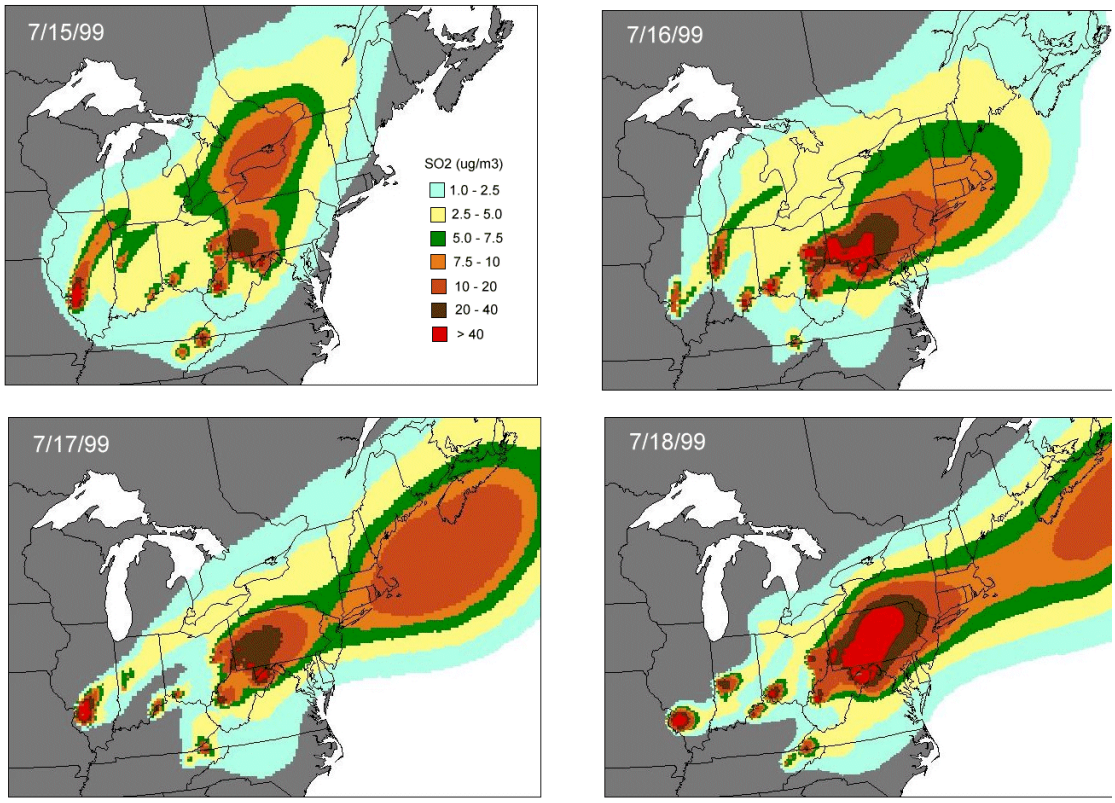
Figure III-18. Summer aerosol ionic concentrations at Rye, NH.



Measured ions include SO_4, NO_3, NH_4, Na, Cl, Ca, Mg and K. Preliminary data provided courtesy of University of New Hampshire Climate Change Research Center, AIRMAP Program.

Finally, researchers have modeled "forward trajectories" of SO_2 plumes from major sources across the region. The results indicate the spatial extent of a sulfate particle plume passing through the Northeast during the 1999 episode (Figure III-19) (Poirot, 2000b). While the trajectories do not take into account plume rise, deposition, or transformation chemistry, their combined spatial pattern is consistent with the sulfate monitoring data for this period. The modeled plume is also strikingly consistent in shape and location with the satellite image shown in Figure III-16 (Husar, 1999) and with another modeling effort that reproduced a sulfate plume extending from the Midwest through the Northeast and out over the north Atlantic Ocean (Westphal, 1999).

Figure III-19: Forward trajectories from HYSPLIT model of SO_2 plumes from 17 power plants in the Midwest during July 15-18, 1999 (Poirot, 2000b).



SO_2 emission rates are based on 1998 continuous emission monitoring data. Concentrations correspond to 24-hour averaging periods ending at 9 p.m. local time on the identified dates. The HYSPLIT model did not calculate plume rise, deposition, or transformation chemistry, therefore the "SO_2" plumes can be thought of as precursor plumes for sulfate plumes.

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IV. Federal Regional Haze Requirements

Congress first adopted a national program aimed at protecting visibility and reducing haze in national parks and wilderness areas over two decades ago. The objectives of this program, as articulated in the 1977 Amendments to the federal Clean Air Act, were:

> "[T]he prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution."

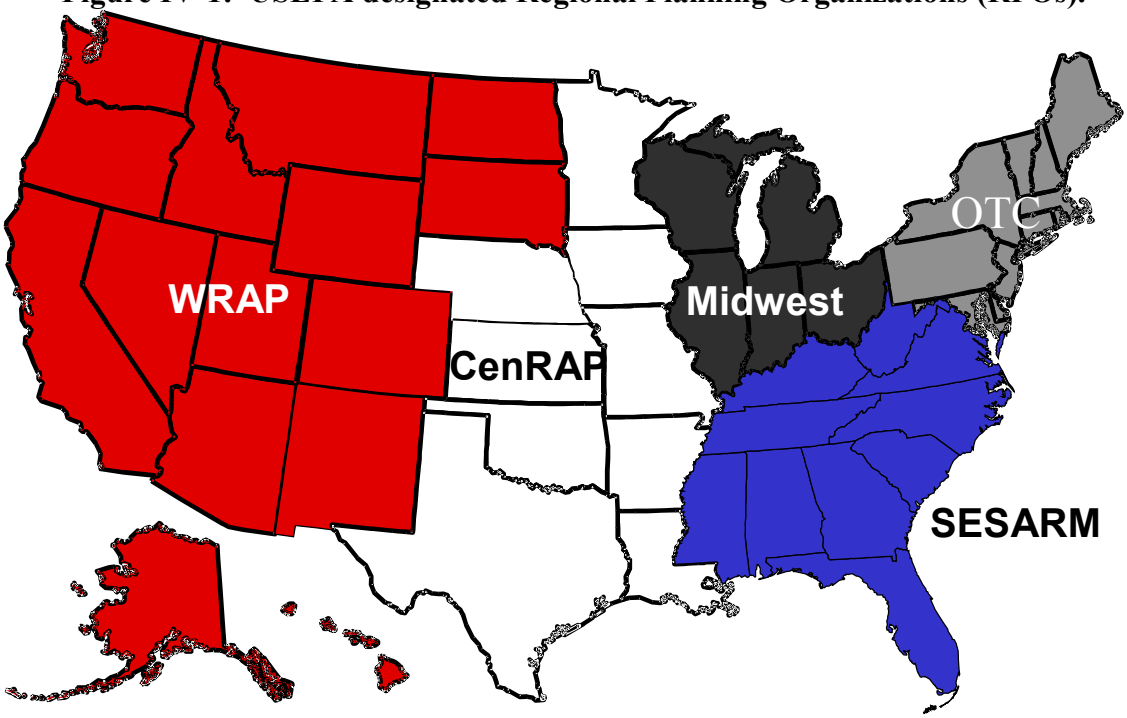
In short, Congress was aiming for nothing less than the restoration of pristine, unpolluted vistas in the nation's most cherished natural areas.

Though the goal of the federal regional haze program, as adopted in 1977, was a lofty one, the actual pollution control efforts it inspired over the ensuing two decades were relatively modest. The specific regulations subsequently issued by USEPA in 1980 to implement national visibility goals focused largely on local sources of visibility impairment and plume blight in Class I areas, and specifically deferred the more controversial issue of regional haze. Thus, only emissions sources or groups of sources to which specific visibility impairment could be "reasonably attributed" were subject to pollution control requirements. (As it turned out, such a finding was made in only one state and for only one Class I area throughout the 1980s.) Moreover, only those states that hosted Class I federal areas were required to make haze reduction efforts and to submit plans demonstrating "reasonable progress" toward the national goal. Congress took some interim steps to address these shortcomings in the 1990 Clean Air Act Amendments, which authorized additional research funds to study visibility impairment and established a procedure for creating Visibility Transport Commissions. These Commissions were to be made up of Governors from states with sources that contributed to visibility impairment even in Class I areas outside their borders and represented a first step toward addressing the problem of haze on a regional basis. Despite these efforts, by the late 1990s, average visual range in eastern Class I areas remained less than a third of what it would be under natural conditions.

In July of 1999, USEPA initiated a second phase of the federal haze program by issuing a new set of federal requirements (64 Fed. Reg. 35,714 (July 1, 1999)). Known as the 1999 regional haze rule, the new USEPA requirements seek to invigorate visibility protection efforts by setting a specific deadline of 2064 for achieving national visibility goals and by redirecting state and federal approaches toward reducing haze. Specifically, the 1999 rule moves away from a localized approach and the concept of "reasonably attributable" impairment from specific pollution sources to a more regional approach which recognizes that visibility impairment is generally caused "by the emission of air pollutants from numerous sources located over a wide geographic area." Importantly, the new rule requires that all states with sources that "may reasonably be anticipated to cause or contribute" to poor visibility in a protected area (40 C.F.R. §51.300(b)(ii)) develop regional haze implementation plans, regardless of whether those states themselves

contain any mandatory Class I areas. In order to facilitate effective program coordination among states and to effectively implement regional haze reduction strategies, USEPA has designated five regional planning organizations (RPOs) covering all areas of the U.S. (see Figure IV-1). The Ozone Transport Commission (OTC) was selected to serve as the RPO for the Northeast and Mid-Atlantic regions. It includes all states along the eastern seaboard from Washington, DC to Maine. Interested tribes can also join, giving them a first-ever opportunity to participate directly in air quality planning in the OTC region. RPOs for other regions include: Southeast States Air Resource Managers (SeSARM), the Midwest RPO coordinated by Lake Michigan Air Directors Consortium (LADCo), Central Regional Air Partnership (CenRAP), and the Western Regional Air Partnership (WRAP).

Figure IV-1: USEPA designated Regional Planning Organizations (RPOs).



This chapter describes the specific requirements that apply to states under the original federal haze program and under USEPA's more recent regional haze rule. The first section identifies the states and Class I areas subject to federal haze requirements in the Northeast and Mid-Atlantic regions. The second section summarizes key elements of the first phase of the federal haze program and, in particular, its application of Best Available Retrofit Technology (BART) requirements to certain emissions sources. The third and lengthiest section describes in some detail the provisions of the 1999 rule, including: regulatory timeline, regional planning options, State Implementation Plan (SIP) requirements, BART requirements, SIP revisions, progress reporting, adequacy determinations, and coordination between states and federal land managers.

A. Class I Areas in the Northeast and Mid-Atlantic Regions

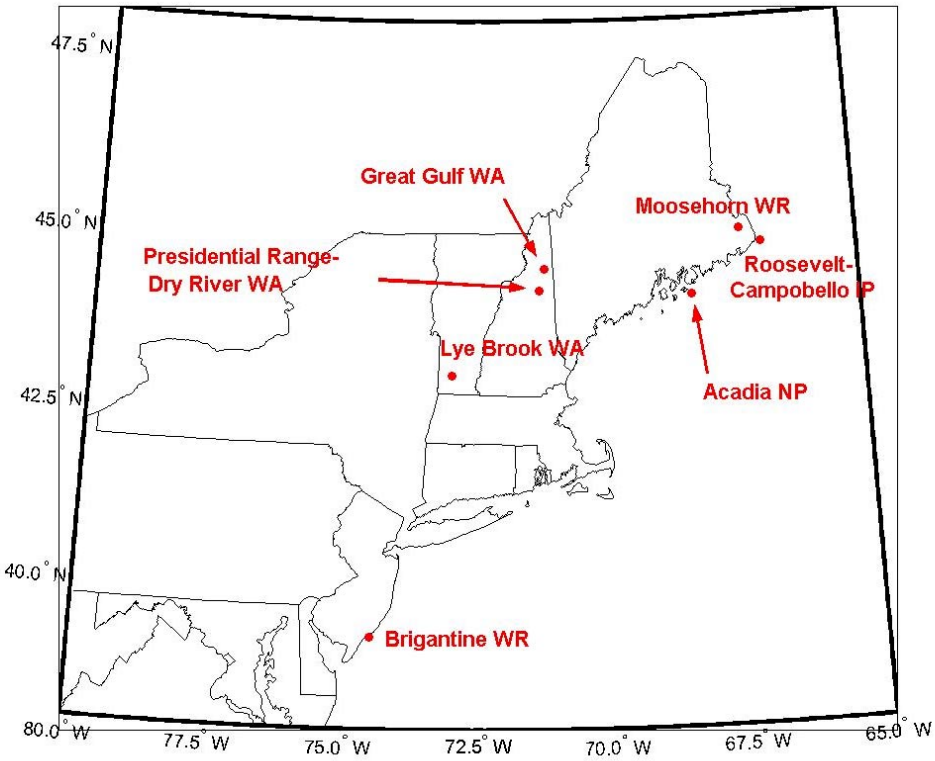
Federal haze requirements are intended to restore pristine visibility conditions to historical "Class I" areas. Historical (or "mandatory") Class I areas are defined as national parks over 6,000 acres, wilderness areas and memorial parks over 5,000 acres, and all international parks established as of August 7, 1977. There are seven Class I areas in the Northeast and Mid-Atlantic regions. They include:[51]

- Acadia National Park, ME
- Brigantine Wilderness, Edwin B. Forsythe National Wildlife Refuge, NJ
- Great Gulf Wilderness, White Mountain National Forest, NH
- Lye Brook Wilderness, Green Mountain National Forest, VT
- Moosehorn Wilderness, Moosehorn National Wildlife Refuge, ME
- Presidential Range–Dry River Wilderness, White Mountain National Forest, NH
- Roosevelt Campobello International Park, New Brunswick

Figure IV-2 shows the location of each of these Class I areas.

[51] A more complete description of each listed area appears in Chapter IX.

Figure IV-2: Map of federal Class I areas in the OTC RPO region.



Note: designations are shown with each Class I area. NP = National Park, WA=Wilderness Area, WR = Wilderness Areas located within a Wildlife Refuge, and IP = International Park.

B. Requirements Under the First Phase of the Federal Haze Program (1980-1999)

Following the adoption of national visibility goals in the 1977 Clean Air Act Amendments, USEPA issued a first set of haze regulations in 1980. These regulations were largely aimed at addressing visibility impairment that was "reasonably attributable" to a single source or small group of sources. Visibility planning requirements applied only to states that had Class I areas; hence, in the Northeast and Mid-Atlantic regions, only to Maine, New Hampshire, New Jersey, and Vermont. States with Class I areas were required to submit implementation plans (SIPs) by September 2, 1981 that contained the following planning elements:

1. Revision of existing SIPs for NAAQS attainment to assure reasonable progress toward the national visibility goal of preventing any future, and remedying any existing, impairment of visibility caused by manmade pollution in mandatory Class I areas;

2. Determinations concerning which existing stationary facilities should be required to install best available retrofit technology (BART) to reduce their contribution to visibility impairment in Class I areas;

3. Development, adoption, implementation, and evaluation of long-term strategies (10-15 years) for making reasonable progress toward the national visibility goal;

4. Adoption of certain measures to assess potential visibility impacts due to new or modified major stationary sources, including measures to notify Federal Land Managers (FLMs) of proposed new source permit applications, and consideration of visibility analyses conducted by FLMs in new source permitting decisions; and

5. Implementation of visibility monitoring in Class I areas.

In addition, states with Class I areas were required to review and revise their long-term visibility strategies every three years.

C. Requirements Under the New Regional Haze Rule (1999-2064)

In 1999, almost 20 years after its original 1980 haze rule, USEPA issued a new set of regulations to address regional haze and visibility impairment in the nation's Class I areas [64 Fed. Reg. 35714 (July 1, 1999)]. At the time, USEPA stated that it had deferred release of the new rule in order to integrate further refinements in the scientific understanding of regional haze and to incorporate the results of several recent studies, including a 1993 National Research Council report (NRC, 1993) and the 1996 Grand Canyon Visibility Transport Commission report (GCVTC, 1996).

Unlike the 1980 regulations, the 1999 rule applies to all 50 states and the District of Columbia and is not limited to states containing mandatory Class I areas. The goal remains the restoration of pristine visibility conditions in Class I areas, though under the new rules this goal is given a specific target date of 2064. As has already been noted, the 1999 rule introduces a regional approach that accounts for the contribution of numerous emissions sources across a broad geographic area to visibility impairment and haze. The following subsections describe specific elements of the new regional haze rule. Requirements concerning SIP submittals and objectives are listed in 40 CFR sections 51.308(d) and 51.308(e). Provisions pertaining to the establishment of reasonable progress goals, baseline and natural visibility conditions; development of long-term visibility improvement strategies and monitoring strategies; and other SIP requirements may be found in Section 51.308(d). Section 51.308(e) outlines best available retrofit technology (BART) requirements.

Note that the synopsis provided in this chapter covers only the main elements of the new regional haze rule. States[52] may need to address other elements or planning requirements in addition to those mentioned here. This synopsis does not include several sections of the 1999 rule that specifically pertain to the Grand Canyon Visibility Transport Commission and do not apply to Northeast and Mid-Atlantic planning efforts.

[52]Here "states" refers to states as well as tribes who successfully petition to be treated as a state for the purposes of the regional haze rule under 40 CFR 49.

States will need to consult the complete text of the regional haze rule (which is reprinted in Appendix A of this report) for further detail and to ensure that they are complying with all applicable requirements.

C.1 Timeline for Regional Haze SIP Submittals

USEPA's 1999 regional haze rule links the timing of visibility SIP submissions to the designation of fine particulate ($PM_{2.5}$) nonattainment areas. These designations were due to be completed by 2004 to 2005 under USEPA's 1997 rule to establish a new National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$. As is discussed in Chapters VI and IX, the $PM_{2.5}$ NAAQS is currently under review by the Supreme Court. The outcome of this review may or may not affect the timing of eventual $PM_{2.5}$ attainment designations.[53] In any case, states that are working together in a regional planning effort to address haze are allowed additional time to develop and submit SIPs. (Note that a separate timeline option is available to the 16 Grand Canyon Visibility Transport Commission states in the western U.S; but this option does not apply to states in the East.)

Table VI-1 describes the SIP requirements and submittal deadlines specified in the 1999 regional haze rule. Clearly, the timing and outcome of a Supreme Court decision concerning the $PM_{2.5}$ NAAQS has the potential to affect these deadlines. Under the 1999 rule, states with areas that are in attainment or unclassifiable with respect to the $PM_{2.5}$ NAAQS will have one year after USEPA publishes their $PM_{2.5}$ designation to submit regional haze SIPs *unless* they commit to a multi-state regional planning process. States with areas designated non-attainment for $PM_{2.5}$ will be required to submit their haze SIPs at the same time as they submit $PM_{2.5}$ SIPs, generally 3 years after designation. For states participating in a multi-state regional planning process (which may include states with and without $PM_{2.5}$ non-attainment areas), haze SIPs will be due at the same time as the latest $PM_{2.5}$ SIP due date applicable to any state in the regional planning effort. Finally, states must notify USEPA of their commitment to a multi-state regional haze planning effort within one year after USEPA publishes a $PM_{2.5}$ designation for any area of the state (the requirements for such a commitment are outlined in 40 CFR §51.308(c)).

According to USEPA, the $PM_{2.5}$ designation process will begin after states collect three years of $PM_{2.5}$ monitoring data. This is expected to occur by December 31, 2001 for most areas, and no later than December 31, 2002 for the remaining areas. Allowing up to six months for quality assurance and certification of the data, USEPA has indicated that the data needed to make designations should be available between July 2002 and July 2003. The Transportation Equity Act for the 21st Century (TEA-21) statutorily requires states to submit designations to USEPA within one year of data availability; hence presumably between July 2003 and July 2004. However, USEPA also expects that some states may submit designations sooner, perhaps as early as late 2002 or early 2003. Early

[53] The Supreme Court is reviewing both EPA's proposed new NAAQS for fine particle matter and a recent EPA proposal to revise the existing ozone NAAQS. At the same time, EPA is engaged in a re-evaluation of the health impacts of fine particles, which may result in a new NAAQS proposal for $PM_{2.5}$.

designations would move up the deadlines for regional haze SIP submittals. USEPA is required to act within one year after receiving state designation submissions; assuming that most submissions occur between July 2003 and July 2004, USEPA's designations should be released between July 2004 and July 2005.

Table IV-1: Options for submitting regional haze SIPs.

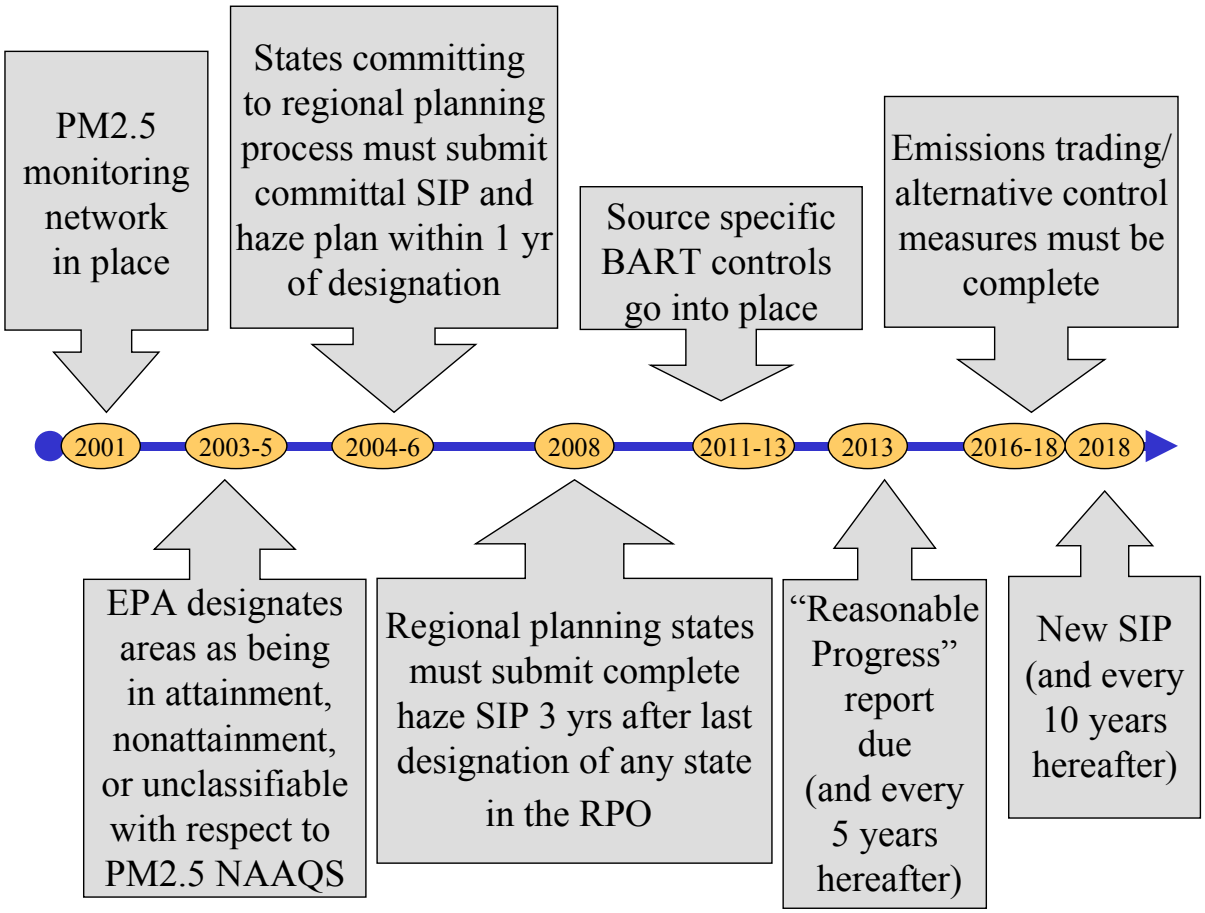
For the case…	**…states must submit the first regional haze SIPs no later than:**	**… and the SIP must meet:**
Areas designated as attainment or unclassifiable for $PM_{2.5}$.	One year after USEPA publishes the designation (generally 2004-2006).	All requirements of 40 CFR §51.308(d) and (e) (unless committing to multi-state regional planning effort).
Areas designated as nonattainment for $PM_{2.5}$.	At the same time as $PM_{2.5}$ SIPs are due under CAA §172 (3 years after publication of designation, generally 2006-2008).	All requirements of 40 CFR §51.308(d) and (e).
States participating in multi-state regional planning efforts for combined attainment and nonattainment areas.	Two phases: Phase I: Commitment to regional planning due one year after USEPA publishes the first designation for any area within the state, and…	The regional planning requirements listed in 40 CFR §51.308(c).
	Phase II: Complete implementation plan due at the same time as $PM_{2.5}$ SIPs are due under CAA §172 (3 years after designation publication).	The "core requirements" listed in 40 CFR §51.308(d) and BART requirements in 40 CFR §51.308(e).

Table adapted from 64 Fed. Reg. 35,714 (July 1, 1999), at 35,725.

Figure IV-3 summarizes the regional haze SIP planning timeline for states participating in regional planning activities.[54] States that opt not to participate in the regional process may have to submit haze SIPs between July 2005 and July 2006 (if they do not have $PM_{2.5}$ non-attainment areas). For most other states (i.e., those with $PM_{2.5}$ non-attainment areas *or* states participating in a multi-state regional planning process), haze SIPs should be submitted in the July 2007 to July 2008 timeframe, but in any case no later than December 31, 2008.

[54] This figure also assumes the timeline for monitoring data and $PM_{2.5}$ designations described above.

Figure IV-3: Regional haze SIP timeline for states participating in regional planning activities.



C.2 Options for Regional Planning

States that opt to participate in a multi-state regional planning effort must submit a "committal SIP" to USEPA by the earliest date a regional haze SIP would otherwise have been due for any area in the state. For states with $PM_{2.5}$ attainment and unclassifiable areas, this commitment would be due in the 2004-2006 timeframe (one year after USEPA publishes the $PM_{2.5}$ designation). The requirements for a committal SIP are outlined in 40 CFR §51.308(c) and include the following:

1. A demonstration by the state of current participation in a regional planning process, and an agreement to continue participating with other states in the development and future revisions of the state's regional haze SIP.
2. A showing that emissions within the state contribute to visibility impairment in a Class I area outside the state, or that emissions from outside the state contribute to visibility impairment in a Class I area within the state. The state may make its showing using available inventory, monitoring, or modeling information.

3. A description of the regional planning process, including a description of participating states, goals, objectives, management, and the decision-making structure of the planning group, deadlines for completing significant technical analyses and developing emission management strategies, and a schedule for state review and adoption of regulations implementing the regional group recommendations.
4. A commitment by the state to submit a regional haze SIP containing the core requirements of 40 CFR §51.308(d) and §51.308(e) by the latest date an area within the planning region would be required to submit a regional haze SIP, but no later than December 31, 2008. The state must also commit to coordinate future plan revisions with other states in the regional planning effort, and to fully address the recommendations of the regional planning group.
5. A list of all BART-eligible sources within the state.

C.3 Core Requirements of Regional Haze SIPs

Whether a state develops a regional haze SIP on its own, or participates in a multi-state regional planning effort, all states must submit a SIP that meets the core requirements of 40 CFR §51.308(d) and the BART requirements of 40 CFR §51.308(e). These requirements include:

1. For each Class I area within the state, the state must establish *reasonable progress goals* (expressed in deciviews) for improving the most impaired days. The state must also establish SIP requirements that ensure no degradation on the least impaired days. As a starting point for determining the reasonable progress goals, USEPA has established the presumption that such goals should return visibility to natural conditions by 2064. The goal set for interim periods could be greater or less than this presumptive rate based on costs of compliance, time necessary for compliance, energy and non-air quality impacts of compliance, and the remaining useful life of potentially affected sources. If the reasonable progress goals do not achieve a rate of improvement consistent with attaining natural visibility conditions by 2064, then the state must demonstrate its chosen rate of improvement is reasonable to USEPA.

2. In determining reasonable progress goals, the state must calculate baseline and natural visibility conditions for each Class I area. Baseline conditions are the 20 percent most impaired and 20 percent least impaired days (expressed in deciviews) in a calendar year based on available monitoring data collected from 2000 to 2004.

3. Using the above calculations, the state must determine the uniform rate of improvement (in deciviews) that would need to be maintained during each implementation period to go from baseline conditions to natural conditions by 2064. States must consider this rate of progress in setting their reasonable progress goals. This uniform rate of progress goal may be adjusted downward (allowing for slower progress), if compliance cost and other aforementioned factors dictate.

4. All states must submit a *long-term strategy* for regional haze for each Class I area within the state (if any) and for each Class I area outside the state that may be affected by air pollution sources within the state.

5. The state must submit a *monitoring strategy* for measuring, characterizing, and reporting visibility impairment in all Class I areas within the state. States without a Class I area must submit procedures for using monitoring data and other information to evaluate their contribution to visibility impairment at Class I areas in other states.

6. Each state must submit a *statewide emissions inventory* for pollutants reasonably anticipated to cause or contribute to visibility impairment in any Class I area.

Each of these core requirements contains an additional subset of elements listed in 40 CFR §51.308(d) that states will need to review and address when developing their regional haze SIPs.

C.4 Best Available Retrofit Technology (BART) Requirements

As part of their regional haze SIP submittals, each state must submit a list of all BART-eligible sources within its boundaries and an inventory of the haze-related pollutant emissions from these sources. BART-eligibility is defined under 40 CFR §51.301(hh) and is limited to "existing stationary sources" that went into operation on or between August 7, 1962 and August 7, 1977 that have the potential to emit 250 tons or more of any pollutant that may cause visibility impairment in a Class I area. The 26 specific types of sources to which BART requirements may apply are listed below:

(1) Fossil-fuel fired steam electric plants of more than 250 million Btu/hour heat input
(2) Coal cleaning plants (thermal dryers)
(3) Kraft pulp mills
(4) Portland cement plants
(5) Primary zinc smelters
(6) Iron and steel mill plants
(7) Primary aluminum ore reduction plants
(8) Primary copper smelters
(9) Municipal incinerators capable of charging more than 250 tons of refuse per day
(10) Hydrofluoric, sulfuric, and nitric acid plants
(11) Petroleum refineries
(12) Lime plants
(13) Phosphate rock processing plants
(14) Coke oven batteries
(15) Sulfur recovery plants
(16) Carbon black plants (furnace process)
(17) Primary lead smelters
(18) Fuel conversion plants
(19) Sintering plants
(20) Secondary metal production facilities

(21) Chemical process plants
(22) Fossil-fuel boilers of more than 250 million Btu/hour heat input
(23) Petroleum storage and transfer facilities with a capacity exceeding 300,000 barrels
(24) Taconite ore processing facilities
(25) Glass fiber processing plants
(26) Charcoal production facilities

Each state SIP must include the emissions limits and compliance schedule to be applied to each BART-eligible source that is found to cause or contribute to visibility impairment in any Class I area. Detailed BART requirements and an enumeration of the two supporting analyses that are required as part of the BART determination are provided under 40 CFR §51.308(e)(1). These additional analyses include: (1) a technical analysis to determine the best system of continuous emission control technology available and associated emission reductions achievable for each BART-eligible source and (2) an impact analysis to assess the degree of visibility improvement at affected Class I areas expected to result from BART reductions. In the technology analysis, the state must consider available control options, the costs of compliance, the energy and non-air quality environmental impacts of compliance, any pollution control equipment in use at the source, and the remaining useful life of the source. Reductions from BART measures must be installed and operated as expeditiously as practicable but in no event later than five years after approval of the SIP.

In addition, states have the option of pursuing an emissions trading program or alternative measure if it can be demonstrated that this will result in greater reasonable progress than a source-by-source application of BART requirements. Section 51.308(e)(2) outlines the elements of such a demonstration. Finally, any BART-eligible source has the option of applying to USEPA for an exemption from BART requirements subject to the provisions of 40 CFR §51.303(a)(2)-(h).

USEPA is currently preparing additional BART guidance to be added to 40CFR§51 as Appendix Y. The guidance should be available early in 2001[55] and is intended to clarify BART requirements. It will cover applicability, engineering analysis, cumulative air quality analysis and trading alternatives; in addition it will update the "reasonably attributable" BART guidance issued in 1980. More specifically, the guidance is expected to outline a potential trading program with emphasis on timelines and budgets; but is not expected to address allocation, allowance tracking, or details of program structure. At this point it is anticipated that USEPA will allow trading of haze related emissions reductions across source sectors but not across pollutant species.

[55] On September 22, 2000 the guidance report arrived at the White House Office of Management and Budget for evaluation of the economic impact BART regulations will have on industry. After OMB approval, the BART guidance will be published in the Federal Register. This will coincide with the public comment period (Air Daily, volume 7, no. 185, 9/27/00).

C.5 Requirements for Comprehensive Periodic SIP Revisions

Each state must revise and submit an updated regional haze SIP to USEPA by July 31, 2018 and every ten years thereafter. These periodic SIP revisions must reassess each of the core requirements described above in light of new monitoring data, haze analyses, and any other relevant information. They must also provide updated information on visibility conditions for the most impaired and least impaired days and report on progress toward achieving natural background conditions. This update must be based on the most recent five-year period for which data are available prior to the revision submittal date. Finally, SIP revisions must evaluate the effectiveness of the state's long-term strategy for achieving reasonable progress goals and affirm or revise these goals in light of available information from the prior implementation period(s).

C.6 Periodic Reporting on Achievement of Reasonable Progress Goals

The 1999 rule requires states to submit periodic reports every five years after submitting an initial regional haze SIP. The periodic reports are intended to evaluate progress towards meeting reasonable progress goals for any Class I areas affected by air pollution sources within the state. Progress reports must be in the form of implementation plan revisions and must comply with procedural requirements set forth in sections 51.102 and 51.103. The regional haze rule lists a minimum set of elements in 40 CFR §51.308(g) that must be addressed in the periodic reports.

C.7 Adequacy Determination for Existing Implementation Plans

When states submit periodic reports under 40 CFR §51.308(g), they must also take one of several actions listed in 40 CFR §51.308(h) based on the information contained in these reports. The action options are:

1. A negative declaration that the state's regional haze plan needs no further substantive revision.
2. Notice to USEPA that the state's regional haze plan is or may be inadequate due to emissions from sources in another state(s). This action will re-initiate regional planning efforts. The notifying state must then work with the other state(s) to develop additional strategies.
3. Notice to USEPA that the state's regional haze plan is or may be inadequate due to emissions from sources in another country.
4. A determination by the state that its SIP is or may be inadequate due to emissions from sources within the state. The state would then be required to revise its SIP to address these deficiencies within one year.

C.8 Coordination Between States and Federal Land Managers

There are four requirements in the regional haze rule pertaining to coordination between states and Federal Land Managers (FLMs) on regional haze planning.

1. By November 29, 1999, states must notify FLMs in writing of the name of the state official to whom FLMs may submit any recommendations concerning visibility impairment, related monitoring strategy, and other implementation issues for Class I areas.
2. States must give FLMs the opportunity to consult with state authorities in person at least 60 days prior to any public hearing on regional haze SIPs or revisions thereto. This consultation must include an opportunity for FLMs to discuss assessments of visibility impairment in Class I areas and to make recommendations on reasonable progress goals as well as on strategy implementation.
3. In developing or revising implementation plans, states must describe how they have addressed any comments or recommendations from FLMs.
4. State SIPs and SIP revisions must provide for ongoing consultation with FLMs, including consultation on the development and review of plan revisions, 5-year progress reports, and any other programs with the potential to affect visibility conditions in Class I areas.

References

GCVTC, *Recommendations for Improving Western Vistas, Report to the U.S. EPA*, Grand Canyon Visibility Transport Commission, 10 June 1996.

NRC, *Protecting Visibility in National Parks and Wilderness Areas,* National Research Council Committee on Haze in National Parks and Wilderness Areas. National Academy Press, Washington, DC: 1993.

V. Building a Regional Haze Plan

As discussed in the previous chapter, USEPA's 1999 regional haze rule will require states and interested tribes to develop implementation plans for reducing haze and improving visibility at Class I sites. In response to these requirements, Northeast and Mid-Atlantic states and tribes will need to define visibility goals, establish measures of reasonable progress, and identify the relative contribution of different pollutant sources. This chapter covers a number of analytical elements and technical considerations that will be important in this effort. The first section begins by providing more detail on the calculation of light extinction generally (a topic that was introduced in Chapter II). It then discusses the estimation of "natural, background" visibility conditions and the methodology used to quantify existing visibility impairment from available monitoring data. The next section summarizes recent visibility trends at Class I sites in the Northeast and Mid-Atlantic regions. A discussion of the atmospheric chemistry involved in particle formation is deferred until the end of the chapter. Here we present basic information regarding the chemical mechanisms involved with the formation of atmospheric aerosols and additional considerations which may affect how control strategies are devised. These include: (1) the hygroscopic nature of sulfates and nitrates, (2) the interaction of ammonium with sulfates and nitrates and (3) the influence of biogenic hydrocarbons.

A. Characterizing "Natural Background" and Current Visibility Conditions

A.1 Calculating Light Extinction

As noted in Chapter II, total light extinction is a function of the individual light absorption and light scattering properties of particles present in the atmosphere. This total is frequently expressed as a light extinction coefficient (b_{ext}) in units of inverse length (such as Mm^{-1}). In simple terms, the light extinction coefficient is a measure of the proportion of light extinguished per unit of distance traveled through the atmosphere. B_{ext} can be empirically determined or "reconstructed" simply by summing the scattering and absorption coefficients of the relevant particle constituents, as indicated by the following equation (note that the equation includes Rayleigh scattering, b_{Ray}):[56,57]

$$b_{ext} = b_{SO4} + b_{NO3} + b_{OrgC} + b_{Soil} + b_{Coarse} + b_{ElemC} + b_{Ray}$$

The calculation of extinction coefficients for each individual chemical species is described by the following equations (FLAG, 1999):

[56] As noted in Chapter II, absorption by nitrogen dioxide gas is not generally significant on a regional scale, though it can play a role in coherent pollution plumes (FLAG, 1999). Hence the discussion in this chapter considers elemental carbon as the only contributor to atmospheric light absorption.

[57] Particles in the atmosphere may exist as an internal mixture of several chemical species. IMPROVE assumes that the contribution of each particle constituent can be determined separately and summed to determine total light extinction.

$b_{SO4} = 3[(NH_4)_2SO_4]f(RH)$[58]
$b_{NO3} = 3[NH_4NO_3]f(RH)$
$b_{OrgC} = 4[OrgC]$
$b_{Soil} = 1[Soil]$
$b_{Coarse} = 0.6[Coarse]$
$b_{ElemC} = 10[ElemC]$.

The bracketed quantities represent ambient air concentrations expressed in micrograms per cubic meter ($\mu g/m^3$). The numeric coefficients represent "dry" scattering efficiencies[59] (m^2/g), while the relative humidity adjustment factor f(RH) accounts for the hygroscopic properties of sulfate and nitrate (i.e. their tendency to absorb water in the atmosphere). As relative humidity increases this factor becomes larger, which in turn produces a higher coefficient of light extinction for the hygroscopic particles. Provided concentrations and humidity levels are known, the light extinction coefficients for individual particle constituents can be straightforwardly calculated and summed to estimate the overall light extinction coefficient, b_{ext}.

It should be noted that a number of uncertainties are embedded in these calculations; hence reconstructions of light extinction may not be precise. For example, the equations reflect simplified assumptions about the role of relative humidity and may not adequately account for the non-linear relationship between humidity and particle growth rate. Moreover, the values used for relative humidity generally represent an average over a large geographic range and long periods of time. Ideally, relative humidity should be recorded and stored with each concentration measurement so that an appropriate factor can be calculated for each observation. Second, different humidity adjustment factors should be used for the sulfate and nitrate fraction of aerosol particles given differences in the rate at which particle size grows for these two constituents with increasing relative humidity. Third, the above equations assume that organic carbons are non-hygroscopic and do not require a relative humidity adjustment. In many instances little information is available about the specific constituents of secondary organic aerosol particles and of their potential affinity for water. Whether or not a relative humidity adjustment factor should be applied to the organic fraction is therefore an issue of current debate (Saxena et al., 1995). The sensitivity of reconstructed light extinction to each of these assumptions is an area that warrants further investigation.

Reconstructed light extinction compares fairly well with light scattering as measured by transmissometers and nephelometers; however, the level of agreement is dependant on how relative humidity is treated in the calculation (Malm, 2000b). Choice of humidity adjustment factors and decisions about how to average relative humidity, both spatially and temporally, will therefore have a significant impact on the accuracy of

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[58] IMPROVE assumes that all sulfate is in the form ammonium sulfate ($(NH_4)_2SO_4$) and that all nitrate is in the form ammonium nitrate (NH_4NO_3). Other forms of these species exist in nature as detailed in Section D of this chapter. These differing forms may have different scattering efficiencies and relative humidity adjustment factors.

[59] Dry scattering efficiencies were determined for 550 nm (0.55 μm) light (green light). There may be discrepancies between this value and those determined by integrating over the entire visible spectrum (400-700 nm).

reconstructed light extinction and on the relative contribution assigned to different particle constituents. USEPA is currently planning to develop guidance on these issues by 2001.

Applying current methods to the pollutant concentrations measured by the IMPROVE monitoring program over the last ten years yields average reconstructed light extinction ranging from very low levels (i.e., near natural conditions) to greater than 150 Mm^{-1}. Reconstructed values in the Northeast and Mid-Atlantic range from 70 Mm^{-1} to over 90 Mm^{-1} (Fox et al., 1999).

As noted in Chapter II, light extinction is often expressed in terms of visual range, a unit of measurement that is generally more accessible to the general public and to policymakers. Visual range is inversely proportional to light extinction and can be readily derived from total light extinction using the Koschmeider equation:

$$\text{Visual Range (km)} = 3.912/b_{ext}(km^{-1}) = 3912/b_{ext}(Mm^{-1})$$

The deciview (dv) measure that is frequently used to measure perceptible changes in visibility has a similarly direct, mathematical relationship to light extinction. Specifically, it is proportional to the natural log (ln) of light extinction (in Mm^{-1}) divided by 10 Mm^{-1}:

$$dv = 10 \cdot \ln(b_{ext}/10\ Mm^{-1})$$

The form of the deciview equation essentially sets dv = 0 for Rayleigh conditions (no particles) at an altitude of about 1800 meters ($b_{Ray} = 10\ Mm^{-1}$). Increases in deciviews above this zero threshold thus provide a measure of perceived haziness relative to a particle-free atmosphere at 1800 meters of altitude (Pitchford and Malm, 1994).

Federal haze regulations require states to express baseline conditions and reasonable progress goals in terms of deciviews (40 CFR §51.308). To derive these values, states must use atmospheric light extinction coefficients calculated from aerosol measurements (40 CFR §51.301(bb)). Therefore, states will need to calculate reconstructed particle extinction coefficients and total light extinction using available particle monitoring data and appropriate relative humidity factors. Current regulations do not allow states to use visual range records from airports or other sources to derive light extinction coefficients for purposes of developing regional haze implementation plans. However, these sources may be useful in corroborating visibility trends analyses.

A.2 Estimating "Natural Background" Reference Conditions

Estimating "natural background" reference conditions is an important aspect of compliance with the new regional haze rule since a return to these conditions is the ultimate aim of the rule.

There are only two significant components to light extinction under natural conditions: Rayleigh scattering and scattering by naturally present aerosols. The Federal Land Managers' Air Quality Related Values Workgroup (FLAG) uses a Rayleigh

scattering value of 10 Mm^{-1} for the entire U.S. (FLAG, 1999). This value corresponds to Rayleigh conditions at about 1800 m in altitude (Sisler and Malm, 2000). However, Rayleigh scattering varies with altitude and at sea level is estimated to be about 12 Mm^{-1} (Trijonis et al., 1990). To avoid understating "natural" background visibility impairment at coastal sites (which could result in setting unrealistic goals for haze reduction efforts), the analysis conducted for this report assumes a Rayleigh coefficient of 12 Mm^{-1} for the Acadia, Brigantine, Moosehorn, and Roosevelt Campobello sites. This assumption reduces calculated background extinction levels by 2 Mm^{-1} but leads to a change of only 0.3 dv in estimated natural background conditions on the deciview scale.[60]

For natural aerosol particle concentrations, this report utilizes annual average values from the 1990 NAPAP visibility report, which FLAG also uses. These values come from three information sources (Trijonis et al., 1990):

1. compilations of natural versus anthropogenic emissions,
2. ambient measurements in remote areas (especially in the southern hemisphere), and
3. regression analyses using anthropogenic and/or natural tracers

Table V-1 lists the assumed "natural" concentrations of six major types of light attenuating particles in the eastern United States.

Table V-1: Assumed natural aerosol particle concentrations in the eastern U.S. (Trijonis et al., 1990).

Particulate Aerosol Component	Annual average concentration, Eastern U.S. ($\mu g/m^3$)
Sulfates (as ammonium sulfate)	0.2
Ammonium nitrate	0.1
Organic Carbon	1.5
Elemental Carbon	0.02
Soil Dust	0.5
Coarse	3.0

A caveat applies to the natural ambient aerosol particle concentrations assumed for some Class I areas in the Northeast and Mid-Atlantic. Because these values do not include marine aerosols they may understate natural aerosol particle levels at coastal sites (i.e., at Acadia, Brigantine, Moosehorn, and Roosevelt Campobello). Further investigation of this issue is needed. However, it should also be noted that because marine aerosol particles tend to be larger in size, they are less efficient than other

[60] Due to the logarithmic relationship between deciviews and light extinction.

particles at scattering visible light.[61] Hence, a substantially larger concentration of marine aerosol particles would be necessary to achieve the same level of visibility impairment as secondary fine particles. In the absence of site-specific information, this report uses the values in Table V-1 as surrogates until better estimates for the marine aerosol contribution become available.

Most areas experience significant variability in natural ambient aerosol particle concentrations. This is due to variation in natural emissions of particulate forming species as well as to variations in meteorology and relative humidity. Comparing observed 20 percent best and worst days under current, actual conditions to a single estimate of "natural" conditions based on annual average concentrations and humidity values may result in inaccurate estimates of needed reductions. In some areas, it may be necessary to develop estimates of both 20 percent best and 20 percent worst natural background conditions for comparison with baseline conditions. USEPA is currently working to develop guidance on estimating natural background haze conditions and is expected to release its recommendations in 2001.

To calculate coefficients of natural background light extinction in the Northeast and Mid-Atlantic, the concentrations shown in Table V-1 were combined with average annual relative humidity factors from the 1999 FLAG draft report and subjected to the calculations described in Section A.1 above. Table V-2 gives the resulting Rayleigh coefficients, relative humidity factors, and calculated natural background visibility levels for each Northeast and Mid-Atlantic Class I area.

Table V-2: Estimated natural background visibility conditions at Northeast and Mid-Atlantic Class I areas.

Site	b_{Ray} (Mm^{-1})	F(RH)	Particle extinction (Mm^{-1})	Total extinction (Mm^{-1})	Deciviews
Acadia	12	3.8	11.92	23.92	8.7
Brigantine	12	3.9	12.01	24.01	8.8
Great Gulf	10	3.9	12.01	22.01	7.9
Lye Brook	10	3.8	11.92	21.92	7.8
Moosehorn	12	3.9	12.01	24.01	8.8
Presidential Range-Dry River	10	3.9	12.01	22.01	7.9
Roosevelt Campobello	12	3.9	12.01	24.01	8.8

[61] Specifically, marine aerosol dry scattering efficiencies are 0.4 m^2/g versus 3-5 m^2/g for sulfate (Seinfeld and Pandis, 1998).

A.3 Estimating Visibility Impairment from Available Fine Particle Monitoring Data

USEPA's 1999 regional haze rule requires states to establish baseline conditions for Class I areas as part of the visibility planning process. These baseline conditions are defined as the average of visibility impairment on the 20 percent most impaired and 20 percent least impaired days (expressed in deciviews) in a calendar year (40 CFR §§51.301(dd), 51.301(ee)). The rule further requires that states determine baseline conditions using five years of monitoring data collected from 2000 to 2004 (40 CFR §51.308).

As indicated in Chapter III,[62] IMPROVE monitoring data are available for several northeastern and mid-Atlantic Class I sites, including Acadia National Park and the Moosehorn Wilderness Area in Maine; the Brigantine Wilderness Area in New Jersey; the Great Gulf Wilderness Area in New Hampshire; and the Lye Brook Wilderness Area in Vermont. There are no historical IMPROVE data for the Presidential Range – Dry River Wilderness Area in New Hampshire and the Roosevelt Campobello International Park in Maine, but the Great Gulf and Moosehorn sites, respectively, provide representative conditions for these Class I areas due to their close proximity.

The IMPROVE web site provides speciated data for all sampling days at IMPROVE monitors.[63] Total particle light extinction can be calculated using this information and the methodology discussed in previous sections of this chapter. Table V-3 lists the particle species for which IMPROVE provides data and the formulae and assumptions used to calculate their atmospheric concentrations. Ambient concentrations are in turn used to calculate reconstructed particle light extinction coefficients.

[62] A more detailed discussion of visibility and particle monitoring programs may be found in Chapter VIII.

[63] Archival IMPROVE data are available via an ftp link located at the web address http://alta_vista.cira.colostate.edu/. The website is part of a cooperative program on visibility in Class I areas between the National Park Service Air Resources Division and the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University in Ft. Collins.

Table V-3: Formulae and assumptions used with IMPROVE sampling measurements to derive reconstructed particle light extinction (adapted from Sisler and Malm, 2000).

Species	Formula	Assumptions
SULFATE	4.125[S]	All elemental S is from sulfate. All sulfate is from ammonium sulfate.
NITRATE	1.29[NO3]	Denuder efficiency is close to 100%. All nitrate is from ammonium nitrate.
LAC (Light absorbing carbon)	[EC1] + [EC2] + [EC3] – [OP]	All high temperature carbon is elemental.
OMC (Organic mass from carbon)	1.4{[OC1] + [OC2] + [OC3] + [OC4] + [OP]}	Average organic molecule is 71% carbon.
SOIL (Fine Soil)	2.2[AL] + 2.49[SI] + 1.63[CA] + 2.42[FE] + 1.94[TI]	[Soil K] = 0.6[Fe]. FeO and Fe_2O are equally abundant. A factor of 1.16 is used for MgO, Na_2O, H_2O, CO_2.
RCFM (Reconstructed fine mass)	[SULFATE] + [NITRATE] + [LAC] + [OMC] + [SOIL]	Represents dry ambient fine aerosol mass for continental sites.
CM (Coarse Mass)	[MT] – [MF]	Consists only of insoluble soil particles.

The bracketed symbols in the second column of Table V-3 correspond to species concentrations and to the labeling conventions used in the IMPROVE database. The labeling convention is:

[S]	= Elemental sulfur
[NO3]	= Nitrate
[EC#]	= Detailed elemental carbon species measured by thermal optical reflectance (TOR) with three bins (# = 1,2,3)
[OC#] & [OP]	= Detailed TOR organic species with bins (# = 1,2,3,4)
[AL]	= Aluminum
[SI]	= Silicon
[CA]	= Calcium
[FE]	= Iron
[TI]	= Titanium
[MT]	= Total mass (PM_{10})
[MF]	= Fine mass ($PM_{2.5}$)

Because the IMPROVE database reports concentrations in units of nanograms per cubic meter, the data must be divided by 1000 to convert to units of micrograms per cubic meter ($\mu g/m^3$). The IMPROVE guide to interpreting data, which details IMPROVE sampling techniques and data analysis, is included with this report as Appendix B.

Summaries of the sampling data for each IMPROVE site are tabulated in Appendix C of this report. The data are grouped into the 20 percent least impaired (Group 10), the 40-60 percent mid-range (Group 50), and the 20 percent most impaired (Group 90) visibility days aggregated by particle mass and light extinction for each IMPROVE monitor.[64] A minor discrepancy between the IMPROVE monitoring program and new regional haze rules is that the former sorts data according to a "sample year" which runs from March to February, whereas the federal rule specifies the use of data from a calendar year (January – December) to determine baseline conditions.

The methodologies used to sort and average IMPROVE data also deserve some mention. For example, the data can be sorted by total measured (gravimetric) fine particle mass or by reconstructed fine particle mass, the latter being simply the sum of measured mass for individual particle species (ammonium sulfate, ammonium nitrate, organic carbon, elemental carbon, and fine soil). The two methods can yield different results because mass measurements for certain species are occasionally missing. Hence, sorting by reconstructed fine mass excludes sample days when speciated values are missing, whereas sorting by gravimetric mass includes all sample days. Malm has noted that this can lead to significantly different results, particularly for small data sets (Malm, 2000b).

Table V-4 provides an example, taken from Malm (2000b), of how this can happen. The table presents five entries corresponding to the five highest gravimetric fine mass (FM) samples in a hypothetical data set. Three of the entries have missing values for some of the speciated components, so the reconstructed fine mass cannot be calculated for these observations. Summing the average mass of each species and including all samples yields a reconstructed fine mass average of 11.61 $\mu g/m^3$. Relative to this total, the average organic carbon fraction is 22 percent (2.5 /11.61). If, however, samples 2,3, and 5 are excluded because of missing data for certain constituent species, the average reconstructed fine mass totals 10.75 $\mu g/m^3$. Based on samples 1 and 4 only, the average organic carbon fraction would appear to be just 14 percent (1.5/10.75). Currently, there is no preferred or standard approach to dealing with missing data components and researchers continue to investigate the implications of different approaches. The guidance currently being prepared by USEPA on how to track "reasonable progress" is expected to address this issue (as noted previously, this guidance is expected to be released in 2001).

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[64] It should be noted that the appendix lists the 10th and 90th percentile values as a surrogate for the average of the upper and lower 20 percentiles of the complete distribution of data. These will not necessarily be equal.

Table V-4: Hypothetical example of 20 percent highest fine particle observations with missing speciated values.

Observations	FM	Sulfate	Nitrate	Organics	Light-Absorbing Carbon	Soil	RCFM
1	10	6	1	1	1	2	11
2	13	4	---	6	0.8	1	---
3	10	7	1.1	---	---	1	---
4	10	5	0.8	2	0.7	2	10.5
5	12	8	---	1	0.5	1	---
AVERAGE	11	6	0.96	2.5	0.75	1.4	10.75 (11.61)

This example is taken from Malm, 2000b. FM = gravimetric fine particle mass. RCFM = reconstructed particle fine mass. As shown in the table, excluding observations with missing values leads to an average RCFM of 10.75. Using the ensemble average of each species, and keeping observations with missing values, sums to an ensemble average RCFM of 11.61.

The tables presented in Appendix C sort IMPROVE data according to gravimetric fine particle mass, thus they do not exclude days with missing data for specific particle species. For purposes of this report, however, the IMPROVE data were regrouped by calendar year (January – December) and sorted on the basis of reconstructed light extinction. Because light extinction could not be reconstructed for days with missing speciated values, this approach excluded some samples. A further difference results from the fact that, as noted in Chapter III, different particle species are more or less efficient at scattering light. Thus visibility may be less impaired on a day when fine particle mass concentrations are high due to an atypically large soil component than on a day when the particle mass is made up of a higher proportion of sulfates and nitrates. In short, a grouping of the 20 percent days with highest or lowest light extinction values may not correspond exactly to a grouping of days according to undifferentiated particle mass concentrations.

The results obtained by re-sorting the IMPROVE data, in terms of the relative contribution by different particle species to total fine particle mass concentration and total light extinction, are presented in Chapter III (see Figures III-3a/b and III-4a/b). A comparison of these results to those tabulated in Appendix C suggests that either methodology produces broadly consistent findings. Nor does the exclusion of some sampling days appear to significantly alter the relative contributions attributed to different particle species. This result is perhaps not surprising given the relatively large sample size involved. About 100 samples per year are collected at the IMPROVE sites of which generally a dozen or fewer are excluded because of missing values for particular particle constituents.

Though it may not matter greatly which methodology is chosen to sort and analyze fine particle monitoring data, it probably *will be* important to apply that methodology consistently over time, especially since changes in visibility are likely to occur in relatively small increments over the near term. Measures of progress, in other words, may be considerably more sensitive to confounding by methodological

inconsistencies than measures of absolute particle concentration or visibility impairment at any given point in time.

B. Recent Visibility Trends in the Northeast and Mid-Atlantic

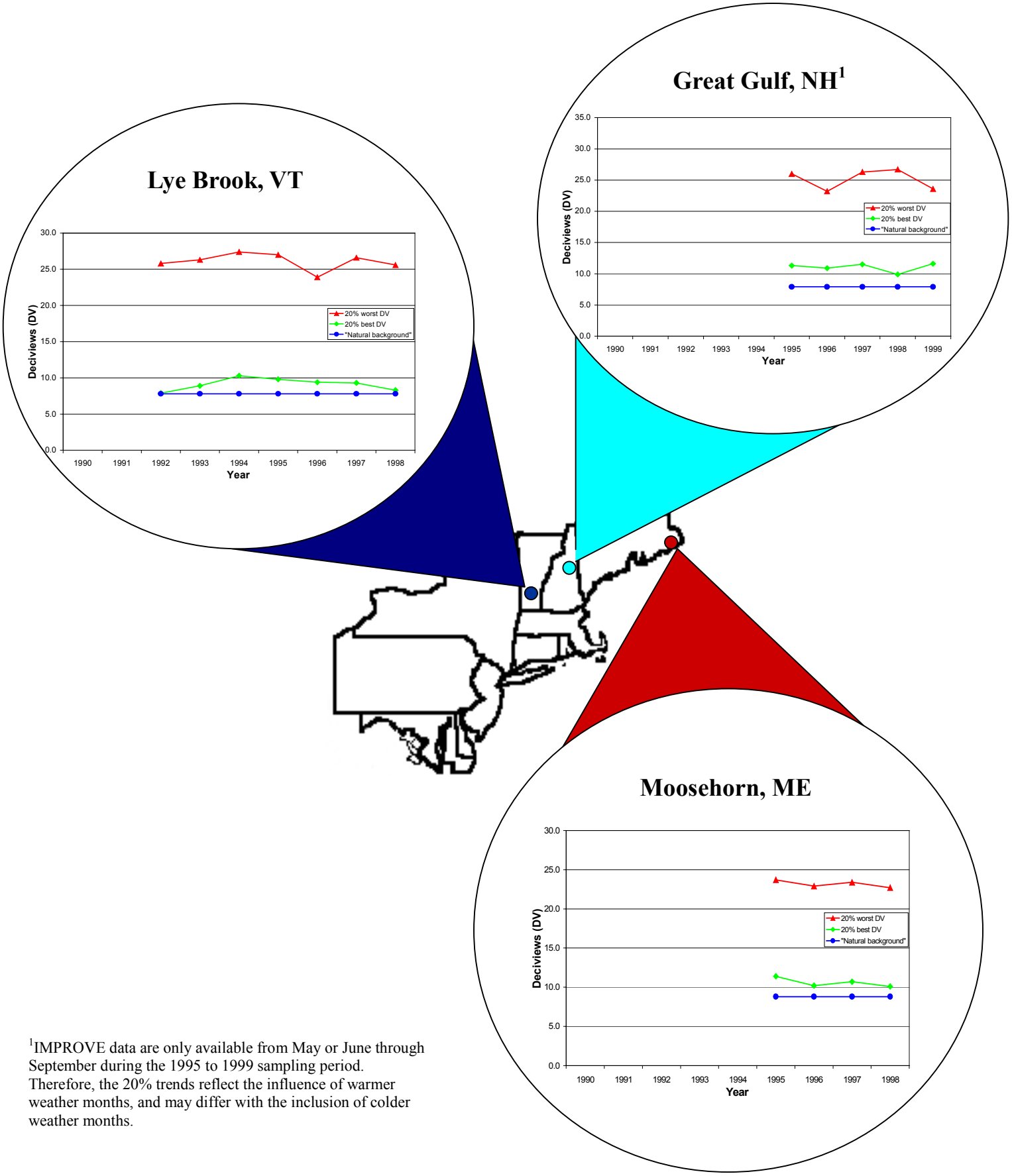
Figure V-1 presents recent visibility trends (in annual average deciviews) at northeastern and mid-Atlantic IMPROVE sites for the 20 percent most and least visibility impaired days. The graphs also show reconstructed "natural background" levels at each site, as estimated in Table V-2, to indicate the magnitude of the gap that will need to be closed, especially in terms of the 20 percent haziest days, to attain national visibility goals. These trends are presented only as qualitative indicators of baseline conditions. Under the new regional haze rule, states will need to determine baseline conditions based on monitoring data from 2000 to 2004 and choose their preferred method for sorting and analyzing the 20 percent most and least impaired days.

The trend plots suggest that the 20 percent least impaired days at Class I areas in the upper Northeast are near natural background levels. As was previously noted in Chapter III, this is not the case for the more southern Brigantine site, perhaps due to the closer proximity of this site to urban and industrial areas. In addition, it is possible that marine aerosols play a greater role than assumed in these estimates, in which case natural background visibility impairment could be slightly understated at Brigantine (this bias could also affect natural background conditions at other northeastern sites, such as Acadia and Moosehorn). If so, the actual gap between current visibility impairment and natural background conditions would be somewhat narrower (though probably not substantially so) than it appears in these plots.

As of 1999, there were no complete years of sampling data for the Great Gulf site, so the trends at this site pertain only to the subset of summer months from May or June through September. Since the haziest days typically occur in the warm months, average deciview values for the 20 percent most impaired summertime days may be higher than for the year as a whole. A comparison of the Great Gulf values to those found at the nearby Lye Brook site (for which complete data are available) suggests that the difference, if any, is not large.

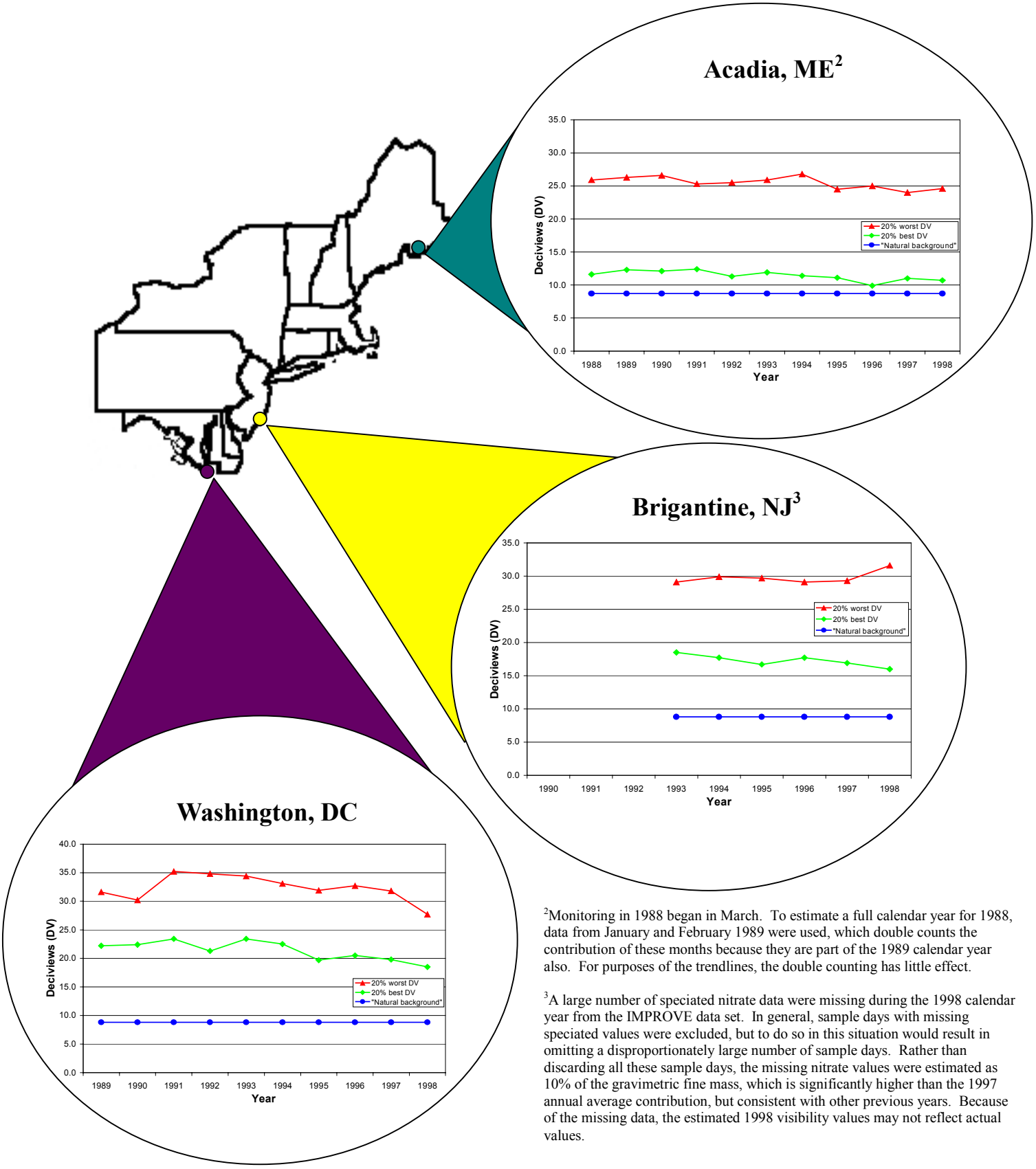
Due to the short time length for most of the trend plots, it is difficult to draw definitive conclusions about recent visibility trends in the Northeast and Mid-Atlantic. The Acadia and Washington, DC sites have the longest data records and both seem to show some level of visibility improvement in the 20 percent most impaired and least impaired days. The apparent improvement at Acadia, however, is very modest. Sisler and Malm have indeed found a negative slope in deciview values (indicating improved visibility) at these sites through 1996, but the decline was statistically significant only for the 20 percent least impaired days at Acadia (Sisler and Malm, 2000). More recently Malm found a statistically significant visibility improvement trend at Acadia for the 20 percent most impaired days using IMPROVE data through 1998 (Malm, 2000b).

Figure V-1: Visibility Trends in the Northeast and Mid-Atlantic



[1]IMPROVE data are only available from May or June through September during the 1995 to 1999 sampling period. Therefore, the 20% trends reflect the influence of warmer weather months, and may differ with the inclusion of colder weather months.

Figure V-1: Visibility Trends in the Northeast and Mid-Atlantic, continued.

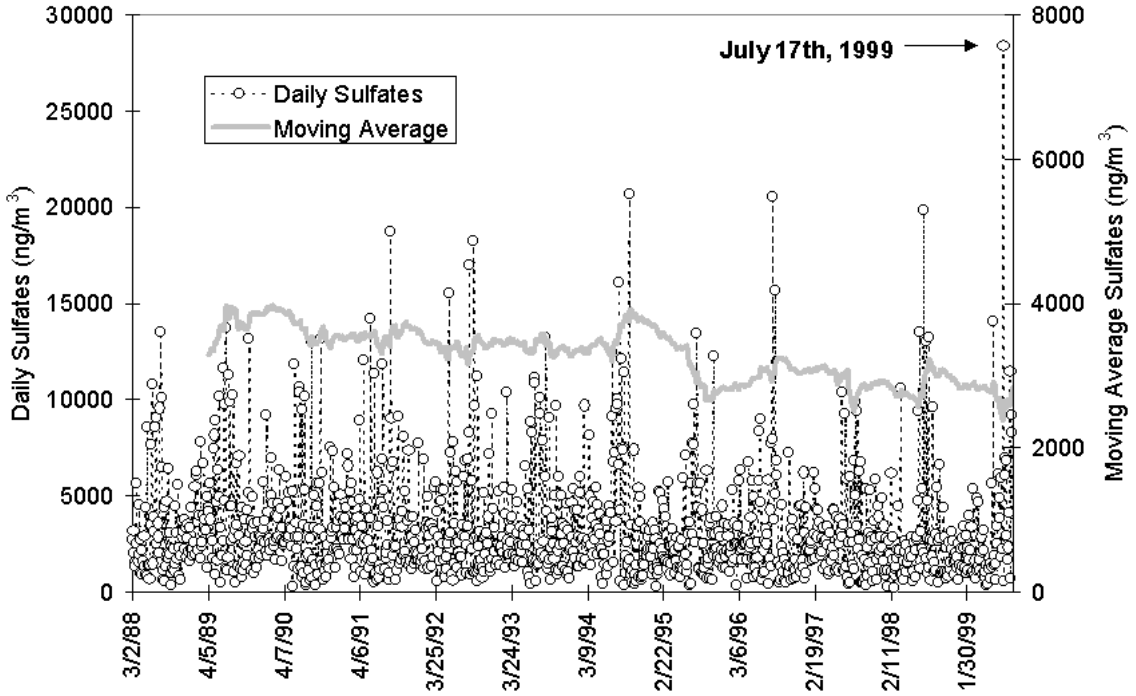


[2]Monitoring in 1988 began in March. To estimate a full calendar year for 1988, data from January and February 1989 were used, which double counts the contribution of these months because they are part of the 1989 calendar year also. For purposes of the trendlines, the double counting has little effect.

[3]A large number of speciated nitrate data were missing during the 1998 calendar year from the IMPROVE data set. In general, sample days with missing speciated values were excluded, but to do so in this situation would result in omitting a disproportionately large number of sample days. Rather than discarding all these sample days, the missing nitrate values were estimated as 10% of the gravimetric fine mass, which is significantly higher than the 1997 annual average contribution, but consistent with other previous years. Because of the missing data, the estimated 1998 visibility values may not reflect actual values.

In fact, a closer examination of daily versus annual average ammonium sulfate concentrations at Acadia suggests that while average concentrations have perhaps shown some underlying decline, the highest concentrations experienced on peak days have remained largely unchanged (Poirot, 2000). Figure V-2 superimposes a trend line representing a rolling average of concentrations from the previous 100 sampling days (representing about one year of monitoring data) on a graph of daily average ammonium sulfate concentrations. Though there is some evidence for a downward trend in the rolling 100-sample average, the highest 24-hour values actually occur after 1995. Particularly striking is the 24-hour value recorded on July 17, 1999 – a day when much of the Northeast and Mid-Atlantic experienced exceptionally poor visibility conditions (the July 1999 haze episode is described in detail in Chapter III). In fact, the ammonium sulfate levels recorded on that day were about 40 percent higher than any previous 24-hour measurement at the Acadia site.

Figure V-2: Trends in 24-hour average ammonium sulfate concentrations and a rolling average of 100 samples from 1988 to 1999 at Acadia National Park in Maine.



Interestingly, Malm's most recent analysis of visibility trends on the 20 percent most impaired days at Acadia from 1988 through 1998 finds statistically significant decreasing slopes in organic carbon and nitrate mass concentrations but does not find a statistically significant decline for sulfate mass concentration (Malm, 2000b). Like sulfate, organic carbon and nitrate precursors might have been affected by pollution control programs introduced in the 1990s. In particular, efforts to reduce summertime ground-level ozone concentrations have led to a variety of initiatives to reduce hydrocarbon and NO_X emissions in the Ozone Transport Region. Reductions in these pollutants could directly reduce organic carbon and nitrate concentrations at some Class I

sites. To the extent these control programs have succeeded in reducing regional ozone levels, they could indirectly affect the formation of organic aerosols with a biogenic component (e.g., terpenes emitted by vegetation), which may play an important role especially at the more remote rural sites. Both ozone and nitrate serve to oxidize terpenes (Finlayson-Pitts and Pitts, 2000) and thereby promote the formation of biogenically derived organic particulate.

In general, however, the trend plots in Figure V-1 present a mixed picture and do not suggest much discernible improvement in visibility at northeastern and mid-Atlantic Class I sites over the second half of the 1990s. A clearer indication of current visibility trends may emerge with additional years of monitoring data; meanwhile, the implementation of planned additional NO_X and SO_2 emissions reductions starting in 2000 may begin to produce more pronounced visibility benefits.

C. Atmospheric Chemistry

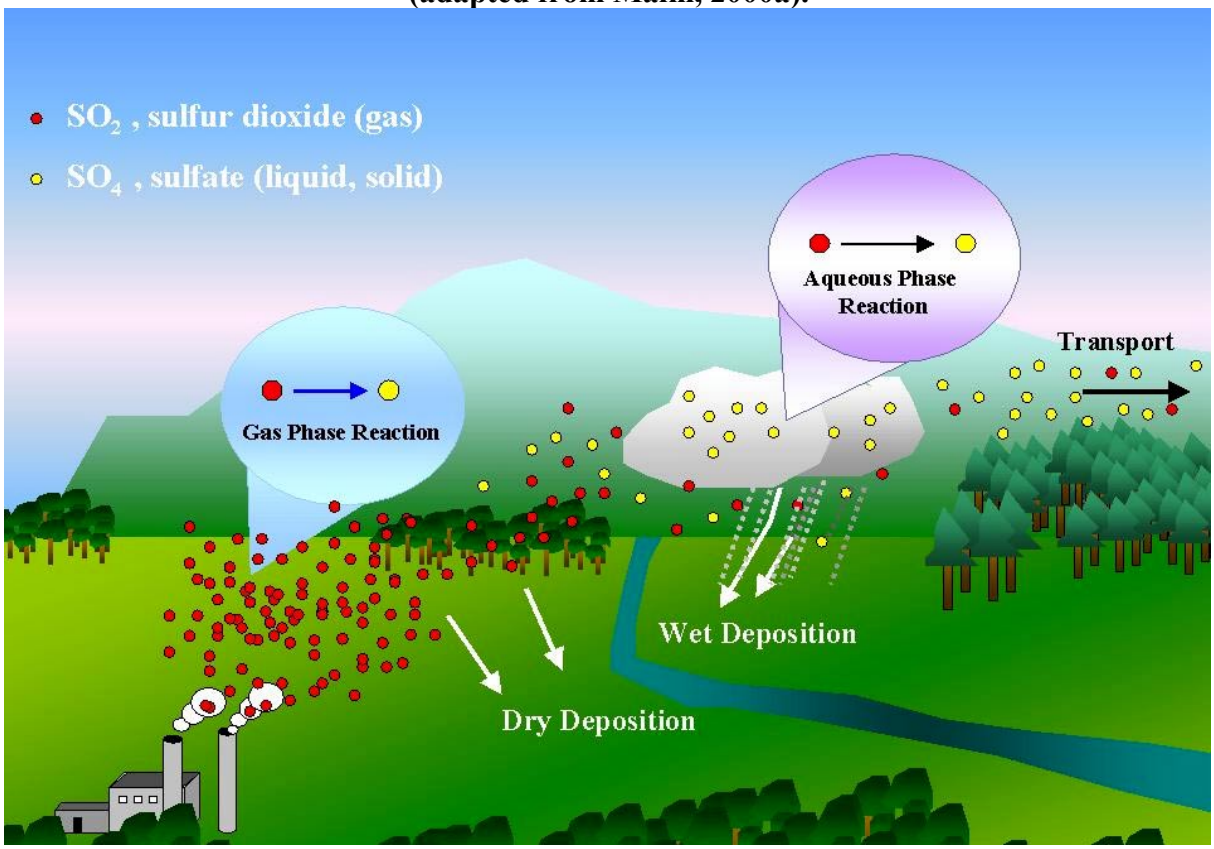
The processes by which primary pollutants, such as sulfur dioxide (SO_2), nitrogen oxides (NO_X) and volatile organic compounds (VOCs), are transformed into the visibility impairing species which are observed at visibility monitoring sites (i.e. sulfates, nitrates, and secondary organic aerosol) are complex. While a full description is not included in this report, a general presentation of some basic information regarding these processes is given here with appropriate references to other sources of information containing greater detail.

The atmospheric residence time of emitted SO_2 can range from as short as a few minutes (e.g. in the presence of clouds and high relative humidity) to as long as 13 days or more[65] before it is chemically transformed into another form. SO_2 is principally removed by two chemical processes (gas phase reaction with the hydroxyl radical (OH) and aqueous (or liquid) phase processes inside a droplet) as well as by dry deposition in the gas phase (see Figure V-3).

Gas phase chemical reactions result when two or more molecules in the atmosphere come into contact and chemically react to form different molecules. In this case, SO_2 can be transformed into sulfuric acid (H_2SO_4), which can further react to form solids in the presence of ammonium ion. These solids include letovicite ($(NH_4)_3H(SO_4)_2$,) ammonium bisulfate (NH_4HSO_4) and ammonium sulfate ($(NH_4)_2SO_4$) (Seinfeld and Pandis, 1998). All of these forms of sulfate have a high affinity for water. Sulfuric acid will condense directly onto existing liquid droplets in the atmosphere. In the case of the solid forms of sulfate, water will condense onto their surface up to the point of deliquescence, defined by a phase change that results in a liquid particle. In the liquid phase, letovicite, ammonium bisulfate and ammonium sulfate will dissociate to form the

[65] The atmospheric lifetime (or residence time) of sulfur dioxide is defined as the length of time from release until 36% (or 1/*e*) of released sulfur dioxide molecules remain. Thirteen days represents the atmospheric lifetime of SO_2 with respect to oxidation by OH and assumes no other loss processes (Finlayson-Pitts and Pitts, 2000).

Figure V-3: Schematic representation of sulfate formation mechanisms (adapted from Malm, 2000a).



bisulfate ion (HSO_4^-) and sulfate ion ($SO_4^=$). Sulfuric acid in the liquid phase ($H_2SO_4(aq)$) along with these other ionic forms of sulfate are collectively termed "sulfate."

SO_2 is also a highly soluble gas (has a high affinity for water) and, in the presence of liquid droplets, will readily condense onto their surface. In the aqueous phase, SO_2 is oxidized within the liquid to form sulfuric acid, the bisulfate ion or the sulfate ion. The aqueous phase processes that lead to the transformation from SO_2 to sulfate are highly complex and remain a subject of current research (Seinfeld and Pandis, 1998; Finlayson-Pitts and Pitts, 2000).

NO_X emitted to the atmosphere follow much the same processes with even more rapid gas phase oxidation of NO_2 by the hydroxyl radical to form nitric acid (HNO_3). Nighttime oxidation of NO_2 by O_3 can also lead to HNO_3 formation, and this path may be important during winter when hydroxyl levels are lower and nights are longer. Nitric acid can then further react with ammonium to form the solid ammonium nitrate, which also has a high affinity for water and can attract enough water to deliquesce into a liquid droplet. Nitric acid will also condense directly onto existing droplets (it too is highly soluble) where it will dissociate to form aqueous phase nitrate ion (NO_3^-). The term

"nitrate" is used to refer to aqueous phase nitrate ion as well as to dry deposited nitric acid.[66]

The formation of secondary organic aerosols (SOA) from precursor emissions of volatile organic species is similarly complex. As noted in Chapter II, organics consist of literally thousands of different molecules (all containing carbon within their molecular formula) with widely varying reactivities and lifetimes. These chemicals react with the hydroxyl radical or other oxidants in the atmosphere to form new species which again may have a wide range of physical properties. As these chemicals travel and meteorological conditions (i.e. temperature and relative humidity) change, their tendency to condense onto existing particles may be altered. The exact composition of the organic fraction of SOA is not well understood and remains an area of active research (Finlayson-Pitts and Pitts, 2000). It should be noted that there are many primary sources of organic carbon fine particles, including automobile exhaust, meat cooking, wood smoke and paved road dust. These sources emit organic carbon directly as a solid and thus no subsequent phase change is necessary.

The condensational processes by which many organics are incorporated into fine particles are no different that those governing the previously discussed forms of sulfate and nitrate. Thus it is generally inaccurate to think of haze as being caused by discrete particles of sulfate, nitrate, or organic compounds. Rather, various combinations of sulfate, nitrate, and organic compounds will attach to tiny nuclei moving through the atmosphere; eventually growing into particles of sufficient size to effectively scatter light. By comparison, primary pollutants – such as elemental carbon (soot) or crustal material – are generally present in the atmosphere as discrete particles. Encounters between other particle constituents and ammonium sulfate are more frequent when ambient ammonium sulfate concentrations are high: as a result, sulfate will tend to comprise a larger fraction of total particle mass under these conditions.

C.1 Hygroscopic Nature of Sulfates and Nitrates

The hygroscopic nature of sulfate and nitrate containing aerosol particles has been discussed already; however, given the fact that their ability to scatter visible light is greatly enhanced as they grow in size, some details of this process bear mention.

Sulfate aerosol particles, composed of sulfuric acid and ammonium sulfate and possibly other constituents as described above, typically have a diameter between 0.1 to 1.0 μm. Sulfate particles will grow substantially as relative humidity increases, particularly when the relative humidity reaches or surpasses 90 percent. Pure ammonium sulfate particles are rarely seen in natural conditions; however, in laboratory experiments, these hygroscopic particles remain in the solid phase until the relative humidity reaches 80 percent, at which point the particle deliquesces and changes from solid to liquid (Seinfeld and Pandis, 1998). Relative humidity in the summer months typically exceeds 80 percent in the eastern U.S.; hence, particles containing large amounts of ammonium

[66] Dry deposited nitric acid will quickly dissociate to form nitrate ion when it comes into contact with moist soils and vegetation.

sulfate often have greatly enhanced scattering. In sum, the substantial visibility impairment common in the East is a function of both the high sulfate concentrations and high humidity found in this part of the country.

Nitric acid is an extremely soluble gas that readily forms nitrate in the liquid phase. Nitric acid may also react with ammonium to form ammonium nitrate. Experiments with ammonium nitrate particles demonstrate that these particles will exist as solids until the relative humidity reaches 60 percent, at which point they will deliquesce to the liquid phase (Seinfeld and Pandis, 1998). With a deliquescence point substantially below that of ammonium sulfate, particles containing a mixture of the two may have a substantially lower deliquescence point than ammonium sulfate alone. These particles will scatter substantially more visible light as they become larger.

C.2 Potential Competition Between Ammonium Sulfate and Ammonium Nitrate

As the discussion above indicates, there are interactions between ammonium sulfate and ammonium nitrate in the atmosphere that will need to be considered in establishing reasonable progress goals. Specifically, the competition between these two chemical species may mean that a given reduction in sulfate precursors will not result in expected visibility improvement because ammonium ion previously bound to sulfate will be available to combine with gas-phase nitric acid and form ammonium nitrate (West et al., 1999; Middleton and Laulainen, 2000).[67] The result could be a non-linear response to early emissions reduction efforts, particularly if these efforts focus solely on SO_2.

An investigation by Carnegie Mellon University researchers indicates that in the eastern U.S., replacement of sulfate particles by nitrate particles could be important during colder winter months, but would be relatively uncommon during the warmer summer months[68] (West et al., 1999). This would suggest that an SO_2-focused strategy may indeed lead to expected haze reductions during the summer, when the great majority of the 20 percent most impaired days in a given year occur at most northeastern and mid-Atlantic Class I areas. For the minority of days with poor visibility during the winter months, however, competition from ammonium nitrate could partially offset the particle reductions achieved by cutting SO_2 emissions.

C.3 Biogenic Hydrocarbon Influence on Regional Haze

In general, organic carbon is the second most abundant particle species on poor visibility days at northeastern and mid-Atlantic Class I areas. A number of laboratory studies have shown that the semi-volatile oxidation products of higher molecular weight hydrocarbons can form secondary organic aerosols (Pandis et al., 1991; Zhang et al., 1992; Odum et al., 1996; 1997a, 1997b; Hoffmann et al., 1997). Due to analytical challenges and the relatively large number of hydrocarbon species present in the air, however, relatively little is known about the molecular composition of ambient organic aerosols.

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[67] In general, sulfate has a stronger affinity for ammonia than does nitrate. This ensures that when enough sulfate is available, it will preferentially scavenge any ammonia present in the atmosphere. If the amount of sulfate is reduced, however, a greater amount of ammonia becomes available to react with nitrate.
[68] This is due to the tendency for ammonium nitrate to thermally dissociate in warmer weather.

Precursor emissions for secondary organic aerosols come from both manmade (anthropogenic) and natural (biogenic) sources. Anthropogenic sources include motor vehicles, industrial processes, and consumer products. For areas influenced by mobile sources (i.e., motor vehicles), research indicates that the quantity of so-called "aromatics," such as benzene, toluene, and xylenes, in the gasoline strongly determines the potential for secondary aerosol formation from gasoline vapor (Odum et al., 1997a). Biogenic sources include trees and other vegetation. In the forested sections of the eastern U.S., which include most of the Class I areas, emissions of biogenic hydrocarbons can be quite significant (Geron et al., 1994). The fact that organic carbons generally account for the second largest fraction of fine particle mass and visibility impairment at these sites (and up to 40 percent of total fine mass on the 20 percent least impaired days) would appear to support this hypothesis.

The major biogenic hydrocarbons are isoprene, monoterpenes, and sesquiterpenes, although oxygenated and sulfur-containing compounds also occur (Griffin et al., 1999). The biogenic hydrocarbons differ in size, with isoprene containing five carbons, monoterpenes containing ten, and sesquiterpenes having fifteen.

Secondary organic aerosols generally form from the oxidation of hydrocarbons containing seven or more carbons (Grosjean, 1992; Grosjean and Seinfeld, 1989). The smaller isoprene molecule — which plays a substantial role in ozone formation — is therefore probably not an important precursor of secondary organic aerosols. In contrast, many of the larger biogenic terpenes effectively form secondary aerosols (Pandis et al., 1991; Zhang et al., 1992; Odum et al., 1996; Hoffmann et al., 1997). In fact, a number of biogenic terpenes have a greater potential to form secondary aerosols than does gasoline vapor (Griffin et al., 1999).

Although isoprene does not appear to be an important precursor of secondary organic aerosols, it may have important indirect impacts on visibility by virtue of its role in promoting ozone formation. Isoprene by itself does not produce ozone, but it can greatly enhance ozone production in the presence of NO_X. As noted previously in this report, ozone in turn enhances the oxidation of biogenic hydrocarbons, thereby promoting their transformation into light-scattering organic aerosol particles. Biogenic hydrocarbons can also be oxidized by nitrate radical (NO_3) formed from NO_X, a process that can produce large yields of secondary aerosol particles (Griffin, et al., 1999). Thus oxidation by NO_3 and ozone represent anthropogenic influences on biogenic secondary organic aerosol formation, much as NO_X is an anthropogenic influence on isoprene's ability to enhance ozone formation. In sum, it would be inaccurate to characterize the biogenic contribution to aerosol particle concentrations at northeastern and mid-Atlantic Class I as a purely "natural" component of visibility impairment. Rather, the presence of biogenic aerosols may be substantially influenced by pollutants that are anthropogenic in origin, including NO_X and ozone.

Conifers such as pine, spruce, and fir trees are significant emitters of terpenes. In the case of monoterpenes, forest emissions are relatively high in northern New England (Geron et al., 1994). Unlike isoprene emissions from deciduous trees (e.g., oaks), terpene emissions from coniferous forests occur year-round. Terpene emission rates are highly temperature dependent, however; hence terpene emissions in June, July, and August

(when visibility conditions are generally worst) can be two to four times greater than winter emissions (Lamb et al., 1993).

While sulfate accounts for the largest share of current levels of light extinction in the northeastern and mid-Atlantic Class I areas, eventual achievement of national visibility goals will require addressing the other contributors to regional haze. Organic carbon is typically the second most important component of regional haze in the Northeast and Mid-Atlantic. A better knowledge of its molecular constituents may be necessary to determine the best strategies for reducing its contribution to poor visibility. These may include both strategies aimed at directly reducing emissions of anthropogenic hydrocarbons (such as gasoline vapor), and strategies aimed at reducing other anthropogenic pollutants such as NO_X that indirectly influence the formation of biogenic secondary organic aerosols. In fact, NO_X reductions could influence visibility through as many as three separate mechanisms: first, by directly reducing the formation of aerosol nitrate; second, by maximizing the visibility improvement achieved through sulfate reductions (especially in the wintertime); and third, by reducing the formation of biogenic secondary organic aerosols.

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VI. Haze Associated Pollutant Emissions

This chapter discusses major sources and current emissions of haze-forming pollutants in the eastern U.S., as well as anticipated changes in emissions due to existing or pending control programs. Each of the chief haze constituents, including sulfate, organic carbon, nitrate, elemental carbon, and crustal material are addressed. The final section of this chapter describes on-going efforts to inventory ammonia emissions. As discussed in Chapter V, ambient levels of ammonia in the atmosphere are important given their role in the formation of light-scattering ammonium sulfate and ammonium nitrate aerosol particles.

A. Sulfur Dioxide (SO_2)

SO_2 is the primary precursor pollutant for sulfate particles. Sulfate particles, as noted in Chapter III, commonly account for more than 50 percent of particle-related light extinction at northeastern Class I areas on the clearest days and for as much as 80 percent on the haziest days. Hence, SO_2 emissions are an obvious target of opportunity for reducing regional haze in the eastern U.S. Fossil fuel combustion, of coal and to a substantially lesser extent of petroleum products, accounts for most anthropogenic SO_2 emissions. In fact, in 1998 a single source category — coal-burning power plants — was responsible for two-thirds of total SO_2 emissions nationwide (USEPA AIRS, 2000).

A.1 Inventory

Figure VI-1 shows the trend in national SO_2 emissions over the ten-year period between 1989 and 1998 (USEPA, 2000a). It indicates a decline in total emissions of about 20 percent over this period, with a significant step-wise drop coinciding with the implementation of Phase I of the federal Acid Rain Program in 1994-95 (see discussion below). After 1995, emissions actually began to increase again slightly, a trend that probably reflects increased electricity demand in the late 1990s combined with the availability of excess emissions allowances that were banked as a result of substantial initial over-compliance with Phase I requirements in the mid-90s. This led to relatively low market prices for allowances later in the decade, which tended to encourage allowance purchases rather than implementation of control measures as electricity output continued to grow.

A.2 SO_2 Control Programs

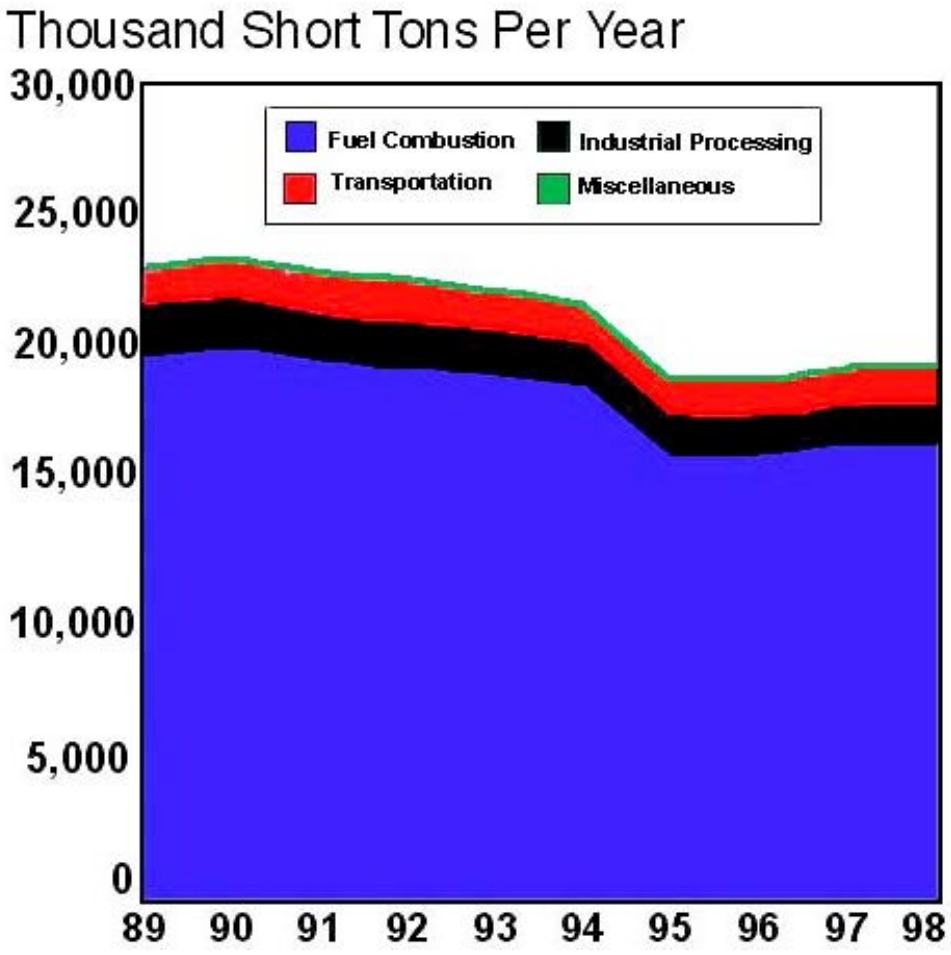
SO_2 emissions from power plants were first regulated at the federal level under the 1970 Amendments to the Clean Air Act. The 1970 Amendments directed USEPA to establish a National Ambient Air Quality Standard (NAAQS) and New Source Performance Standard (NSPS) for SO_2. From the late-1970s through the 1980s, these regulatory developments resulted in a gradual decline in SO_2 emissions, but did not result in major overall reductions. The primary strategy for avoiding NAAQS violations was to dilute SO_2 emissions through the use of tall smokestacks; this tactic, which, of course, facilitated atmospheric transport, was regarded as acceptable at a time when the long-

range impacts of pollution were not generally understood or considered. NSPS requirements applied only to new or substantially modified power plants – a relatively small number compared to the population of existing facilities.

In the mid-1990s, substantial SO_2 emissions reductions from existing power plants were implemented as a component of the national Acid Rain Program. This program was introduced under Title IV of the Clean Air Act Amendments of 1990. Title IV aimed to cut national SO_2 emissions from power plants by 10 million tons from 1980 levels, to an eventual cap of just under 9 million tons annually. More modest reductions in NO_X emissions were also included in the program; these are discussed in Section C.2 of this chapter. The reductions were to be implemented using a national cap and trade program in which sources were allocated an initial emissions allowance based on their historic emission rates and were then free to trade allowances.

The first phase of the federal Acid Rain Program was implemented in 1995 with 110 of the highest emitting power plants subject to emissions limits. As indicated by Figure VI-1, Phase I implementation resulted in net emissions reductions of approximately 4 million tons, with total power plant emissions falling to just under 12 million tons. However, it is worth noting that the reductions achieved at Phase I plants

Figure VI-1: National SO_2 emissions trend from 1989 to 1998 (USEPA, 2000a).



between 1990 and 1995 actually totaled 4.7 million tons. This was a full 3.4 million tons lower than required in 1995 and represented over-compliance of close to 40 percent with Phase I requirements. After 1995, as noted previously, power plant emissions began to rise again slightly and by 1998 had increased by nearly 1.3 million tons over the SO_2 levels achieved in 1995, to a total of over 13 million tons.

The second phase of the Acid Rain Program went into effect in 2000. It further reduced allowable emissions (to an average rate of 1.2 pounds of SO_2 emissions per million Btu of fuel input or lbs/mmBtu) and extended emissions limits to a larger group of power plants (including all units with a generating capacity greater than 25 megawatts). Full implementation of the Phase II requirements should eventually limit total SO_2 emissions from power plants to just under 9 million tons per year. However, power plant emissions for most of the 2000-2010 period are expected to remain closer to 9.5 million tons, in part because of the availability of bonus allowances to ease compliance for certain sources and because of the carryover of excess allowance from over-compliance in Phase I of the program. As of 2000, over 10 million tons of SO_2 emissions allowances had been carried over from Phase I into Phase II (NESCAUM, 2000).

As indicated by Figure VI-1, fossil fuel combustion by large industrial facilities, transportation sources and certain industrial processes account for a substantial portion of the remaining national SO_2 inventory. In 1995, sources other than power plants contributed over 6 million tons to the national inventory.[69] Roughly half this total was attributable to fossil fuel combustion at large industrial facilities. The Acid Rain Program encourages emission reductions at large industrial sources by giving them the option of participating in allowance trading markets if they make reductions. Finally, new regulations proposed by USEPA to limit the sulfur content of highway diesel fuel and gasoline should, if implemented,[70] provide important reductions in sulfur emissions from the transportation sector. As currently proposed, fuel sulfur content limits would go into effect by 2006 and would reduce sulfur emissions from cars and trucks by approximately 90 percent. Relative to power sector reductions, however, additional SO_2 reductions from the transportation sector will be fairly small. In sum, remaining sulfur emissions from other industrial facilities, the transportation sector, and other sources are likely to keep the total national inventory well above 10 million tons, even after Title IV emissions caps are fully implemented.

B. Volatile Organic Carbons (VOC)

After sulfate, organic carbon generally accounts for the next largest share of fine particle mass and particle-related light extinction at northeastern Class I sites. As indicated in Chapter II, the term organic carbon encompasses a large number and variety

[69] Note that this represents a decline of 2.1 million tons from the non-utility contribution of 8.4 million tons in 1980.

[70] EPA's proposal for substantially limiting fuel sulfur content faces substantial political opposition; hence there is still some question, at the time of this writing, as to whether it will be implemented as currently proposed.

of chemical compounds. The organic carbon present at Class I sites almost certainly includes a mix of species attributable to manmade pollution sources and biogenic hydrocarbons, which are emitted from vegetation. As this section indicates, efforts to reduce manmade organic carbon emissions have been undertaken primarily to address summertime ozone formation in urban centers. In the future, efforts to control fine particle pollution both for visibility reasons and for public health protection may prompt additional control efforts for this class of pollutants.

B.1 Inventory

Inventory data on organic carbon emissions are available as a result of past and ongoing ozone attainment planning efforts.[71] Current inventories typically refer to "volatile organic compounds"or VOCs, a term that designates those hydrocarbons whose volatility in the atmosphere makes them particularly important from the standpoint of ozone formation. Understanding transport dynamics and source regions for organic carbon in northeastern Class I areas is likely to be more complex than for sulfate. This is partly because of the large number and variety of organic carbon species, the fact that their transport characteristics vary widely, and the fact that a given species may undergo numerous complex chemical reactions in the atmosphere. Thus, the organic carbon contribution to visibility impairment at most Class I sites in the East is likely to include manmade pollution transported from a distance, manmade pollution from nearby sources, and biogenic emissions, especially terpenes from coniferous forests.

The VOC inventory is dominated by transportation sources, including exhaust from gasoline passenger vehicles and diesel-powered heavy-duty vehicles, as well as evaporative emissions from transportation fuels. VOC emissions also come from a variety of so-called area sources (this category includes sources such as solvents, architectural coatings, dry cleaners, etc.) as well as some point sources, including industrial facilities and petroleum refineries.

Biogenic VOCs may play an important role within the rural settings typical of Class I sites. As discussed in Chapter V, the oxidation of hydrocarbons containing seven carbons or more is generally the most significant pathway in the formation of light scattering organic aerosol particles (Odum et al., 1997). Smaller reactive hydrocarbons that may contribute significantly to urban smog (ozone) are less likely to play a role in organic aerosol formation (though it should be noted that ozone levels can have an indirect effect in terms of promoting the oxidation of other available hydrocarbons, including biogenic emissions). [72]

In short, further work is needed to characterize the organic carbon contribution to regional haze in the Northeast and Mid-Atlantic regions and to develop inventories that will be of greater value for visibility planning purposes.

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[71] Ozone is formed in the atmosphere from chemical reactions involving NO_X and VOC in the presence of sunlight. Because solar energy is a fundamental driver in this process, ozone is primarily a summertime air quality concern.

[72] See further discussion of the biogenic component of organic emissions in Chapter V, Section C.3.

B.2 VOC Control Programs

To date, some of the most important VOC control efforts for purposes of ozone mitigation have focused on mobile sources. Automobiles, in particular, have been subject to increasingly stringent regulation of their tailpipe exhaust and evaporative emissions since the early 1970s. These regulations have resulted in per mile reductions of up to 98 percent in VOC emissions from light duty vehicles. At the same time fuel modifications, such as the federal reformulated gasoline program, have been used to reduce evaporative and other fuel-related emissions. Some of the resulting benefits have been offset by a substantial increase in vehicle miles traveled and fuel consumed over the same time period, but on the whole, VOC emissions from passenger vehicles have declined significantly over the last three decades.

In addition, states in the ozone transport region (OTR) have undertaken a number of initiatives aimed at reducing VOC emissions from non-mobile point and area sources as part of their ozone attainment SIPs. By 2007, these initiatives will reduce VOC emissions from solvent utilization by 33 percent from area sources and by 45 percent from point sources relative to 1990 levels. Over the same time period, the storage and transport sector will be required to reduce area source emissions by 45 percent and facility (point source) emissions by 12 percent. Finally, by 2007, emissions from chemical manufacturing facilities and "other industrial processes" are to be reduced by 46 and 58 percent, respectively, below 1990 levels.

C. Oxides of Nitrogen (NO_X)

Nitrate generally accounts for a substantially smaller fraction of fine particle mass and related light extinction than sulfate and organic carbon at northeastern Class I sites. (Notably, it may play a more important role at urban sites and in the wintertime.) Nevertheless, NO_x emissions contribute directly to visibility impairment in the eastern U.S. by forming light-scattering nitrate particles. In addition, NO_x may have an indirect effect on summertime visibility by virtue of its role in ozone formation, which in turn promotes the formation of secondary organic aerosols.

C.1 Inventory

Power plants and mobile sources are the dominant source of NO_x emissions. Nationally, power plants account for more than one-quarter of all NO_x emissions, over 6 million tons. Their relative contribution is much higher, however, in parts of the industrial Midwest where high NO_x emissions are associated with a significant power plant contribution. By contrast, the NO_x inventories for more urbanized Mid-Atlantic and New England states are dominated to a far greater extent by mobile sources.

Since 1980,[73] nationwide emissions of NO_X from all sources have shown little change. In fact, emissions increased by 2 percent between 1989 and 1998 (EPA, 2000a). This increase is most likely due to industrial sources and the transportation sector, as

[73] 1980 is the base year for all control programs under the CAA's Title IV requirements.

power plant combustion sources have shown modest emissions reductions during this same time period.

C.2 NO_x Control Programs

Most current regulatory efforts to reduce NO_x emissions from power plants and mobile sources are motivated by ozone attainment needs; in addition, more limited reductions are currently being required for purposes of mitigating the NO_x contribution to acid deposition. Because of the link to ozone, some of the most important NO_x control efforts – notably those involving major point sources – are seasonal; i.e. they require emissions controls only during the summer months. Tailpipe NO_X emissions standards for automobiles, of course, provide year-round reductions. In addition, modest NO_X reductions from power plants (totaling approximately 2 million tons nationally) are required under the federal Acid Rain Program; these reductions are similarly year-round.

NO_x was first regulated at the federal level by the 1970 Clean Air Act Amendments which directed USEPA to develop both a NAAQS for NO_2 and NSPS standards for NO_x emissions from new or substantially modified stationary sources. Because violations of the NO_2 NAAQS were relatively uncommon (notably, Los Angeles was one area in non-attainment of this standard in the 1970s) and because NSPS applied to a relatively limited number of sources, these regulations did not result in broad-based control efforts. In addition, they were largely met by the use of so-called low-NO_x burner technology, a form of emissions control that is based on combustion modifications rather than smokestack controls. In the late 1970s and 1980s, low-NO_x burner technology tended to achieve emissions reductions on the order of 30 percent.

By 1990, the previously under-appreciated importance of NO_x in ozone formation was increasingly recognized. The 1990 Clean Air Act Amendments for the first time required NO_x controls at existing large stationary sources located in ozone non-attainment areas. As a result, most power plants in the Ozone Transport Region became subject to Reasonably Available Control Technology (RACT) requirements in 1995. Combustion modifications (such as low-NO_x burners and overfire air) continued to suffice for meeting most of these requirements; modern versions of these technologies are capable of achieving control efficiencies of over 40 percent. The RACT requirements introduced in the mid-1990s for purposes of ozone control overlapped to a considerable degree with the NO_x limits that were applied to certain units in 1996 under the Phase I requirements of the Acid Rain Program.

Meanwhile, states within the Ozone Transport Region were recognizing that additional NO_x reductions would be necessary to address pervasive, regional ozone problems in the Northeast and Mid-Atlantic regions. In 1994, the Ozone Transport Commission (OTC) adopted a Memorandum of Understanding (MOU) that committed participating states to go beyond existing RACT requirements to achieve total NO_x reductions of 55 to 65 percent by 1999 and 65 to 75 percent by 2003. Most OTC member states are participating in Phase II of the OTC MOU and several have created a NO_x budget program to allow for trading of allowances among sources. More recently,

following a two-year, multi-stakeholder process[74] aimed at addressing the problem of ozone transport over a broader area of the eastern U.S., USEPA proposed to extend similar reduction requirements to a 22-state eastern region in an action widely known as the Section 110 NO_X "SIP call."[75] The NO_x SIP call, which was recently upheld in federal court after several legal challenges, will require emissions reductions of approximately 85 percent from uncontrolled levels (equivalent to meeting an average emissions rate of approximately 0.15 lb/mmBtu) at large industrial boilers and power plants over a large portion of the eastern U.S. These reductions were originally to have been implemented by 2003; because of subsequent litigation, however, the implementation date may be delayed to 2004. Importantly, reduction requirements under both the OTC MOU and USEPA's broader NO_X SIP call apply to emissions only during the 5-month ozone season (from May to September).

Significant limits on NO_X emissions from vehicle tailpipes, meanwhile, were first introduced in the late 1970s (in California) and in the 1980s (nationally). On a per-mile basis, current tailpipe standards for NO_X represent a 98 percent reduction from pre-1970 uncontrolled levels; a further reduction of 50 percent will be achieved with the implementation of new federal and California standards in 2005. As in the case of VOCs, absolute emissions reductions from the mobile source sector have not been equally dramatic, owing to the several-fold increase in total vehicle miles traveled over the last four decades. Finally, additional NO_X reductions from heavy-duty vehicles are anticipated in the next decade as a result of new federal regulations for diesel engines.

D. Elemental Carbon and Crustal Material

Elemental carbon and crustal material generally account for a smaller portion of fine particle mass and visibility impairment at northeastern Class I areas[76]. Because ambient levels of these materials have not generally been regulated in the past, inventory data and experience with control measures are generally less extensive than for the other pollutants discussed in this Chapter. This section provides a brief overview of sources and relevant control experience for these fine particle constituents; additional research in this area may be appropriate as part of future haze planning efforts.

Elemental carbon, the chief constituent of soot, is primarily emitted from the combustion of wood, and diesel fuel. Particulate emissions limits currently apply to several combustion sources of elemental carbon, including newer wood stoves and diesel engines. However, these limits frequently apply to larger particles in the 10 micrometer

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[74] The Ozone Transport Assessment Group (OTAG) process involved 27 states and provided the basis for EPA's subsequent Section 110 SIP call.

[75] EPA's action is authorized under Section 110 of the Clean Air Act, which allows the Agency to act to address interstate pollution transport by requiring states to submit implementation plans (SIPs) to reduce their contribution to ozone non-attainment in downwind states. In a separate but related action, several individual northeastern states also petitioned EPA under Section 126 of the Clean Air Act to impose upwind NO_x reductions.

[76] However it should also be noted that the relative fraction of total carbon that is considered elemental versus organic is operationally defined and has large associated uncertainty. See Appendix B for more detail regarding carbon analysis procedures.

size range (PM_{10}) and hence may provide less effective regulation of the smaller particles that are susceptible to long-range atmospheric transport and play a more important role in visibility impairment at Class I sites. Diesel engines are known to be a substantial source of elemental carbon emissions in urban areas of the Northeast, while wood stoves can be an important source of particulate pollution in some rural areas. Figure III-3a demonstrates that while elemental carbon accounts for roughly the same percentage of total fine particle mass in urban areas as in rural areas, the absolute contribution from elemental carbon is two and a half times greater in Washington D.C. than it is in rural areas like Acadia National Park. The evidence that woodsmoke contributes to elemental carbon measurements in rural areas is shown later in this report in Figure VII-2, which illustrates the results of source attribution studies for fine particle observations at Underhill, VT. Particulate emissions from new woodstoves are presently regulated; however, emissions from wood burned in older woodstoves and fireplaces are not. Meanwhile, effective control technologies for other sources of elemental carbon emissions are available, including particulate traps for diesel exhaust. Additional reductions will be achieved by the future federal emissions limits for new diesel engines and by retrofitting existing engines. Currently, a number of northeastern states are initiating smoke testing and other programs to reduce particulate emissions from on-road heavy-duty vehicles; states are also exploring means to reduce emissions from construction equipment and other off-road sources.

Crustal material accounted for as much as 16 percent of particle-related light extinction on the 20 percent of days with the best visibility in 1997 at the Brigantine and Acadia sites. However, its role is generally much smaller in relative terms on the 20 percent worst visibility days. To the extent that the crustal fraction includes material of natural origin (such as soil or sea salt), it may not be particularly amenable to control efforts. However, the crustal fraction can be influenced by human activities, such as construction, agricultural practices, and road maintenance (including wintertime salting). To the extent that these types of activities are found to impact visibility at northeastern Class I sites, control measures targeted at crustal material may prove beneficial. Some experience may be available from the western U.S., where the crustal component has generally played a more significant role in driving overall particulate levels; aspects of this experience may or may not be relevant in the eastern context. In addition, a few areas in the Northeast, such as New Haven, CT and Presque Isle, ME, have some experience with the control of dust and road-salt as a result of their past non-attainment status with respect to the PM_{10} NAAQS.

E. Ammonia Emissions

Knowledge of ammonia emission sources will be necessary in developing regional haze reduction strategies because of the important roles of ammonium sulfate and ammonium nitrate in fine particle mass and light scattering. Overall, it is estimated that in 1998, livestock agriculture and fertilizer use contributed to about 85 percent of all ammonia emissions to the atmospere (USEPA AIRS, 2000). However, better ammonia inventory data are needed as an input to the photochemical models used to simulate fine particle formation and transport in the eastern U.S. Because ammonia has not been

regulated as a criteria pollutant or criteria pollutant precursor, these data do not presently exist at the same level of detail or certainty as for NO_x and SO_2.

Ammonium ion (formed from ammonia emissions to the atmosphere) is an important constituent of airborne particulate matter, typically accounting for 10 to 20 percent of total fine particle mass. Reductions in ammonium ion concentrations can be extremely beneficial because a more than proportional reduction in fine particle mass can result. Ansari and Pandis (1998) showed that a 1 $\mu g/m^3$ reduction in ammonium ion could result in up to a 4 $\mu g/m^3$ reduction in fine particulate matter. However, the benefits of ammonia reduction must be weighed against the significant role it plays in neutralizing acidic aerosol[77] and potentially decreasing dry scattering efficiency of fine particles.

To address the need for improved ammonia inventories, MARAMA, NESCAUM and USEPA have funded researchers at Carnegie Mellon University (CMU) in Pittsburgh to develop a regional ammonia inventory (Davidson et al., 1999). This study is focusing on three issues with respect to current emissions estimates:

1. Wide range of ammonia emission factor values,
2. Inadequate temporal and spatial resolution of ammonia emissions, and
3. Lack of standardized ammonia source categories.

With respect to the first issue, currently available inventories list emission factors that differ by more than an order of magnitude for several animal categories (Lee and Dollard, 1994). These reflect uncertainties in the emission factors themselves as well as variable emissions from some source categories. For example, animal wastes are a source of ammonia in the atmosphere through volatilization from excrement. The rate of volatilization is affected by wind speed, air and soil temperature, relative humidity, soil moisture, and rainfall (Lee and Dollard, 1994; Sommer et al., 1991); as a result, emissions factors are sensitive to the conditions under which they were measured. In addition, current inventories typically do not account for the fact that ammonia emissions are nearly an order of magnitude higher from confined cattle operations than from grazing cattle operations (Roe and Strait, 1998).

The second issue, concerning spatial resolution, reflects the fact that current air quality models require emissions input data at a spatial resolution sufficient for computing air quality in a single grid cell, often 10 square kilometers or smaller. Activity level data for some ammonia sources, however, are available only at the county level. This introduces a level of uncertainty in converting county level emissions to grid-scale emissions for model inputs. Meanwhile, the temporal resolution of ammonia emissions is another area of uncertainty in model inputs. One example is the use of fertilizer. Model inputs typically treat fertilizer emissions as if they are temporally constant (i.e., using a constant yearly average), whereas actual fertilizer applications are episodic and occur at

[77] SO_2 reacts in the atmosphere to form sulfuric acid (H_2SO_4). In the presence of ammonia, this strong acid can be partially neutralized to form ammonium bisulfate or fully neutralized to form ammonium sulfate. If strategies are focused on ammonia without corresponding decreases in SO_2 emissions, resulting fine particles will be substantially more acidic than those presently observed.

brief, specific times during the year. Real world ammonia emissions from fertilizer are therefore characterized by large peaks, which then taper off to background levels, a feature that is generally not captured by current air quality models (Davidson et al., 1999).

The third area of investigation for the Carnegie Mellon researchers focuses on discrepancies in classifying ammonia source categories by different inventories. For example, the current national inventory for 1990 does not include emissions from soils (E.H. Pechan, 1995), yet most other inventories show soil emissions to be significant (Davidson et al., 1999). This discrepancy may be quite significant between inventories. A recent inventory of emissions in the San Joaquin Valley in California ranks soil emissions as second (40 percent of total) only to livestock emissions (50 percent of total) (Roe and Strait, 1998).

One goal of this project is establish an inventory framework with source categories, emissions factors, and activity data that are readily accessible to the user. With such a framework, data can be obtained in a variety of formats[78] and updates can be made easily, allowing additional ammonia sources to be added or emissions factors to be replaced as needed in the future (Strader et al., 1999).

It should be noted that the point source inventory being developed by CMU is based on the USEPA Toxic Release Inventory (TRI) which may or may not be more accurate than available state information. The resulting inventory should be compared to state information for consistency.

[78] For example, the user will have the flexibility to choose the temporal resolution of the output emissions data or to spatially attribute emissions based on land-use data.

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VII. Review of Analytical Tools

To develop successful haze SIPs and TIPs, all states and interested tribes, whether they host a Class I area or not, must develop long-term strategies for helping to achieve natural visibility conditions in Class I areas by 2064. In addition, those states that do have a Class I area will be required to establish visibility goals and demonstrate reasonable progress toward these goals for each Class I area. To assess the effectiveness of a particular control strategy and to produce satisfactory demonstrations of progress, model simulations of "baseline" and future visibility conditions in Class I areas are needed. These simulations will likely employ a number of analytical tools to portray the meteorology, emissions, chemical transformations and other factors that ultimately affect atmospheric light extinction and therefore visibility.

A. The Challenges of Modeling Regional Haze

Model simulations performed for purposes of understanding the contribution of regional haze to visibility impairment in Class I areas will differ significantly from modeling activities aimed at understanding episodic ozone concentrations in urban areas and even episodic fine particle levels in urban areas. This is, in part, because conditions leading to regional haze are geographically widespread and present for much of the year.

Because federal regional haze regulations are aimed at improving aggregate visibility conditions over a 5-year period, it becomes necessary to consider the wide variety of emissions levels and meteorological conditions (including humidity factors) which are experienced over this time period. Simulations of visibility must be representative of daily, seasonal, as well as year-to-year variations which are likely to be experienced in each Class I area, and across the broader regions surrounding them. If shorter time periods or "episodes" are modeled, they must be selected to represent the full range of possible conditions. Performing a year-long model run (or longer) presents a challenge in and of itself, simply in terms of the computation time required by many detailed air quality models. Obtaining, validating and analyzing a year of meteorological (as well as emissions) data for the entire eastern U.S. represents an additional burden which could be significantly eased by the cooperative efforts of state, tribal, regional, federal and academic modeling groups. Due to the nature of regional haze, large spatial scales are also required. It may prove most efficient for some purposes to move from mesoscale models to global models, for which archived meteorological data are already being produced (e.g. NGM, MRF and Eta Model output).

Federal regional haze requirements specify two objectives; improving visibility (eventually to unpolluted natural "background " conditions) on the 20 percent of days with the worst visibility and ensuring no degradation on the 20 percent of days with the best visibility. Maintaining visibility conditions on the 20 percent least impaired days in the more northern Class I areas where current conditions on those days are already quite close to natural background (see Figure V-1) may be a challenge. In these areas, a single major source could degrade visibility measurably on the 20 percent least impaired days. Modeling activities will have to address this issue in developing strategies to comply with the maintenance provisions of the regional haze rule. This may require detailed modeling

studies using source dispersion techniques to assess the impacts of specific sources near certain Class I areas.

The state of science in current aerosol models presents an additional challenge for modeling specific regional haze episodes. This chapter discusses several models in use or in development for the analysis of fine particle nucleation and growth mechanisms. Several of these models contain deficiencies that are expected to be addressed in the near future. As modeling tools are refined and expanded, more accurate simulations of fine particle size and number distributions, as well as compositional information, should be available. Such information is important in calculating reliable estimates of the visibility degradation caused by different haze constituents. Emissions control measures, meanwhile, need not be delayed to await such refinements since current models are already able to provide reliable information about the aggregate determinants and components of regional haze in the eastern U.S. (Huber et al., 2000).

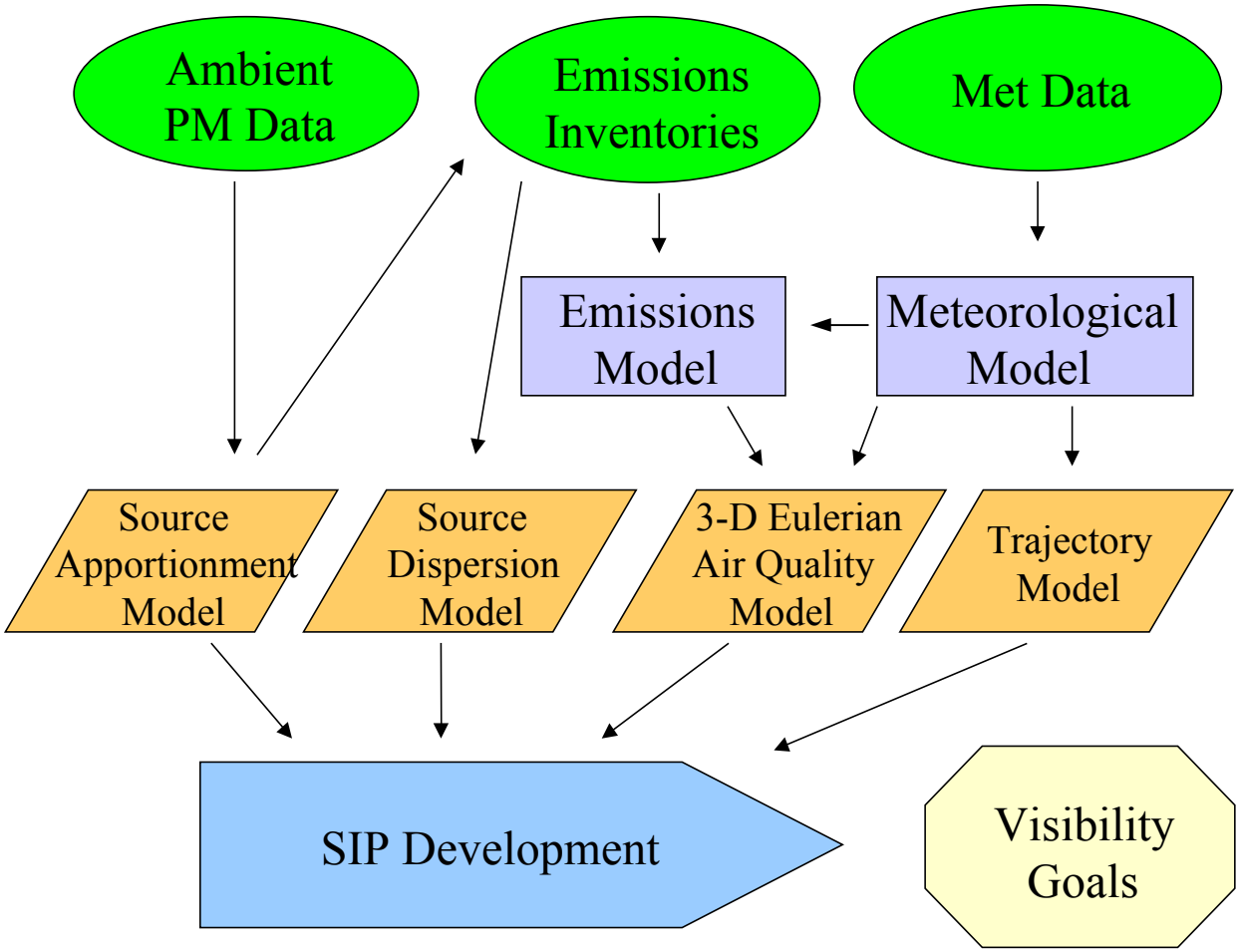
As discussed in Chapter IV, states' first regional haze SIPs will generally be due in the 2007-2008 time frame (though a SIP committing states to regional planning efforts will be due before this). Thus it would be reasonable to expect that significant modeling activities will occur in the 2004-2007 time frame. Given the significant time required to construct and run complex air quality models, states will be required to make choices soon about modeling tools that may not be used for regulatory purposes for another four to seven years. In making these choices, states will need to consider anticipated improvements as well as the current attributes of available modeling platforms. Perhaps even more important will be the need for early regional coordination to ensure that all necessary modeling activities for regional haze SIP development are carried out.

In the following section, the structures of the various modeling platforms are reviewed along with noted strengths or weaknesses. In section C we review comparison studies focused on the performance of several of the particulate models presented here. In section D we discuss how one might use the available tools in SIP development.

B. Available Analytical Tools

Figure VII-1 illustrates the relationship among a number of analytical tools available for modeling regional haze and indicates how they can be of use in the SIP development process. Meteorological and emissions models are required to generate gridded inputs for 3-Dimensional Eulerian air quality models. These 3-D models, in turn, can inform the SIP development process in two ways: first, to simulate average conditions using simplified parameterizations over an extended period of time and second, to simulate specific haze events, such as the mid-July 1999 event discussed in Chapter III, using more sophisticated analysis and more specific parameters.

Figure VII-1: Relationship of modeling tools for SIP development.



A different type of tool, the source dispersion model, can inform the SIP process in a different way. This type of model allows the user to investigate the specific impact of individual emission sources. Yet another tool, called factor analysis, uses receptor-based techniques that take into account speciated measurements of particle composition (and in some cases, the source emission profiles of specific known sources) to determine the individual contribution of known source types to the fine particle levels observed at a particular site. In cases where emissions profiles are generic across a source type, (e.g., if all smelters produce similar emissions) then factor analysis can be used to help identify source categories and validate emission inventories. This technique is often used in conjunction with trajectory models for source apportionment studies which identify the origin of airmasses that correlate with a specific source profile.

B.1 Meteorological Models

Two major types of analytical tools are available for generating meteorological inputs to air quality models: diagnostic and prognostic models. Diagnostic models typically analyze observed atmospheric states at discrete times and locations. These models are usually computationally efficient and simple to apply; however, they can produce large errors when attempting to interpolate over regions with sparse data. Meteorological observations are limited by the existing network for collecting such data and are frequently sparse over mountainous and marine areas. Observations of conditions higher in the atmosphere are often similarly sparse, however, the spatial scales of interest for accurate simulation of atmospheric dynamics aloft are often greater as well. The interpolation of meteorological conditions is inherently imprecise and, when run with insufficient data, can lead to physically unrealistic results. Diagnostic models cannot produce results at a level of resolution finer than the underlying observation set; thus it is important to select a level of modeling resolution that is consistent with available input data.

CALMET (Scire et al., 1998a) is one of the most widely used air quality diagnostic models. It includes specific modules for boundary layer meteorology and complex terrain. This model is frequently used in conjunction with CALPUFF, a dispersion model that was designed to calculate fine-scale pollutant transport over complex terrain.

Prognostic models are based on primitive equations of motion for the atmosphere in a finite-difference form. Thus, while they ensure internally consistent results, these models are highly sensitive to the accuracy of the boundary conditions used to initialize them. To avoid the accumulation of errors which can result from this situation, prognostic models are frequently used in conjunction with Four-Dimensional Data Assimilation (FDDA). This procedure "nudges" certain variables used in the theoretical relationships to keep the results close to those observations which may be available. The use of FDDA substantially reduces errors and is currently the best method for generating reasonably accurate and dynamically consistent data sets (Seaman, 2000). Nevertheless, prognostic models are more complex than diagnostic models and require skill and care when adapted to individual situations.

Two prognostic models are widely used and readily available. They are the Regional Atmospheric Modeling System (RAMS) (Pielke et al., 1992) produced by Colorado State University and the Fifth Generation Mesoscale Model (MM5) (Grell et al., 1994) developed by Pennsylvania State University in conjunction with the National Center for Atmospheric Research. Both are non-hydrostatic models and can be appropriately used at resolutions finer than 10 km; however, a number of considerations must be given to selecting a grid resolution. In general, the finest resolution available will give the most accurate results; however, many parameterizations included in prognostic models (used to estimate variables such as cloud cover, precipitation or heat flux) may break down at very fine resolutions. This occurs when the processes involved are no longer accurately represented by parameterized relationships. In general, for regional modeling purposes, it may be computationally prohibitive to perform a several-day simulation on scales finer than 12 km; additionally, when computation speeds are not

an issue, care should be taken to ensure that embedded parameterizations remain valid at these resolutions. Probably the most important consideration in selecting a resolution is consistency with the chosen air quality model. An interface program designed to transform the output of a meteorological model to the required input format for an air quality model should be used with great care. Interpolation of meteorological fields, spatially or temporally, onto a different grid for use in an air quality model has been shown to introduce errors in maintaining mass consistency (Wang, 1997). This has been identified as a major problem which can be diminished if the meteorological and air quality models share exactly the same coordinate system both spatially and temporally.[79]

Trajectory models, which will be discussed in more detail later, can be thought of as extensions of meteorological models and simply calculate the motion over time of a specified airmass using meteorological data.

B.2 Emissions Models

Emissions information is a required input for air quality models. Emissions inventories developed as part of a state's SIP can be used as a foundation for generating the detailed temporal and spatial emission information required for atmospheric simulations. Emission models are used in conjunction with emission factors to transform countywide emission inventory information to the requisite component-specific emission information at the desired temporal frequency. For regional haze simulations, emissions information will be needed for primary $PM_{2.5}$ and PM_{10}, NH_3, SO_2, NO_X, VOC, elemental carbon (e.g. diesel, wood smoke) and CO for each grid cell within the air quality model's domain for each timestep of the simulation.

Two available emission models are the EPS2.5[80] model and the EMS2000[81] model which are both new versions of older models (EPS2.0 (Causley et al., 1990) and EMS95 (Alpine Geophysics, 1995)) which have been widely used for converting stationary source emissions information. A newer emissions model has been developed which is theoretically similar to the EMS95 model but is computationally more efficient. This model, the Sparse Matrix Operator Kernel Emissions (SMOKE) model[82] has had limited use to date but is promising in its ability to consolidate gridded estimates of stationary, mobile and biogenic sources.

In addition, the MEPPS emission modeling system (Byun and Ching, 1999) has been developed for use with the Models-3/CMAQ framework (discussed later). This model was based on the 1994 version of Geocoded Modeling and Projection System (GEMAP) which has subsequently become known as EMS95. MEPPS has been substantially revised from GEMAP/EMS95 to be more generic and efficient in its operation. The advantages of this modeling system include its incorporation of geographic information system (GIS) code which allows for the easy distribution of emissions to geographic regions; however, the system does require SAS® and Arc/Info®

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[79] NARSTO Synthesis Team Draft Report, 2000
[80] Systems Applications International, Ongoing work assignment with Tom Braverman of U.S. EPA, 2000.
[81] LADCO, User's guide and documentation forthcoming, 2000.
[82] MCNC, A description of the SMOKE emissions model is available online at the following website: http://envpro.ncsc.org/products/smoke/.

software to run. While MEPPS is the currently available emissions processor used by the Models-3/CMAQ system, a version of SMOKE for Models-3 is under development and may be available for use soon.

B.3 3-D Eulerian (Grid) Air Quality Models

Gridded models are perhaps the most complex of the analytical tools explored here. These models attempt to simulate atmospheric processes including meteorological processes and aerosol formation mechanisms. These models, as with other air quality models, all solve some form of the atmospheric mass conservation equation and the atmospheric diffusion equation. These fundamental equations are used to mathematically calculate the formation, transport and fate of chemical species in the atmosphere. Grid-based models are more complex in large part because they divide a geographical domain into individual grid cells, both horizontally and vertically, which interact with each other to simulate atmospheric processes affecting pollutant concentrations such as chemistry, diffusion, advection, sedimentation (for particles), and deposition (wet and dry) (Russell and Dennis, 2000). They then attempt to solve the fundamental equations for each of these grid cells simultaneously.

Gridded Eulerian models vary in terms of their mechanistic complexity and computational intensity. For example, the Regulatory Modeling System for Aerosols and Deposition (REMSAD) (ICF Kaiser/ SAI, 1998) is a relatively simple three-dimensional grid-based air quality model which has been reviewed by a panel of experts (Seigneur et al., 1999a). It has a meteorological pre-processor which reformats MM4 or MM5 model output for use in the REMSAD system. Emissions inputs must also be generated externally.

The core Aerosol and Toxics Deposition Model (ATDM) included in REMSAD is well suited for regional scale deposition modeling due to its grid structure which is based on latitude and longitude in the horizontal and terrain-following sigma-pressure coordinates in the vertical.

The REMSAD aerosol module calculates fine particle mass yields by assuming that the concentrations of certain chemical species are always in the particulate form as $PM_{2.5}$. Though a kinematic treatment of aerosol formation is lacking (along with certain properties such as particle size distribution and water content of particles), REMSAD performs well in terms of calculating sulfate concentrations (sulfate is assumed to exist entirely in the particulate phase). However, it is less successful at simulating total organic PM, nitrate and crustal PM concentrations. Improvements in aerosol inventories as well as aerosol formation mechanisms included in REMSAD may be necessary to address these shortcomings.

A particularly useful feature of REMSAD from a regional haze perspective is the inclusion of a postprocessor, XYVIS, which calculates visibility in deciviews (dv). This calculation is performed using species-specific extinction efficiencies and a relative humidity (RH) function developed by the National Park Service. The advantage of this approach is that the calculations, while not scientifically rigorous, are consistent with the federal regulations, easing the task of producing demonstrations of reasonable progress.

Despite this apparent complexity, REMSAD's extremely simplified chemistry in significantly reduces computation time. The simplified chemistry and the lack of aerosol dynamic modules severely limits REMSAD's ability to accurately simulate specific episodes, but this model may nevertheless be appropriate for simulating average conditions over longer periods of time. It has been suggested (USEPA, 2000) that a year-long simulation may be needed for regional haze purposes, although it is not clear that generating a year of validated and properly formatted meteorological data is not an overly ambitious task.

Currently available emissions inventories for the REMSAD modeling system are based on USEPA 1996 base year national inventory. These inventories have been updated at least to 1997 to include primary $PM_{2.5}$ emissions estimates and speciation of VOC emissions; however, a review performed for the REMSAD system (Seigneur et al., 1999a) determined that better emissions inventories will be needed for testing emissions control strategies related to fine particles.

In contrast to REMSAD, air quality models such as the EPA Models-3 Community Multiscale Air Quality (Models-3/CMAQ)[83] modeling system (Byun and Chin, 1999) or the Urban Airshed Model – Aerosol (UAM-AERO) (Lurmann et al., 1997) are more appropriate for simulating episodic fine particle events. Due to their complexity these models are far more computationally demanding and require many hours of computer time to simulate a single day.

The Urban Airshed Model – Aerosol (UAM-AERO) is based on the Urban Airshed Model – Variable (UAM-IV) (Scheffe and Morris, 1993) which has been developed for episodic ozone events. It is an Eulerian, multilayer, nested grid model with grid spacing typically from 4 to 50 km. The UAM-IV and UAM-AERO models do have a plume-in-grid module which allows them to properly account for complex chemistry that occurs immediately downwind of large point sources before diluting the resulting species into an entire grid cell. UAM-AERO uses the CB-IV chemical mechanism which contains a fairly complete treatment of gas phase chemistry. In terms of aerosol dynamics, UAM-AERO uses a sectional representation of particle size distribution. This approach has been shown to accurately reproduce major features of the particle size distribution and should be sufficient for visibility studies (Wu et al., 1996) but may have limited accuracy in terms of studying fine details of the distribution's evolution (Zhang et al., 1999).

Models-3/CMAQ is the result of USEPA's efforts to develop and foster a community modeling system. The Models-3 software system is intended to provide an easy-to-use framework for air quality modeling applications and tools for analysis. The initial release of a beta version of the software (June 1998) has been criticized for its less than seamless installation and operation. However, the completed framework promises

[83] USEPA has suggested that Models-3/CMAQ is appropriate for year-long simulations; however, we note that this may represent a prohibitive task given the significant computation time required for CMAQ's more sophisticated chemical mechanisms and aerosol dynamics modules. The same restrictions in regard to developing year-long meteorological and emissions inputs apply equally to Models-3/CMAQ and long-term models such as REMSAD.

to be significantly more powerful than typical air quality models due to its sophisticated user interface which attempts to simplify and organize the entire simulation process.

Deficiencies in some aspects of the science code for this modeling system have been noted as well. In order to achieve some computational savings, Models-3/CMAQ represents the particle size distribution by three gaussian distributions (one for each of the three modes: nuclei, accumulation, and course) each with a fixed standard deviation. Zhang et al. (1999) noted that the modal representation used in Models-3/CMAQ has difficulty accurately representing coagulation and condensation processes due to the use of a fixed standard deviation for each mode. This study also suggests that Models-3/CMAQ (and other air quality models including UAM-AERO) may benefit from an updated particle nucleation parameterization which is based on gas/particle partitioning instead of calculated nucleation rates.

A newly released version of Models-3 (August, 2000) promises to rectify many of these early deficiencies. The Models-3/CMAQ system is intended to evolve over time as users contribute additional modules and make modifications; however, the current version of Models-3 is compatible with the output of the MEPPS emission processor and the MM5 meteorological model. A recent hands-on training of the Lake Michigan Air Directors Consortium (LADCo) modeling staff left the impression that the Models-3 system offers exciting opportunities in the future and that the data input and output visualization components are well developed now (LADCo, 2000). This same review, however, faulted the graphical user interface for being "cumbersome and flawed" and recommended using the Models-3 system without the interface.

The CMAQ Chemical Transport Model (CCTM) is the centerpiece of the CMAQ framework. A choice of advection schemes is available for horizontal and vertical advection. Vertical velocity can be handled either by eddy diffusion, or the Asymmetric Convective Model (ACM) for convective conditions. Eddy diffusion is used for horizontal diffusion. Gas phase chemistry is handled by either the RADM2 or CB-IV mechanisms and can be used with either the Sparse Matrix Vectorized Gear (SMVGEAR) or the Quasi-Steady State Approximation (QSSA) solver.

Models-3/CMAQ uses the Region Particulate Matter (RPM) aerosol model (based on RADM) to calculate lognormal distributions of the three modes of particles, ultrafine, accumulation and course. Cloud processes are also modeled borrowing algorithms from RADM to model deep convective clouds and shallow clouds at the 36 and 12 km resolutions. Models-3 does have plume-in-grid capability for gas phase species, and a plume-in-grid mechanism for PM is under development.

Other Eulerian grid models are available for regional haze planning and may be preferable to those discussed above. Environ is expected to release the latest version of CAMx-AERO which some states may prefer to other models. Another model, the Urban-Regional Multiscale (URM) model, has been used in the Southern Appalachian Mountain Initiative (SAMI) to look at haze in that region. Results so far have shown reasonable agreement between modeled simulations and observations for aggregate visibility characteristics averaged over several days (Huber, et al., 2000).

B.4 Source Dispersion Models

Another type of model for understanding the distribution of haze forming particulate matter in the atmosphere is the source dispersion model. CALPUFF (Scire et al., 1998b, Strimaitis et al., 1998) is a Lagrangian puff model which has recently been proposed as a USEPA Guideline model for regulatory applications involving long range transport. This model was designed to assess the impacts of transport, dispersion, chemical conversion, and wet and dry deposition of SO_2 and NO_X emissions from point sources such as power plants (Scire, 2000). Emissions are advected as Gaussian puffs according to specified meteorological inputs (the output of the CALMET meteorological system which can be used in a diagnostic or prognostic mode). This is similar to the approach used for trajectory modeling, but as these puffs are advected, various parameterizations calculate concentration changes in the puff due to diffusion, convection, wet and dry deposition, as well as movement over and around complex terrain features. Impacts on specified receptors are calculated by summing the contribution from each puff to the receptor site at a given time.

The variety of physical and chemical mechanisms available, including a particulate module, and the flexibility with regard to the number of potential emission sources and receptor sites, make this model adaptable for use over regional scales that encompass a large number of point or area emission sources.

In comparisons with the USEPA's ISCST3 model, another popular source dispersion model, CALPUFF was better able to simulate SO_2 concentrations due to power plant emissions (Strimaitis et al., 1998).

Regardless of which source dispersion model is selected, this approach may provide a powerful demonstration of the impact that emissions have on particulate concentrations and visibility conditions in Class I areas.

B.5 Receptor Models

The fundamental difference between source models and receptor models is that receptor models take monitored data as their input and try to determine characteristics of the sources. Source models assume known sources and try to estimate the future characteristics (e.g. pollutant levels) usually at monitored sites for comparison. Among receptor techniques there are both mathematical techniques, predominantly factor analysis, and ensemble trajectory techniques. Source apportionment modeling is a mathematical approach to receptor based modeling. Based on monitored concentrations of speciated PM mass, source apportionment models calculate the compositional profile of sources which best fit with the observations. When used in conjunction with ensemble trajectory techniques, location information can also be determined. Some of these models may also require information regarding likely tracers or compositional profiles for individual sources in order to isolate their specific contribution to a given observation.

The Chemical Mass Balance (CMB) model (Friedlander, 1973) is regarded as the origin of this receptor based approach. CMB requires the input of source profiles, or a

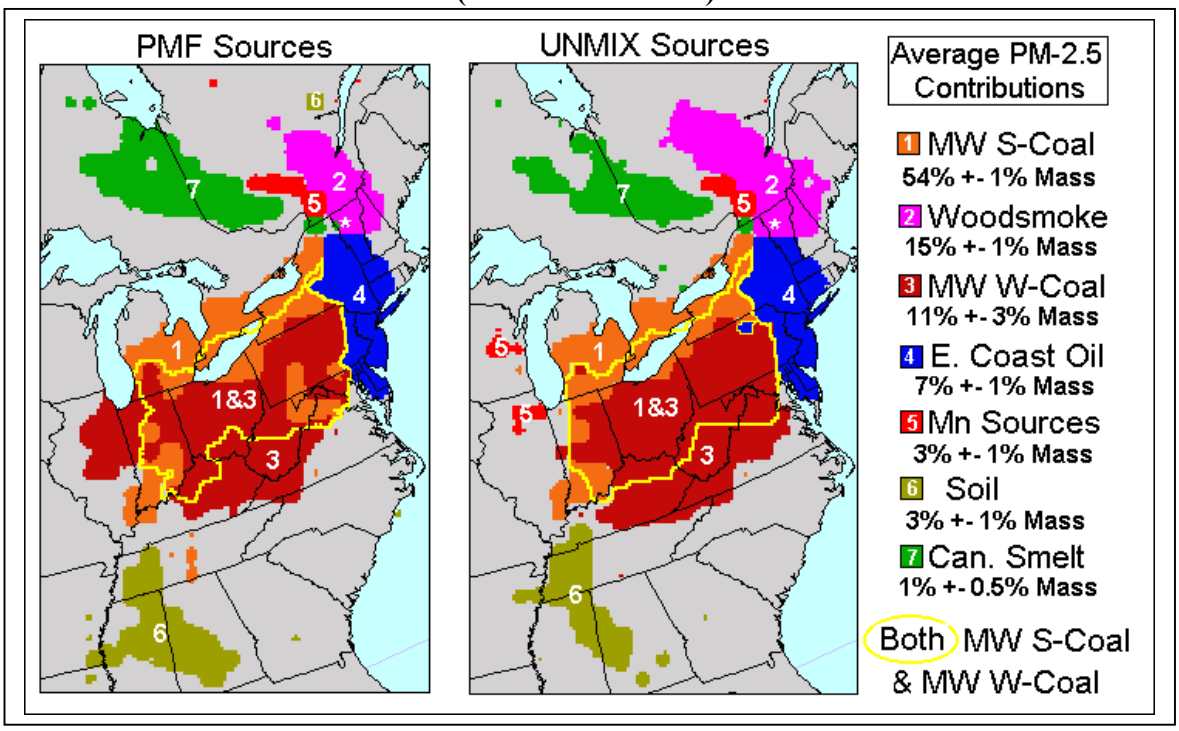
listing of the chemical composition of emissions due to each source to be investigated. This technique calculates the contribution of each source to a specific measurement which provides the best fit to the observed concentrations. While this process is straight forward for PM2.5 derived from primary emission sources, the use of CMB modeling for secondary PM constituents is problematic. Techniques are, however, being developed which allow CMB to deal with this in a limited way that isolates the total mass of secondary component but cannot apportion it to specific sources.

Though developing accurate source profiles can be a costly and time-consuming process, the USEPA maintains an archive of source profiles (SPECIATE) on the internet (http://www.epa.gov/ttn/chief). The most recent version of this model, CMB8, is expected to be available from USEPA soon and will offer a graphical user interface that should greatly ease the use of this tool.

A more recent technique employed by receptor models is that of factor analysis or the closely related principle component analysis (Harmon, 1976). Simply stated, these techniques calculate not only the best combination of sources needed to match the observations, but also the individual compositional profiles of each source identified to contribute to that observed measurement. By looking at all the data, these models can identify correlations that occur between different species indicating origin from a common source. Once sources have been identified, these models then proceed to calculate the contribution of each source to individual measurements. Positive Matrix Factorization (PMF) (Paatero, 1994) and UNMIX (Henry, 1997) are popular examples of multivariate receptor models employing the factor analysis and principle component analysis techniques.

When combined with ensemble trajectory techniques, those measurements that are dominated by particular sources can be related to geographical source locations. An example of how these techniques can work together is shown in Figure VII-2 where both UNMIX and PMF were used to calculate the profiles for sources that affect the Underhill, Vermont PM monitor. Residence time analysis was used with back trajectories to determine the most likely geographical area of influence from each source identified by UNMIX. Potential Source Contribution Function (PSCF) analysis was used with the PMF results (Poirot et al. 2000). In this figure, seven source profiles were identified by each of the models (PMF and UNMIX) as contributing substantially to the observed PM data collected at Underhill. These source profiles have been associated with specific sources based on the respective modelers' interpretations of their characteristics: Midwestern summer and winter coal, woodsmoke, East Coast oil, Canadian Mn (manganese) sources, soil, and Canadian smelters. Trajectories were then used to associate the upper 10 percent of daily source contribution for each source with a geographical region of influence. In general, these two models agree quite well with each other and have identified regions which likely contribute to the fine particles present in northern Vermont.

Figure VII-2: Factor analysis of 1988-1995 observations at Underhill, VT (Poirot et al. 2000).



B.6 Trajectory Models

Trajectory models, including ATAD (Atmospheric Transport and Dispersion), HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) and the CAPITA Monte Carlo, can aid the SIP development process in several ways. These models can be run in either a foreward direction (starting from source locations) or backward (from receptor locations). The HYSPLIT and CAPITA models are configured to run from the archived output of gridded eulerian meteorological models, while ATAD operates directly from the archived meteorological observations. All three models allow inclusion of dispersion estimates when run in a forward mode. The CAPITA model also allows estimated influences of vertical mixing to be included in the backward mode. Large numbers of backward trajectories from specified receptors can also provide useful input for a variety of ensemble trajectory assessment techniques, such as cluster analysis and residence- time analysis discussed in the preceding section.

In general, Lagrangian trajectories can be used to demonstrate the likely origin of an airmass and, in conjunction with other monitored data, can build a solid case for the origin of pollutants which contribute to haze. Trajectories can be calculated forward and backward from multiple source (or receptor) points at different levels of the atmosphere. Results of such analyses, using the HYSPLIT model (Draxler 1999) are cited earlier in this report (See Figures III-10 and III-12 in Chapter III). HYSPLIT was also used in

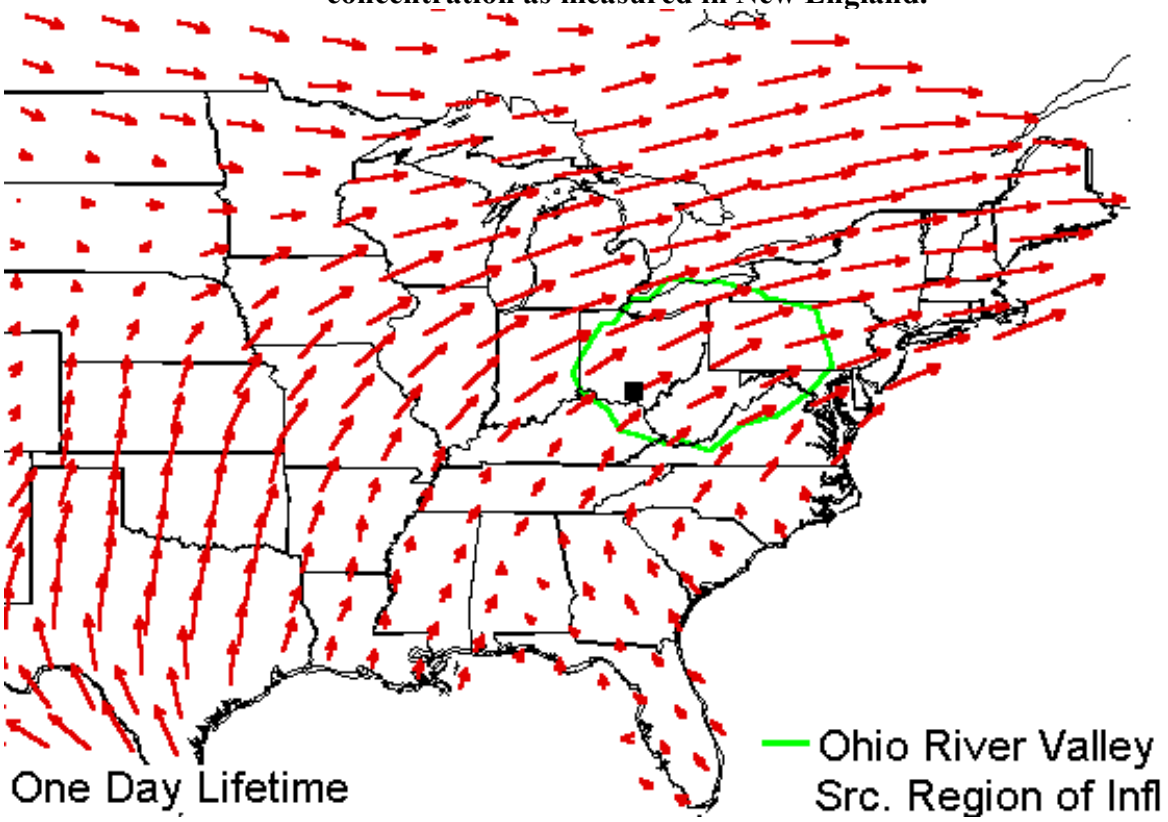
conjunction with a source dispersion option to illustrate the impact of 17 midwestern SO_2 sources during the mid-July, 1999 episode discussed in Chapter III (see Figure III-19).

For regional haze purposes, it would be extremely useful to develop historical and continuing archives of backward trajectories from one or more of these models, for each Class I area for all IMPROVE sample days. This may be an area where the OTC haze group could work closely with the National Park Service, which has considerable expertise in the application of these trajectory models and ensemble trajectory assessment techniques.

The accuracy of trajectory models is highly dependent on the accuracy and resolution of input meteorological data as well as prevailing conditions (e.g. high vertical shear is known to significantly reduce trajectory accuracy (Stunder, 1996)). Spatial (temporal) resolution for currently available meteorological data sets used with the HYSPLIT model is approximately 80km (1 hour). This may not account for complex flows in mountainous or coastal areas. Hence, the development of high resolution meteorological data for the entire domain of interest should be considered.

A similar technique in an Eulerian framework, region of influence analysis, was used during the OTAG (Ozone Transport Assessment Group; see footnote 74) process to sort wind fields by measured pollutant level at a specific site. Averaging wind fields from times of highest observed pollutant level identifies wind patterns which are most likely to lead to high pollutant time periods. Figure VII-3 shows a averaged wind vectors

Figure VII-3: Transport vectors averaged over 20 percent highest daily average ozone concentration as measured in New England.



for the 20 percent of days with the highest daily average ozone concentrations as measured in the New England Region between 1991 and 1995. The source region associated with these high ozone days is shown in green and clearly reflects the role of transport in these events.

C. Comparison of Selected Aerosol Modules

Several recent review articles have been written regarding the structure and performance of air quality models and the aerosol modules used within them. Russell and Dennis (2000) have just published a critical review of photochemical models in the recent NARSTO (North American Research Strategy for Tropospheric Ozone) assessment issue of the journal *Atmospheric Environment*. Although this article is primarily focused on models designed for ozone applications, it provides a thorough overview of model structures and identifies the major features of available aerosol dynamics routines.

A more complete description of the types of particle models that are available is given by Seigeur et al. (1999b). This work provides an overview of source models, including episodic and long-term models, receptor models and other techniques such as inverse modeling and speciated rollback. Seigneur concludes with recommendations related to modeling fine particles, however these are more relevant to the proposed $PM_{2.5}$ standard than to visibility planning as they focus on the modeling of high particulate mass episodes.

Zhang et al. (1999, 2000) present two more detailed examinations of the aerosol dynamics and inorganic aerosol thermodynamics modules included in many widely used air quality models. Coagulation, condensation, nucleation and mass transfer are compared for six different air quality models. Highly detailed aerosol models (which, because of their continuous treatment of the particle size distribution, are too computationally demanding to be used in 3-D air quality models) are taken as "exact" for comparison purposes. In general, results indicate that the sectional size distribution (used by models such as CIT, SAQM-AERO and UAM-AERO) is superior at simulating coagulation and condensation to the modal size distribution representation with fixed standard deviations. The modal representation (which is used by Models-3) can be allowed to vary and it is not clear that these deficiencies remain when variable standard deviations are used. Models produce divergent results when nucleation modules are compared, suggesting that alternatives to the current parameterizations (which are based on theoretical nucleation rates for all models) may be needed. An example given is a parameterization based on relative rates of nucleation and condensation.

In reviewing thermodynamic equilibrium modules, Zhang and coworkers (2000) found that results between models are generally consistent with two exceptions: during high nitrate and chloride concentrations, and low to medium relative humidity conditions. Given the relatively high humidity in the Northeast and Mid-Atlantic and generally lower levels of nitrate than are found in the western U.S. we simply note that these discrepancies should be considered when conditions in the region warrant.

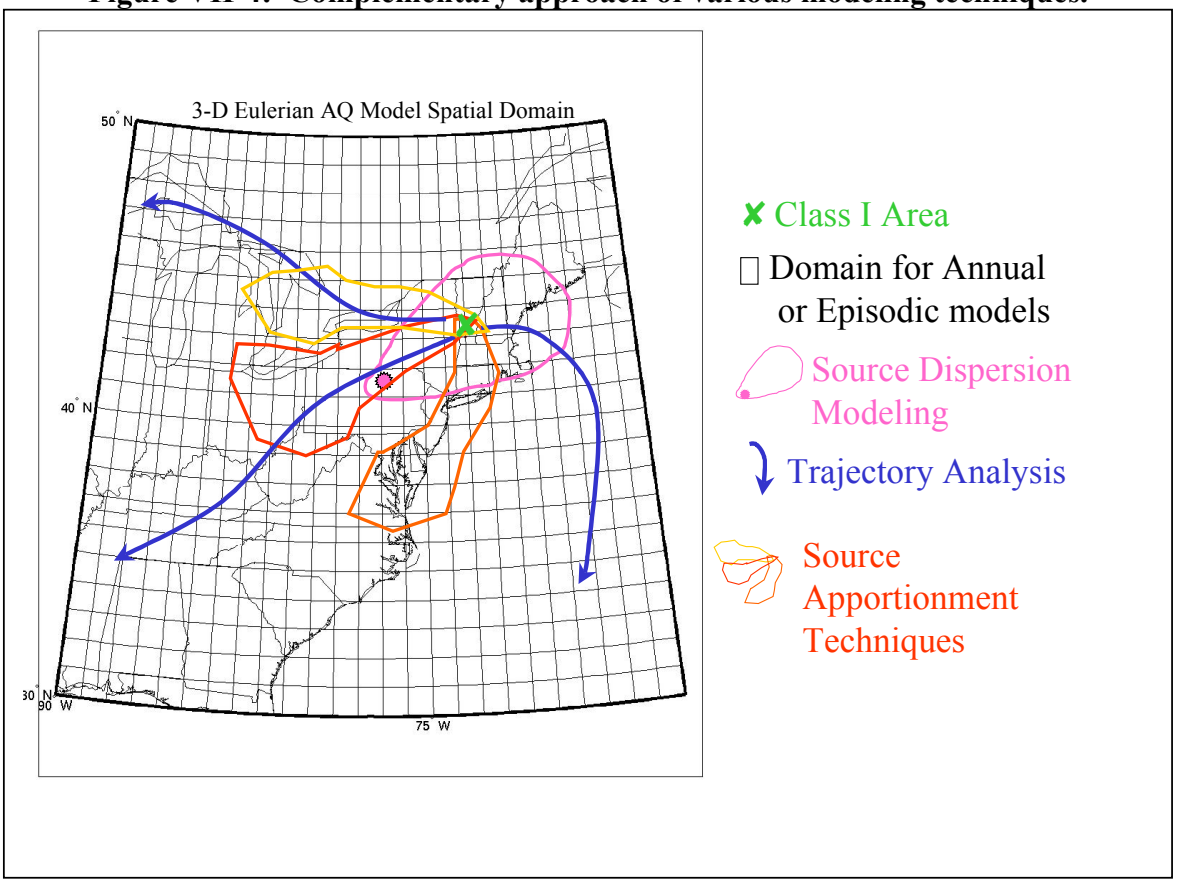
As the state of aerosol science is advancing rapidly and expected applications for visibility compliance modeling are several years away, there is a tremendous need for continued model development as well as for comparative assessments to ensure that remaining deficiencies are addressed in the near future.

D. Recommended Approach for Modeling Activities

A successful demonstration of reasonable progress may include analyses generated by one or more of these models (see Figure VII-1) and will, in fact, benefit from the diversity of information provided by different techniques. Figure VII-4 demonstrates how the use of several different techniques can provide comprehensive geographic information about the source regions that affect a particular Class I area.

For example, a long-term air quality model, such as REMSAD, might show how a change over time in the emissions from a number of geographically dispersed sources would lead to corresponding changes in visibility. A more detailed (and thus more computationally intensive) air quality model, like UAM-AERO or Models-3/CMAQ, may be needed to show precise linkages between known emissions and observed fine particle measurements on shorter time scales. These types of air quality models are represented by the black grid shown in Figure VII-4.

Figure VII-4: Complementary approach of various modeling techniques.



A source apportionment model such as UNMIX, can be used in conjunction with an ensemble trajectory approach, like residence time analysis, to identify sources or source regions whose emissions are associated with a high proportion of particulate matter observed at monitors in a Class I area. These techniques can effectively demonstrate the link between specific source regions and fine particles observed in Class I areas, as depicted by the yellow, red and orange borders shown in Figure VII-4. Trajectory cluster analysis provides strong qualitative support for any conclusions drawn from other air quality models by identifying the most common routes of origin for airmasses which pass over Class I areas (see blue arrows in Figure VII-4).

The impacts of specific sources can be examined using a Lagrangian source dispersion model, like CALPUFF or HYSPLIT (magenta border in Figure VII-4). This may be needed to demonstrate the added visibility impairment that could potentially result from new sources, especially near Class I areas that are already close to natural visibility conditions on the 20 percent best days.

All of these techniques should be pursued for SIP development; however, opportunities exist for distributing these activities amongst states to distribute the burden of modeling activities. In addition to performing model simulations, development of meteorological grids and emissions inventories should be included among the tasks to be performed. States should adopt a role within the structure of the regional process (coordinated through the RPO) to insure that the breadth of analytical techniques will be explored. This combined effort will result in a comprehensive and robust characterization of current visibility conditions in the Northeast and Mid-Atlantic regions and will be necessary to demonstrate reasonable progress toward visibility goals.

The OTC Modeling Committee has developed a technical plan regarding modeling, data analysis and policy issues related to national air quality standards. This plan includes a collaborative effort with LADCO and the North Carolina Department of Environment and Natural Resources to unify regional modeling efforts. Efforts to develop modeling protocols (e.g. consistent time periods, geographical domains, and meteorological and emissions input data) will aid states, tribes, FLMS and other RPOs to work together in creating modeled simulations that are representative of visibility conditions across the regions. These efforts are consistent with the approach described in the preceding paragraph and lay the foundation for developing a complete modeling strategy.

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VIII. Visibility Monitoring

Visibility is typically thought of as "how far" one can see. However, the enjoyment of scenic vistas also depends on "how well" one can see. This includes the ability to observe color, texture, and contrast within the visual range. Given the many attributes of a scene, a variety of monitoring techniques are used to characterize all aspects of a view, including scene, optical, and aerosol monitoring. Effective visibility monitoring programs must incorporate aspects of each technique.

A. Basic Monitoring Techniques

The most direct and comprehensive way to monitor visibility is with photographs and this approach is often used as part of most visibility monitoring programs. However, given the variety of air quality, meteorological and lighting conditions that can exist at an individual site, it can take thousands of photographs to adequately characterize visibility conditions at a particular location. The Interagency Monitoring of Protected Visual Environments (IMPROVE) program, for example, recommends taking photographs three times per day for five years in order to adequately characterize the range of visibility conditions at a single monitoring site. Digital, film and time-lapse photography are all forms of scene monitoring. Major drawbacks of this approach, however, are that it does not provide quantitative information regarding visibility and it is cumbersome to assess, given the variety of conditions that must be subjectively differentiated.

Optical monitoring provides a quantitative and continuous indicator of visibility conditions. The most common forms of optical monitoring data are obtained by measuring the amount of atmospheric scattering and/or absorption of an artificial light source (lamp) of known luminescence. A major drawback of optical monitoring is that because it measures light and not the particles affecting light, it provides limited information regarding the types of particles or emission sources that contribute to visibility impairment.

Aerosol monitoring provides information on particle composition by making direct measurements and conducting speciation analyses on collected samples. A major drawback of most current aerosol monitoring programs is that they collect samples averaged over a 24-hour period every three days, limiting the temporal resolution of subsequent analyses utilizing these data. Aerosol monitoring also has higher annual operating (lab) costs and is subject to a variety of biases stemming from the equations that are used to convert speciated quantities of particles to estimates of visibility conditions. An advantage of both optical and aerosol monitoring techniques is that natural factors, such as cloud cover and sun angle, do not affect their measurement.[84] In this manner, optical and aerosol instruments do not measure visibility per se, but measure visual air quality, or that portion of visibility impairment due to air pollution. Since these techniques typically utilize ground-based instruments, they are not well suited for

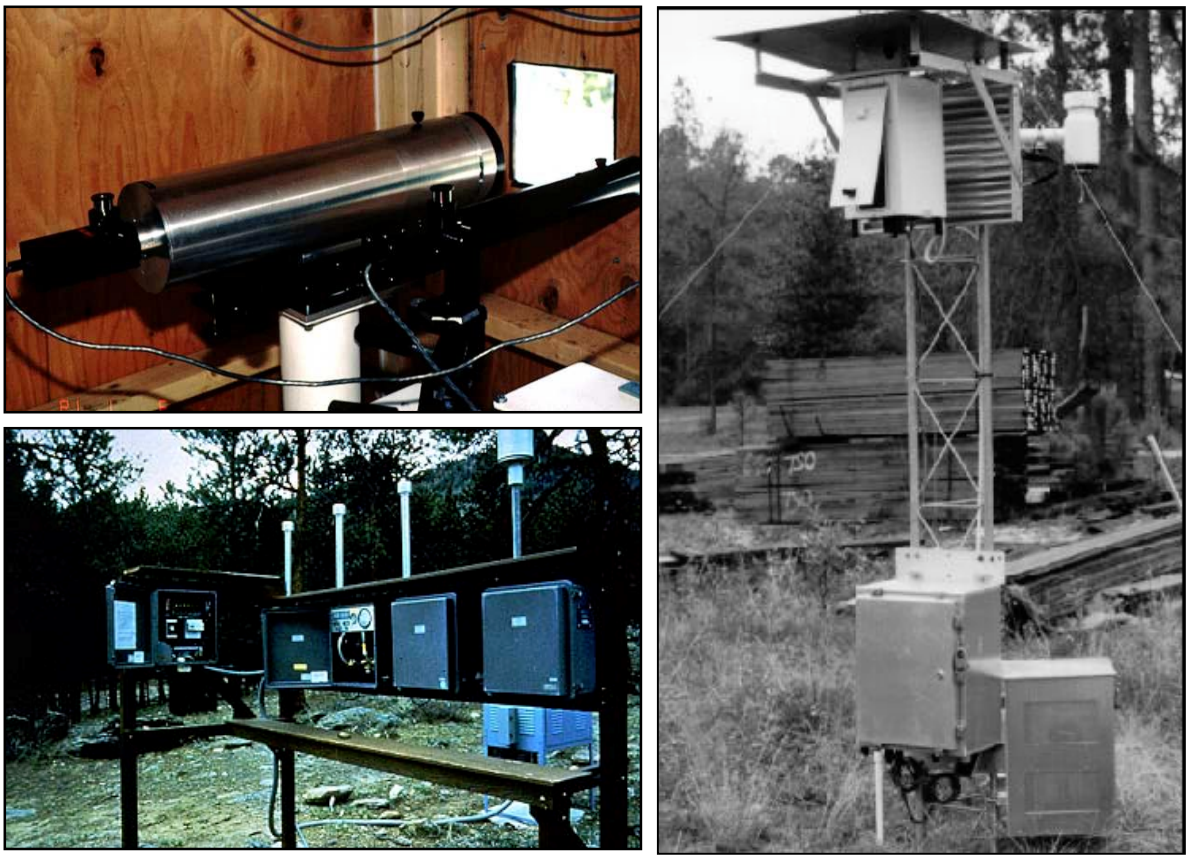
[84] Most optical measurements are affected by rain, fog, and mist. For this reason, optical data collected during periods with relative humidity in excess of 95 percent (as a surrogate for rain, fog, or mist) are usually flagged as suspect or invalid.

distinguishing a uniform haze from a surface-level haze. In addition, they may not detect elevated layers of haze or plume blight.

The transmissometer and nephelometer are the most common instruments used for optical monitoring. Transmissometers operate over an open path of 1 km to 10 km and measure total light extinction (b_{ext}) by determining the loss of light (due to scattering and absorption of the intervening atmosphere) from an artificial light source of known luminescence at a fixed distance. Nephelometers measure light scattering (b_{scat}), which is responsible for most light extinction in rural areas of the eastern U.S. Nephelometers operate over a very short open path (few inches) and are easier to install and maintain than transmissometers. However, they measure only a portion (albeit a large majority) of total light extinction. Light absorption (b_{abs}) can be measured continuously by aethalometers, which measure the intensity of light transmitted through a filter tape that ambient air has passed through and on which absorbing particles have collected. Relatively few aethalometers have been deployed in the field, however, and absorption is typically determined through aerosol measurements or by subtracting nephelometer data (b_{scat}) from transmissometer data (b_{ext}).

Several varieties of instruments are available for aerosol monitoring, but the one historically used and recommended by USEPA is the IMPROVE monitoring method. This method employs a set of four aerosol samplers that simultaneously collect a 24-hour sample every third day onto a variety of filter media. Three of the samplers collect $PM_{2.5}$ on teflon, nylon, and quartz filters. This allows for a comprehensive analysis of $PM_{2.5}$ species by different laboratory techniques. The fourth sampler collects PM_{10} on a teflon filter to identify the amount of coarse mass in the atmosphere, which can have a significant effect on visibility in dusty or fire-prone areas in the western U.S. Non-IMPROVE aerosol samplers can be used for visibility monitoring, but it is recommended that they collect samples on teflon, nylon, and quartz filters and employ the same laboratory techniques (USEPA, 1999). Photographs of a transmissometer, nephelometer, and IMPROVE aerosol sampling system are provided in Figure VIII-1 (schematic diagrams of these instruments are shown later in Figure VIII-3, 4, and 5).

Figure VIII-1 Photographs (clockwise from top-left) of a transmissometer, nephelometer, and IMPROVE aerosol sampling system.



B. USEPA Monitoring Guidance

In June 1999, USEPA issued guidance to provide a written reference for organizations conducting monitoring of visibility and particulate matter for regulatory, planning, or research purposes (USEPA, 1999). The guidance focuses on instruments and methods currently in use and considered by USEPA and IMPROVE as best suited for use at this time. The guidance is not meant to dictate USEPA monitoring requirements, to define policy, standards, or data interpretation methods, or to address the human perception of visual air quality. Rather, it provides a strategic framework for state monitoring programs.

The guidance is written primarily for individuals familiar with aerometric monitoring principles and those responsible for designing and operating monitoring program to characterize visibility and/or particulate matter. Table VIII-1 summarizes the seven major sections of the guidance.

Table VIII-1: Organization and content of USEPA's visibility monitoring guidance

Section 1	Introduction Presents the purpose of the Guidance, the Guidance organization, and a summary of legislative and regulatory requirements that provide the basis for visibility protection and visibility monitoring.
Section 2	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	Aerosol monitoring Provides detailed examples of standard operating procedures, 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	Optical monitoring Provides detailed examples of optical monitoring protocols, including transmissometer and nephelometer monitoring systems.
Section 5	Scene monitoring Provides detailed examples of scene monitoring protocols, including 35mm and time-lapse monitoring systems.
Section 6	References
Section 7	Glossary of terms and abbreviations

USEPA's visibility monitoring guidance identifies six specific objectives to support the visibility protection regulations for mandatory Class I areas. There are, however, other potential applications and uses for visibility monitoring data including studies on $PM_{2.5}$, climatological effects of fine particles and model verification to name a few. The objectives identified in USEPA guidance are to:

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

B.1 Additional USEPA Resources

In addition to supporting regional haze and visibility monitoring through the IMPROVE program (whose role is described in the next section), USEPA has supported the deployment of a fine particle monitoring network. While the primary purpose of this network is to aid in the designation and enforcement of a $PM_{2.5}$ standard (currently under review by the U.S. Supreme Court), $PM_{2.5}$ observations provide insights regarding the spatial and temporal patterns of visibility impairment. An overview of the national $PM_{2.5}$ monitoring network has been presented by Sheffe and Bachmann (2000).

The fine particle network consists primarily of 850 Federal Reference Method (FRM) or Federal Equivalency Method (FEM) samplers to monitor fine particle mass. Of these monitors, 750 are intended for use in determining NAAQS compliance, while another 100 samplers (2 per state) are to be used in characterizing background and transport.

An additional 200 fine particle mass monitoring sites are to be deployed nationally for spatial averaging purposes or special studies. Data from these monitors will not be considered for purposes of NAAQS attainment designations, provided they operate for less than 2 years.

In addition to the FRM samplers, 100 continuous fine particle mass monitors are to be deployed, of which 52 are to be co-located with FRM monitors in the largest cities (greater than 1,000,000 population). Continuous $PM_{2.5}$ measurements are intended to provide real-time estimates of fine particle levels as well as to provide input to public information systems (similar to current ozone mapping efforts).

Finally, the $PM_{2.5}$ network will include up to 300 routine chemical speciation sites to assess long-term trends in the composition of $PM_{2.5}$. Of these sites, 50 are required to follow a protocol similar to that used in the IMPROVE program and will exist in mostly urban locations as part of a "trends" network. States have significant flexibility using the funding for the remaining 250 speciation sites and are exploring ways to enhance the current state-of-knowledge regarding the magnitude and trends in fine particle constituents. However, it is expected that many of these sites will operate in a manner similar to the 50 "trends" sites.

The final component of the national $PM_{2.5}$ network is the expansion of the IMPROVE program as described in detail in the following section.

C. The IMPROVE Program

Data from the IMPROVE program represent a crucial input to state and tribal planning efforts under the 1999 regional haze rule. The IMPROVE program was established, in part, as a result of a 1985 lawsuit brought by the Environmental Defense Fund (EDF) against the USEPA

which sought to force the Agency to develop Federal Implementation Plans (FIPs) for states without approved visibility provisions in their SIPs. At that time, only seven SIPs with visibility provisions were approved pursuant to the 1980 visibility rule.

Between 1986 and 1999 the IMPROVE program was funded jointly by the National Park Service and USEPA, with USEPA funds coming directly from state Section 105 grants. Since 1999, federal funding has increased to support network expansion. The additional funds are provided through state Section 103 grants.

The National Park Service manages the IMPROVE program with the support of several contractors who perform specific components. These contractors include the University of California at Davis (site selection, filter management, gravimetric and elemental analyses and database management), the Desert Research Institute (elemental and organic carbon analyses), the Research Triangle Institute (ion analyses), Atmospheric Resource Specialists, Inc. (optical, scene and meteorological data collection), and the Cooperative Institute for Research in the Atmosphere (data analysis and website support).

The IMPROVE program has been extremely successful in meeting its monitoring objectives. Methods and procedures used in the network form the basis of USEPA's visibility monitoring guidance and have had a substantial influence on the design of the national $PM_{2.5}$ speciation network. Another tribute to IMPROVE's success is that, with heightened awareness of particle-related health concerns in urban areas, it continues to be the nation's best source of $PM_{2.5}$ trend and speciated data.

The IMPROVE program will play several important roles in the implementation of the regional haze rule and $PM_{2.5}$ standards. These include (Malm, 2000):

- Providing a standard suite of visibility monitoring data (in accordance with USEPA visibility monitoring guidance) for each mandatory Class I area for establishing baseline and natural visibility conditions, tracking progress, verifying predictive models, and providing input for receptor models.
- Providing anchor points for additional routine monitoring, special studies, and comparisons with other areas;
- Satisfying USEPA requirements for states to monitor $PM_{2.5}$ at background and transport locations; and
- Accommodating sites (protocol sites) outside Class I areas, which states may wish to implement for enhanced visibility or other monitoring purposes. Approximately 10 protocol sites are planned for deployment in the Northeast and Mid-Atlantic states (in ME, VT, MA, CT, NY and PA).

In addition to routine monitoring, IMPROVE sponsors research to verify measurements and to improve quality control and operations. It has also provided support to several special studies. These studies are typically done to improve the attribution of visibility impacts to various emission sources and may involve time lapse photography, release and measurement of tracer materials from suspected contributing sources, enhanced surface monitoring, and measurements taken aboard aircraft. Special studies have involved the Mohave electric generating station (1992), Shenandoah National Park (1991), northwest Washington (1990), the

Navajo electric generating station (1987-90), and the photographic monitoring of plume blight from a pulp mill near the Moosehorn Wilderness Area in Maine.

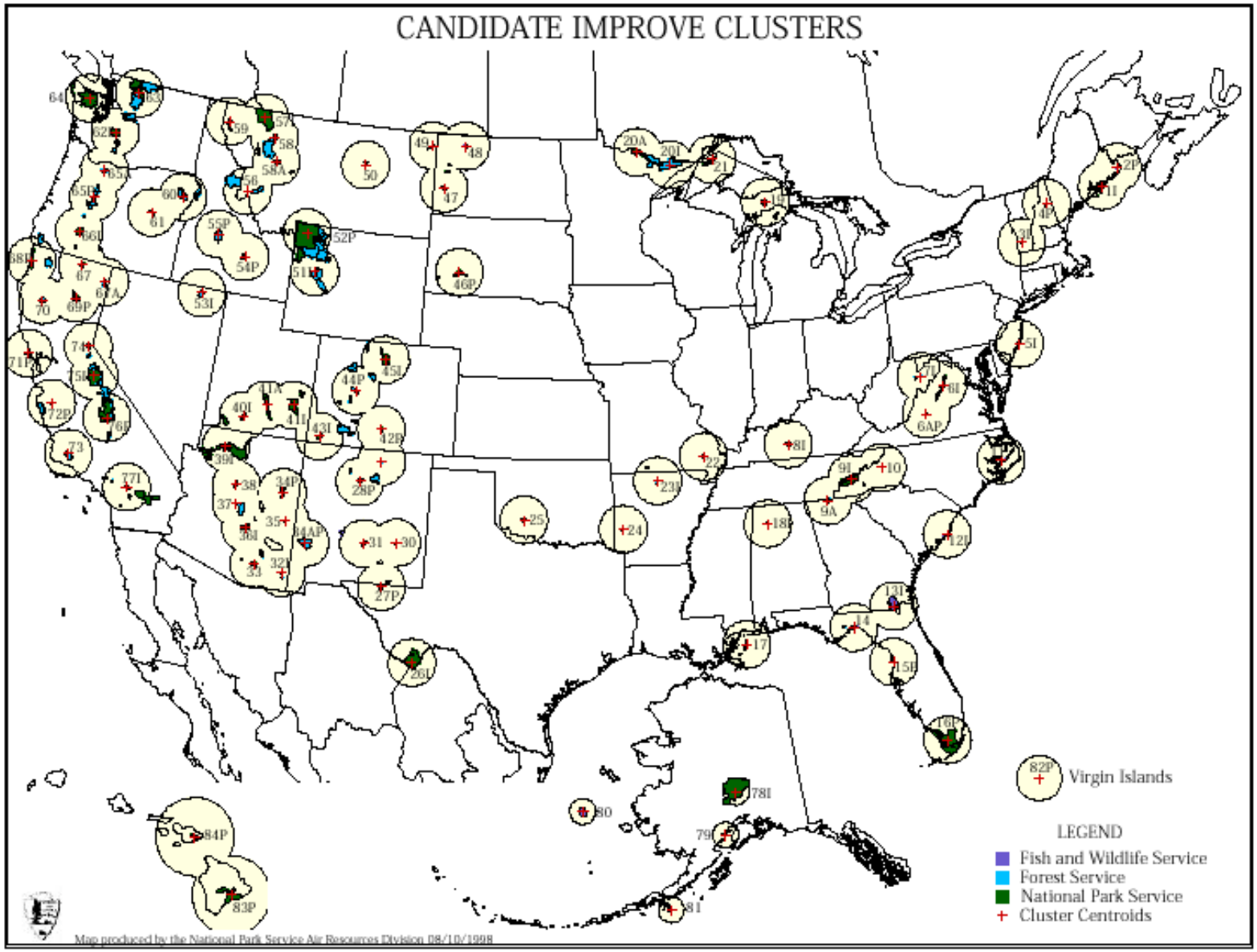
The IMPROVE program is undergoing a significant expansion of its monitoring network, including some operational changes to help implement the regional haze rule and proposed $PM_{2.5}$ standards (Pitchford et al., 2000). These include:

- Distribution of new and improved samplers to all IMPROVE and IMPROVE protocol sites.[85] The new samplers have microprocessors and data loggers that will improve quality control and data capture and enable the transition from Wednesday/Saturday sampling to every third day sampling;
- Expansion from 30 IMPROVE sites and 40 protocol sites to 110 IMPROVE sites and at least 23 protocol sites (10 in the Northeast, 8 in the Midwest, and 5 in Arizona). IMPROVE protocol sites in Maine and New Hampshire will become full IMPROVE sites as a result of this process;
- Accommodation of protocol sites outside Class I areas (e.g., urban areas);
- Accommodation on the Steering Committee of "associated members" (e.g., states providing significant contributions to the program);
- Changing the sampling schedule from Wednesday and Saturday to every 3rd day to coordinate data collection with the $PM_{2.5}$, PAMS, and toxics networks;
- Providing data and reports on an Internet web site;
- Submitting data to AIRS; and
- Publishing new documents and videotapes for public education.

IMPROVE's strategy for monitoring all 156 mandatory Class I areas is to cluster areas that are located close to one another and share the same airshed. Two or more areas are clustered together if a monitor can be located within 100 km of each area and at an altitude of within 100 ft or 10% of the minimum and maximum altitudes in both areas (Pitchford, 1998). Some exceptions to this rule are made on a case-by-case basis. There are two clusters in the Northeast. The IMPROVE monitor in the Moosehorn Wilderness Area meets the cluster criteria, and therefore provides valid data for purposes of visibility monitoring in the Roosevelt-Campobello International Park. The IMPROVE monitor at Camp Dodge, NH slightly violates the elevation criteria, but has been deemed valid by the IMPROVE Steering Committee to represent a cluster for the Great Gulf Wilderness Area and the Presidential Range - Dry River Wilderness Area. Clusters for all Class I areas in the U.S. are provided in Figure VIII-2. As of September 2000, 96 of the 110 clusters have received a new IMPROVE sampler, and most of these have changed their sampling schedule to one in three days.

[85] IMPROVE protocol sites use the same samplers and laboratories as IMPROVE sites but do not necessarily follow the same schedule and siting criteria and may not conduct a full suite of chemical analyses.

Figure VIII-2: Clusters for IMPROVE monitoring of mandatory Class I areas.



Since its inception, the IMPROVE program has been governed by a steering committee comprised of one representative from each of the following organizations: USEPA, the National Park Service, the U.S. Forest Service, the U.S. Fish and Wildlife Service, and the Bureau of Land Management. Efforts by the western states helped bring the Western States Air Rescources Council (WESTAR), NESCAUM, and STAPPA/ALAPCO onto the Committee in 1990. MARAMA joined the Committee in 1998 and Arizona was admitted as an associate member in 1999. Other states may also become associate members, depending on their contributions to the program.

C.1 Anatomy of an IMPROVE Monitoring Site

Table VIII-2 summarizes the suite of visibility measurements included in the IMPROVE program. Ideally, a visibility monitoring site would include all such measurements. However, due to financial and physical constraint, some sites do not host nephelometers and far fewer host transmissometers. Only two Northeast sites host digital cameras due to the relatively recent availability of this technology. All sites host aerosol monitors: they are generally easier to maintain, their data on reconstructed light scattering and light extinction correlate well with nephelometer and transmissometer data, and they provide additional information on the types of sources contributing to visibility impairment.

Schematics of a transmissometer, nephelometer, and IMPROVE aerosol sampling system are shown in Figures VIII-3, VIII-4, and VIII-5. (Photographs of these instruments are provided above in Figure VIII-1.) The minimum clearance between aerosol sampler inlets and nearby trees or structures is shown in Figure VIII-6.

Table VIII-2: Summary of visibility measurements at a fully-instrumented IMPROVE monitoring site.

Instrument	**Type of Visibility Measurement**	**Sampling Frequency**	**Notes** (Underlines indicate the major components of the reconstructed light extinction budget from aerosol monitoring.)
Scene Monitoring			
35 mm camera	Full visual condition (color, texture, contrast, clarity, visual range)	At least 3 times per day (9 AM, 12 PM, 3 PM)	IMPROVE recommends 5 years of monitoring to capture full range of conditions and to produce high quality "slide spectrums" to aid in the presentation and interpretation of quantitative data. Cameras capture elevated haze layers and plumes that may be missed by ground-based instruments.
Time lapse recorder	Full visual condition (color, texture, contrast, clarity, visual range)	At least once per minute	Same as above, except that time-lapse monitoring is done on a case-by-case, special-study basis and is specially suited for capturing the visual dynamics of plume and meteorological events.
Digital camera	Full visual condition (color, texture, contrast, clarity, visual range)	Approx every 15 min	Same as above, except that resolution begins to degrade when printed at sizes larger than 5 x 7 inches. Particularly well suited for real-time monitoring, public reporting, and image archival.
Optical Monitoring			
Transmissometer	Light extinction (b_{ext})	Continuous	Requires open path length of 1-10 km and more maintenance than other types of visibility monitors. Can be affected by fog/mist/rain and atmospheric turbulence, especially if beam is close to ground. Absolute calibration not possible.
Nephelometer	Light scattering (b_{scat})	Continuous	Easier to compare with aerosol data since both are point (rather than long-path) measurements. Can be affected by fog/mist/rain. Absolute calibration possible.
Aerosol Monitoring			
Module A ($PM_{2.5}$ on teflon)	Concentration of $PM_{2.5}$ mass Concentration of elements[1] Light absorption ($_{babs}$)[2]	24-hr average, every 3rd day	Elemental data are used to determine light extinction due to <u>soil</u> and <u>sulfates</u>. They also indicate the type of sources contributing to impairment. Measurement of hydrogen provides a check on organic carbon assumptions. Light absorption measurements are being re-evaluated. Results are not being reported until evaluation is complete. Filters are archived at room temperature.
Module B ($PM_{2.5}$ on nylon, preceded by denuder)	Concentration of ions[3]	24-hr average, every 3rd day	Ion data are used to determine light extinction from <u>ammonium nitrate</u>. Sulfate data provide a check on ammonium sulfate calculated from elemental S. Chloride data provide a check on salt calculated from elemental Na. Denuder removes nitric acid vapor and prevents a positive bias that would result from its deposition on nylon filters. Filters are destroyed by analysis.

Instrument	Type of Visibility Measurement	Sampling Frequency	Notes (Underlines indicate the major components of the reconstructed light extinction budget from aerosol monitoring.)
Module C ($PM_{2.5}$ on quartz)	Concentration of elemental and organic carbon[4]	24-hr average, every 3rd day	Elemental carbon usually accounts for all light absorption in rural areas. Organic carbon is assumed to comprise 71 percent of organic material by mass. A "punch" is taken from the filters for analysis. Remainder of filter is archived.
Module D (PM_{10} on teflon)	Concentration of PM_{10} mass	24-hr average, every 3rd day	PM_{10} data are used to calculate extinction from coarse particles. Filters are archived at room temperature.

[1] Elements with atomic weights from sodium through manganese are measured by Particle-Induced X-ray Emissions (PIXE). Elements with atomic weights from iron through lead are measured by X-Ray Fluorescence (XRF). Hydrogen is measured simultaneously by Proton Elastic Scattering Analysis (PESA).
[2] Light absorption is measured using a Hybrid Integrating Plate and Sphere (HIPS) method, which runs a laser over the filter.
[3] Ions are measured by ion chromatography.
[4] Elemental and organic carbon are determined by Thermal Optical Reflectance (TOR). Organic carbon is operationally defined as the amount of carbon volatilized off the filter by heat in a helium atmosphere. The remaining carbon (volatilized at higher temperatures in the presence of oxygen) is assumed to be elemental carbon. During the heating process, some of the organic carbon may pyrolize (or char) on the filter and only volatilize in the elemental-carbon portion of the analysis. This portion of the "elemental carbon" which should be attributed to organic carbon is determined by monitoring the reflectance of the filter. When the reflectance returns to its initial value (taken prior to heating), then the last of the organic carbon is assumed to have volatilized. No elemental carbon is assumed to have volatilized up to this point.

Figure VIII-3: Schematic of a transmissometer transmitter and receiver station.

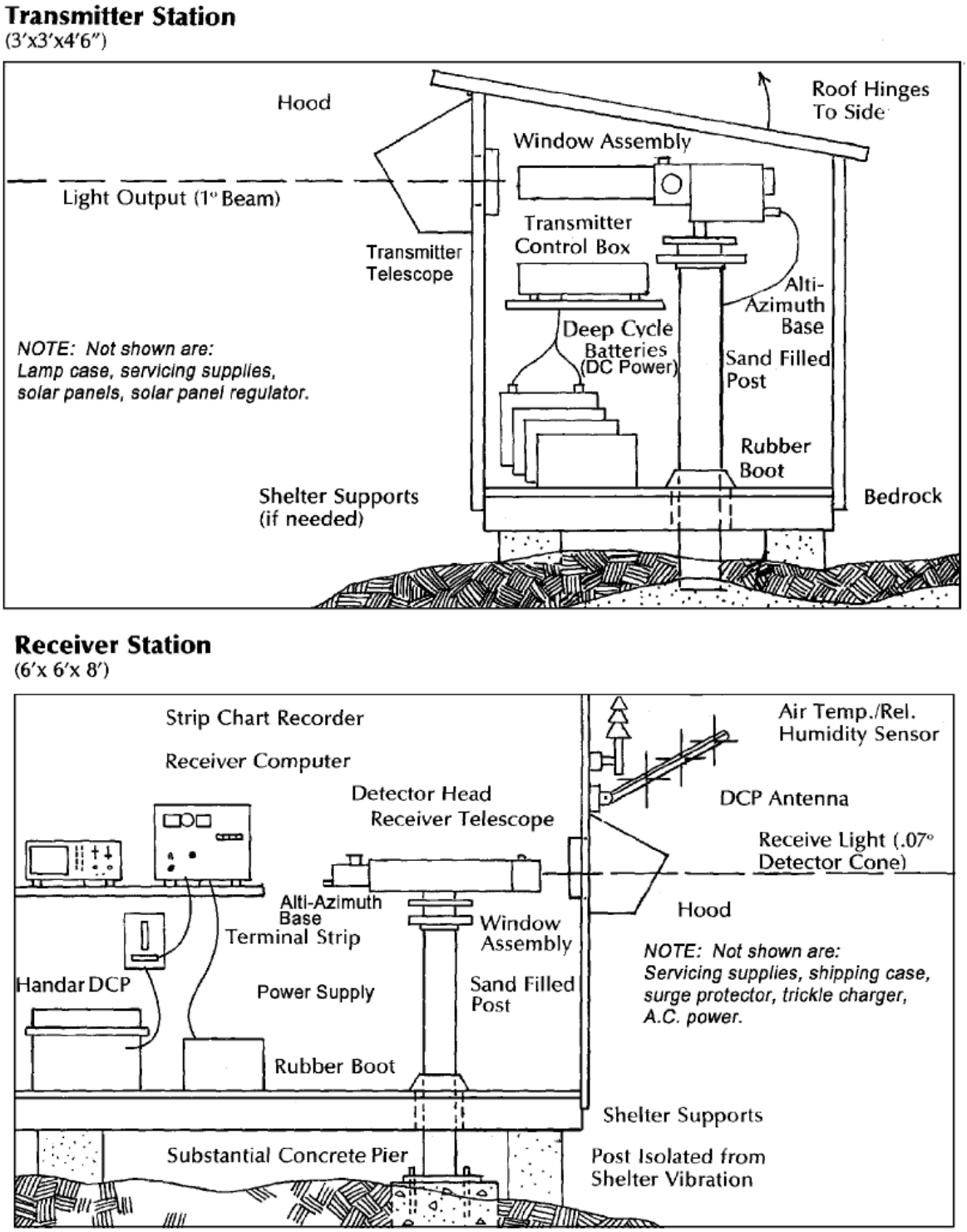


Figure VIII-4: Schematic of a nephelometer.

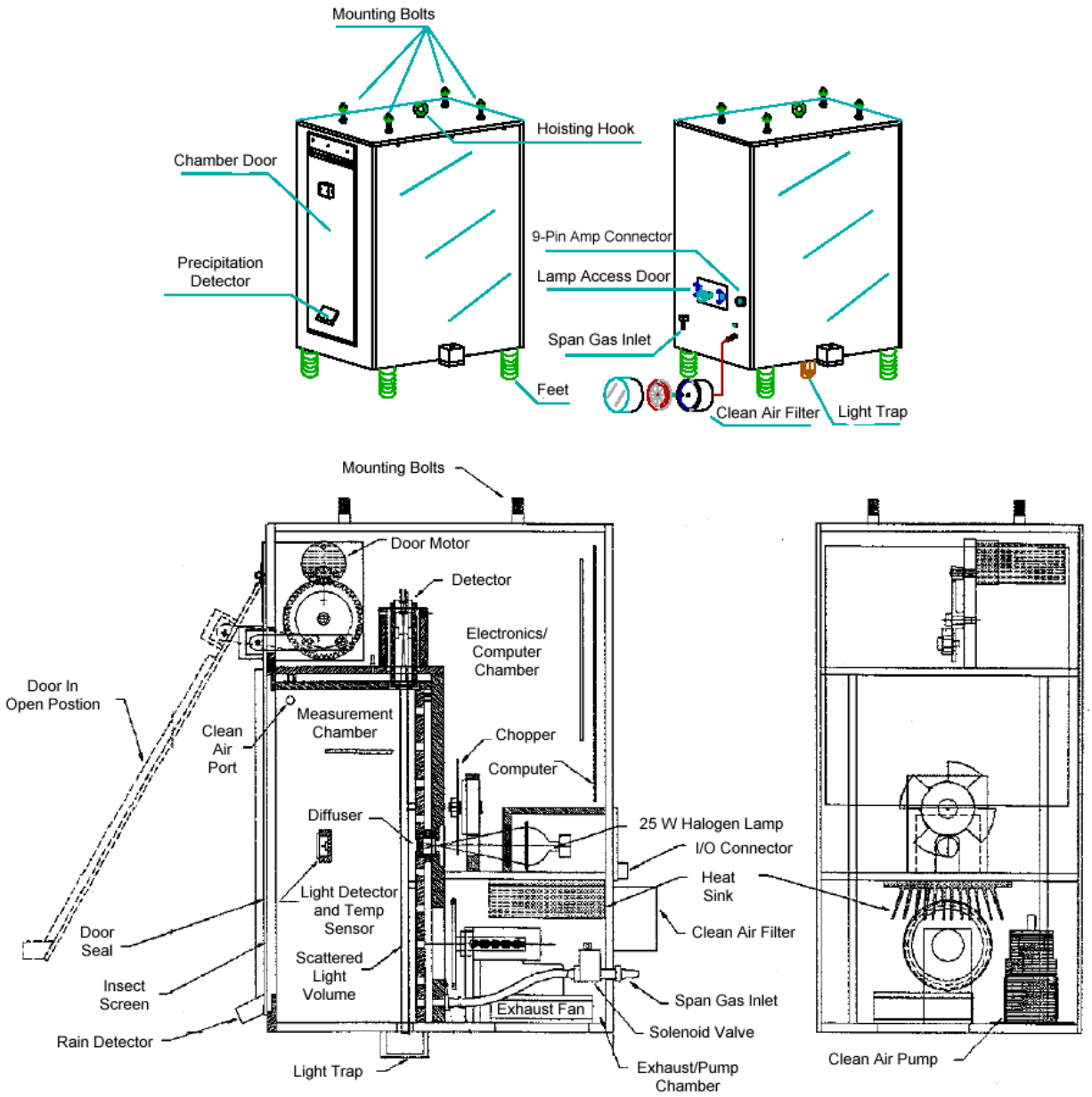
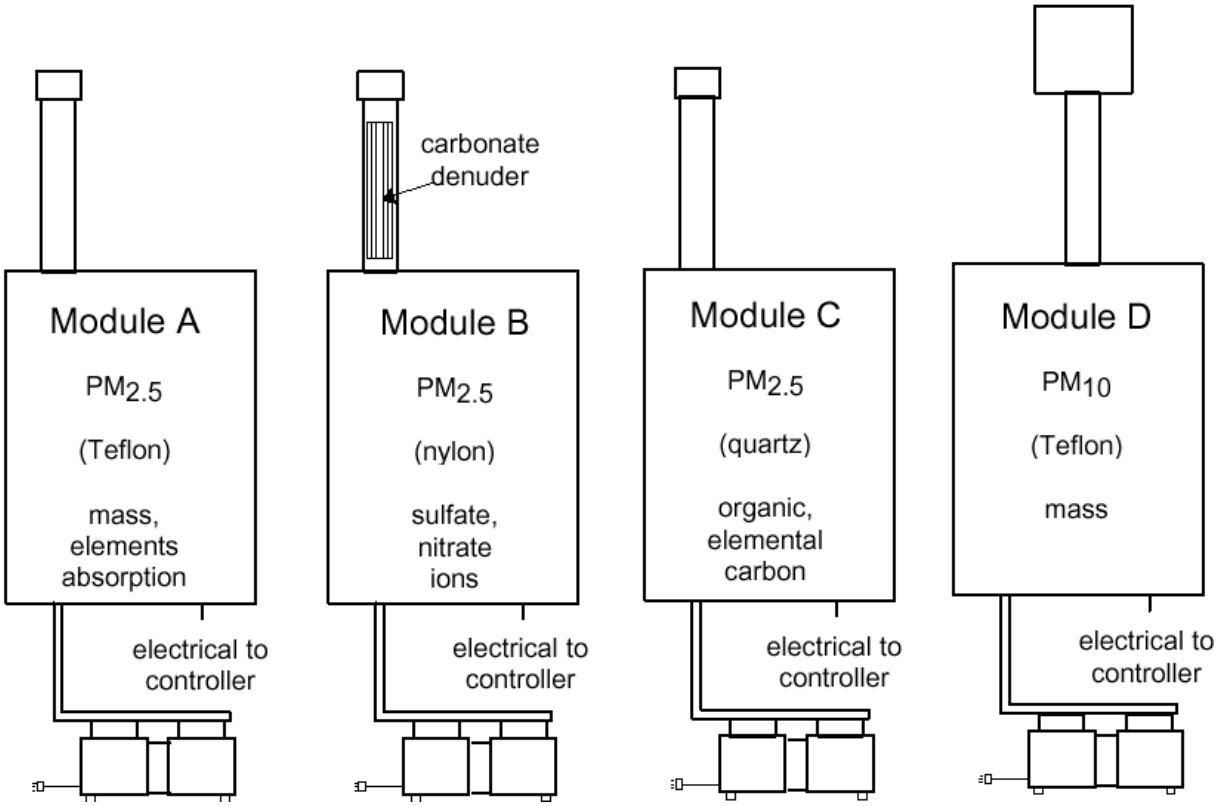
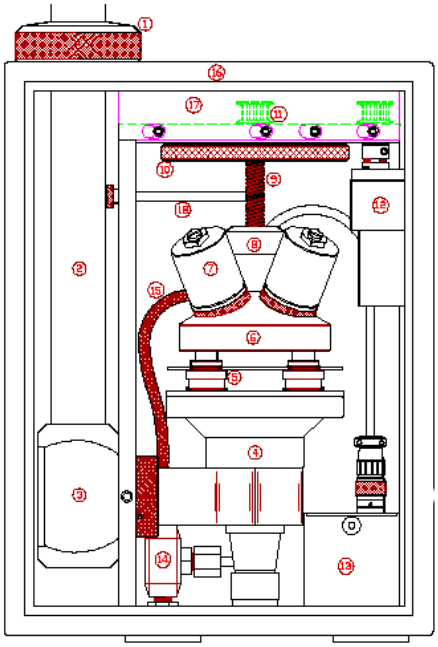


Figure VIII-5: Schematic of an IMPROVE aerosol monitor.





$PM_{2.5}$ 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

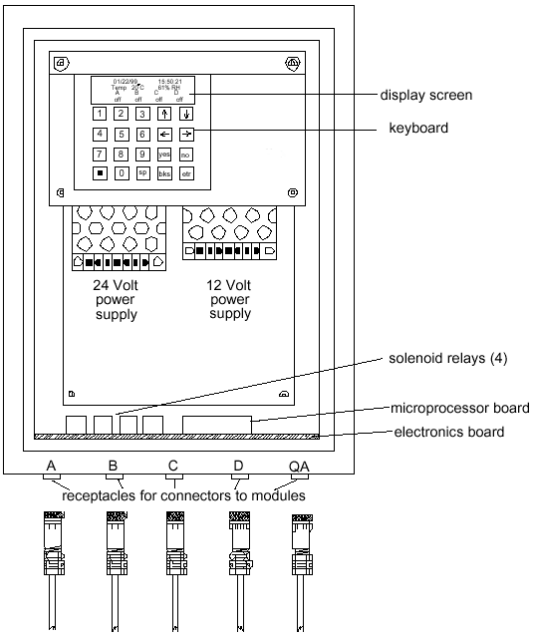
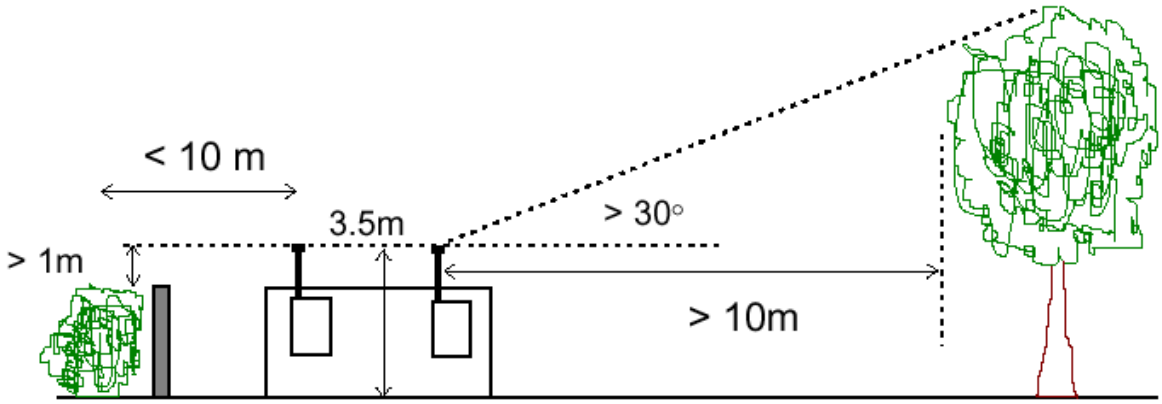


Figure VIII-6: Minimum clearance between aerosol sampler inlets and nearby trees or structures.



D. History, Status, and Future of Visibility Monitoring in the Northeast and Mid-Atlantic

Five visibility monitoring sites currently exist in or near mandatory Class I areas in the Northeast and Mid-Atlantic; their status is summarized in Table VIII-3. Two of the five sites have historically operated as IMPROVE protocol sites. For this reason, a 35 mm photographic archive has not been developed for the cluster containing the Moosehorn and Roosevelt-Campobello areas, and only summertime monitoring has been performed for the cluster containing the Great Gulf and Presidential-Dry River areas. These sites have recently become full IMPROVE monitoring sites. All IMPROVE sites are expected to continue operating in support of the regional haze program.

From 1988 to 1993, the NESCAUM states established a network of seven IMPROVE protocol sites at non-Class I rural areas. This program, known as NEPART (for Northeast particle network), included sites at Underhill, VT; Whiteface Mountain, NY; Bridgton, ME; Mt. Sunapee, NH; Quabbin Reservoir, MA; Mohawk Mountain, CT; and Ringwood, NJ. NEPART was initiated out of the realization that assessment of visibility and acid deposition was hindered by a lack of standardized monitoring methods and by measurements that had been conducted over short periods of time at a spatially limited number of sites. Each NEPART site hosted an IMPROVE Module A sampler and a PM_{10} sampler, both of which operated on Wednesdays and Saturdays (coincident with the IMPROVE schedule) and on every 6th day (coincident with state criteria pollutant schedules). During the first year of NEPART, two sites (Quabbin Reservoir and Whiteface Mountain) also hosted a Module C sampler. Initial funding was provided by the USEPA, while the University of California at Davis provided laboratory analysis for the remaining years as an in-kind service.

Table VIII-3: History and status of visibility monitoring at mandatory Class I areas in the Northeast and Mid-Atlantic states.

Site / Parameter	Instrument	Start Date	End Date[1]	Data Interval	Operating Period[2]	Operating Agency
Moosehorn Wildlife Refuge, ME and Roosevelt-Campobello International Park, NB						
Scene	Timelapse 8mm camera	01/88	08/91	1 per min	year-round	FWS
Scene	Timelapse vid recorder	12/94		1 per min	year-round	FWS
Aerosol	IMPROVE module A	08/94		24-hr avg	year-round	FWS
Aerosol	IMPROVE module B	08/94		24-hr avg	year-round	FWS
Aerosol	IMPROVE module C	08/94		24-hr avg	year-round	FWS
Aerosol	IMPROVE module D	08/94		24-hr avg	year-round	FWS
Acadia National Park, ME						
Scene	35 mm camera	01/80	04/95	1+ per day	year-round	NPS
Scene	Realtime digital camera	07/99		4 per hr	year-round	NPS
Standard visual range	Teleradiometer	10/79	02/86	1+ per day	year-round	NPS
Standard visual range	35 mm camera	03/86	03/87	1+ per day	year-round	NPS
Extinction coefficient	Transmissometer	11/87	06/93	1-hr avg	year-round	NPS
Scattering coefficient	Nephelometer	06/93		1-hr avg	year-round	NPS
Aerosol	Stacked filter unit	09/85	05/86	72-hr avg	year-round	NPS
Aerosol	Stacked filter unit	09/86	11/87	24-hr avg	year-round	NPS
Aerosol	IMPROVE module A	03/88		24-hr avg	year-round	NPS
Aerosol	IMPROVE module B	03/88		24-hr avg	year-round	NPS
Aerosol	IMPROVE module C	03/88		24-hr avg	year-round	NPS
Aerosol	IMPROVE module D	03/88		24-hr avg	year-round	NPS
Meteorology	Relative humidity	11/87		1-hr avg	year-round	NPS
Great Gulf and Presidential-Dry River Wilderness Areas, NH						
Scene	35 mm camera	09/85	08/96	1+ per day	summer	USFS
Standard visual range	35 mm camera	09/85	08/96	1+ per day	summer	USFS
Scattering coefficient	Nephelometer	06/95		1-hr avg	summer[3]	USFS
Aerosol	IMPROVE module A	06/95		24-hr avg	summer[3]	USFS
Aerosol	IMPROVE module B	06/95		24-hr avg	summer[3]	USFS
Aerosol	IMPROVE module C	06/95		24-hr avg	summer[3]	USFS
Aerosol	IMPROVE module D	06/95		24-hr avg	summer[3]	USFS
Meteorology	Relative humidity	06/95		1-hr avg	summer[3]	USFS
Lye Brook Wilderness Area, VT						
Scene	35 mm camera	05/87	10/91	1+ per day	summer	USFS
Standard visual range	35 mm camera	05/87	10/91	1+ per day	summer	USFS
Scene	35 mm camera	06/92	04/95	1+ per day	summer	USFS
Scattering coefficient	Nephelometer	08/93	03/94	1-hr avg	year-round	USFS
Scattering coefficient	Nephelometer	05/96		1-hr avg	summer	USFS
Aerosol	IMPROVE module A	03/91		24-hr avg	year-round	USFS
Aerosol	IMPROVE module B	03/91		24-hr avg	year-round	USFS
Aerosol	IMPROVE module C	03/91		24-hr avg	year-round	USFS
Aerosol	IMPROVE module D	03/91		24-hr avg	year-round	USFS
Meteorology	Relative humidity	08/93	03/94	1-hr avg	year-round	USFS
Meteorology	Relative humidity	05/96		1-hr avg	summer	USFS
Brigantine Wildlife Refuge, NJ						
Scene	35 mm camera	01/97	12/93	1+ per day	year-round	NJ DEP
Standard visual range	35 mm camera	01/87	12/93	1+ per day	year-round	NJ DEP
Scene	35 mm camera	05/92	03/99	1+ per day	year-round	FWS
Scattering coefficient	Nephelometer	04/93	04/94	1-hr avg	year-round	FWS
Aerosol	IMPROVE module A	09/91		24-hr avg	year-round	FWS
Aerosol	IMPROVE module B	09/91		24-hr avg	year-round	FWS

Table VIII-3: History and status of visibility monitoring at mandatory Class I areas in the Northeast and Mid-Atlantic states, continued.

Site / Parameter	Instrument	Start Date	End Date[1]	Data Interval	Operating Period[2]	Operating Agency
Aerosol	IMPROVE module C	09/91		24-hr avg	year-round	FWS
Aerosol	IMPROVE module D	09/91		24-hr avg	year-round	FWS
Meteorology	Relative humidity	04/93	04/94	1-hr avg	year round	FWS

[1]End dates are not provided if parameter is still being measured.
[2]Summer typically indicates June - October
[3]These parameters will be measured year-round beginning in 2000.
Other notes:
(a) Site histories provided Jim Wagner, Air Resource Specialists, Inc., Air Quality Monitoring History Database.
(b) Other, non-visibility measurements are made at may of these sites which may be useful for visibility assessments, such as ozone precursor concentrations, acid deposition, and meteorological variables.

In 2001, four NEPART sites (Underhill, Bridgton, Quabbin, and Mohawk Mtn.) will be re-deployed as IMPROVE protocol sites. Six more IMPROVE protocol sites will be deployed for the first time at Presque Isle, ME; Old Town, ME; Freeport, ME; Cape Cod National Seashore (Truro), MA; Pinnacle State Park (Addison), NY; and Martha's Vineyard, MA. Whiteface Mtn. (a former IMPROVE site) will be another rural site for $PM_{2.5}$ speciation, although it won't be an IMPROVE protocol site.

Upwind of the Northeast, visibility monitoring has occurred at IMPROVE sites located in Washington, DC (protocol site); Shenandoah National Park, VA; James River Face Wilderness Area (previously a protocol site), VA; Dolly Sods Wilderness Area, WV; Mammoth Cave National Park, KY; Shining Rock Wilderness Area, NC; and Great Smoky Mountain National Park, TN. Also upwind of the northeastern states, $PM_{2.5}$ mass concentration and some $PM_{2.5}$ speciation have been measured at seven Clean Air Status and Trends Network (CASTNet) sites. These sites are located in rural areas of NY, PA, OH, KY, IL, and IN. In 2001, aerosol monitoring at these sites will change from the CASTNet method (which takes week-long composites of sulfate and nitrate, but not carbon) to the IMPROVE method (protocol sites). Co-located measurements will be made at one site for at least one year to assess comparability.

Real-time visibility cameras for enhanced monitoring and public outreach purposes are being deployed at several sites. These sites are being chosen and maintained by NESCAUM as a coordinated network known as CAMNET (http://www.hazecam.net). The first CAMNET sites (Acadia National Park, ME and Boston, MA) were launched in the summer of 1999. The Great Gulf/Presidential-Dry River area was brought on line in the summer of 2000. Plans are underway to have sites deployed in Hartford, CT and New York City by 2001.

A map of the IMPROVE sites (for mandatory Class I areas), IMPROVE protocol sites (mostly Midwest CASTNet and Northeast background/transport sites), NEPART sites, and current and planned CAMNET sites is shown in Figure VIII-7.

Not shown on the map are historic and future visibility monitoring sites that may exist in Canada. This needs to be further investigated as it is known that $PM_{2.5}$ has been monitored at several Canadian locations. Also not shown on the map are several urban speciated $PM_{2.5}$ sites,

which will be deployed in 2001 and later years. Data from these sites can be used to assess urban visibility, further verify predictive models, and supplement regional haze analyses (e.g., enhance resolution of spatial gradients, distinguish in-region from out-of-region influences, etc.). Urban $PM_{2.5}$ speciation samplers are slated for Burlington, VT; Portsmouth, NH; Boston, MA; Springfield, MA; Providence, RI; Hartford, CT; Rochester, NY; New York, NY; New Brunswick, NJ; Pittsburgh, PA; Philadelphia, PA; Baltimore, MD; and Washington, DC. Additional $PM_{2.5}$ speciation monitors may be deployed depending on state/regional needs and available resources. Special studies are under way by the USEPA and the IMPROVE program to assess the comparability of data from these sites with those from IMPROVE sites. Initial results from IMPROVE samplers co-located with other samplers are encouraging, as shown in Figure VIII-8. However, the monitoring systems were not run completely independently of each other – i.e., filters from different samplers were handled by the same operator, in the same fashion, and analyzed by the same laboratory, whereas they would normally be handled slightly differently and sent to different laboratories with slightly different machinery and procedures. Results from completely independent co-located monitors should be available late in 2001.

Figure VIII-7: Visibility monitoring sites in the Northeast and Mid-Atlantic region.

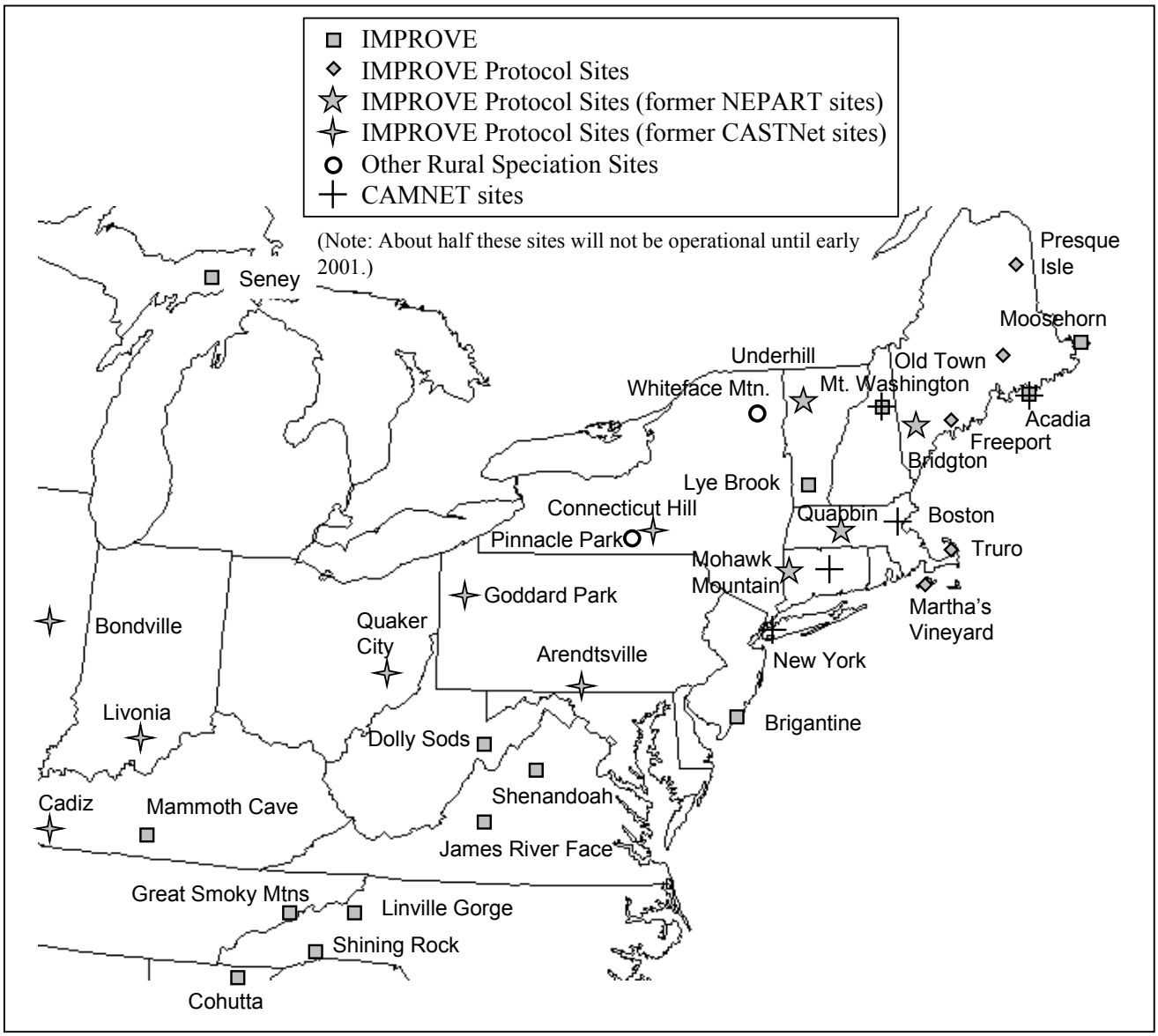
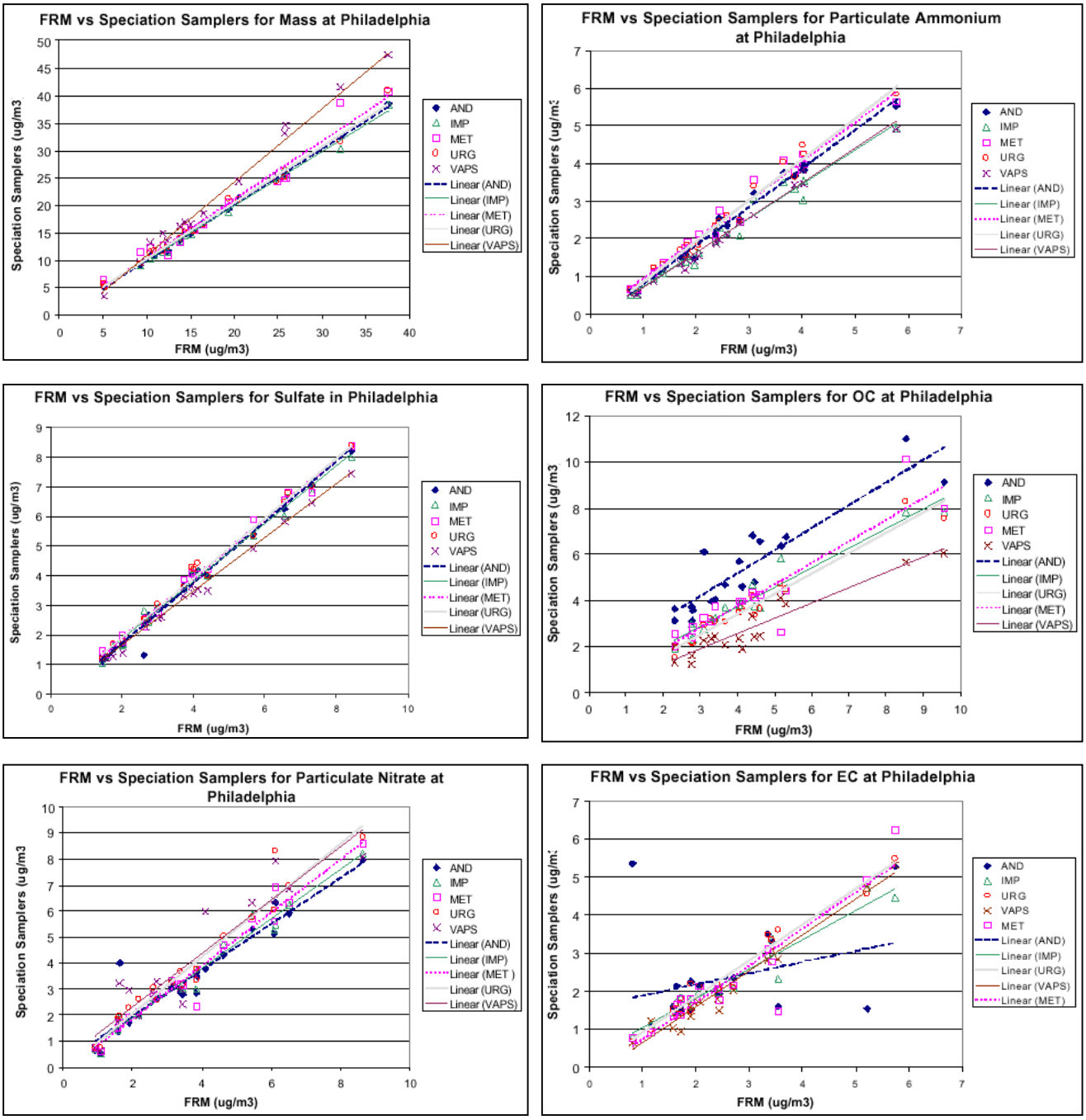


Figure VIII-8: Concentrations of $PM_{2.5}$ mass, sulfate, nitrate, ammonium, organic carbon, and elemental carbon as measured by IMPROVE and other speciation samplers in Philadelphia.



E. Monitoring Recommendations

The Northeast and Mid-Atlantic states need to develop a regional monitoring strategy and update or revise this strategy on an annual basis, as necessary to adequately characterize regional haze. Specific recommendations are provided for the maintenance and enhancement of CAMNET, since it is a likely component of any regional haze monitoring strategy.

Regional haze monitoring strategies should provide the following information:

- Track the history and status of visibility and visibility-related monitoring in the Northeast, Mid-Atlantic, and upwind areas;
- Identify additional monitoring activities that may be warranted, their objectives, and resource requirements;
- Help coordinate state and FLM monitoring programs to address these additional, warranted activities; and
- Provide a basis for the monitoring portion of the SIPs.

Tracking the history and status of monitoring activities is accomplished to some extent in this document. However, better documentation and detail would provide a more appropriate frame of reference for current and future monitoring and would help in the planning of various air quality modeling and data analyses.

Additional monitoring activities could extend IMPROVE-type monitoring into transport corridors, urban vistas, and other locations with scenic resources; provide specialized data for model verification, receptor model input, and other data analyses; garner such data from other organizations (e.g., NOAA, NASA, and FAA); and support public outreach activities. The addition of relative humidity monitoring at IMPROVE and IMPROVE protocol sites would significantly aid in reducing the current uncertainties associated with this parameter and its effect on reconstructed light extinction. Measurements of ammonia at select IMPROVE sites would allow researchers to determine the acidity of deposited aerosol particles under some conditions and should be investigated. Future field studies focused on understanding haze and its precursors should be sure to include detailed measurements of indicator species, such as H_2O_2, HNO_3, NO_Y, NO_X and formaldehyde. These measurements will (1) improve the conceptual model of regional haze in the Northeast and (2) help evaluate computer models.

With respect to outreach activities, a recommendation can be made at this time to maintain and enhance CAMNET. Specifically, some of the web site's pages should be updated, additional sites should be located in upstate New York and the Mid-Atlantic Region, the web site needs to be further promoted to the public, and it should be incorporated into standard outreach materials and activities among state, regional, and federal organizations. An effort should be made by the USEPA to coordinate real-time visibility web cameras. A few currently exist outside CAMNET that are oriented towards air pollution (e.g., Great Smoky Mountains and St. Louis), but they vary in quality, objectives, messages, and geographic coverage. Given the trend in web camera use and burgeoning activities in regional haze planning, now is the time for USEPA to encourage consistent and effective use of real-time visibility cameras. Finally, an investigation should be made into making CAMNET images more interesting and interactive. For example, some web sites merge

photographs from different directions and allow the visitor to “virtually” rotate the camera left and right (360 degrees) and up and down.

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IX. Social and Economic Considerations

The long-term goal of remedying "any" manmade impairment of visibility in Class I areas was adopted by Congress in 1977 without reference to technical feasibility or cost-benefit calculations. Nevertheless, considerations of societal benefit, public welfare, and economic cost will have an important and inevitable impact on the emission control strategies used to attain this goal and on the timeliness with which they are implemented. Ultimately, the willingness of policymakers and the public to support effective regional haze abatement strategies will depend, in large part, on the perceived benefits associated with improved visibility. This chapter provides a mostly qualitative overview of visibility-related social and economic benefits and of available evidence on the public's willingness to pay for them. It does not address the economic costs of reducing pollution to achieve these benefits.

While this chapter is focused on the specific benefits of visibility improvement in northeastern Class I areas, it should be clear from the foregoing chapters that there are important links between regional haze, fine particle pollution, acid deposition, and (more indirectly) ozone. Hence, a discussion of visibility benefits is to some extent inseparable from a discussion of the benefits of addressing these related problems more generally. The final section of this chapter touches briefly on some of the broader public health and ecosystem concerns that, along with visibility concerns, are likely to drive fine particle reduction efforts in the eastern U.S. in the coming years.

To provide context for a discussion of visibility benefits in northeastern Class I areas, the Chapter turns first to a description of these areas and to the environmental and societal value they currently provide.

A. Class I Areas in the Northeast and Mid-Atlantic

Federal mandatory Class I areas include: (1) national parks exceeding 6,000 acres; (2) wilderness areas and national memorial parks exceeding 5,000 acres; and (3) all international parks, in existence prior to August 7, 1977. The USEPA has identified 156 areas that meet these criteria and for which visibility was determined to be an "important value." These areas include a vast array of ecosystems that are subject to somewhat different management objectives. Class I areas in the Northeast and Mid-Atlantic include: one national park managed by the U.S. National Park Service, three wilderness areas managed by the U.S. Forest Service, two wilderness areas managed by the U.S. Fish and Wildlife Service and one international park managed by the Roosevelt Campobello International Park Commission (see Table IX-1). Distinctions between these agencies, and the areas they manage, are described below. In addition, detailed descriptions of each of the Northeast/Mid-Atlantic Class I areas may be found in boxed text within each category of management agency. These descriptions are included to provide the reader with a more concrete sense of the value provided by each of these areas to the broader Northeast/Mid-Atlantic region in terms of recreation, wildlife and habitat protection, and other social, economic and environmental benefits.

Table IX-1: Class I Areas in the Northeast and Mid-Atlantic.

Class I Area	State	Management Agency	Federal Designation	Year Designated	Current Size (acres)
Acadia	Maine	National Park Service	National Park	1919	46,784
Moosehorn	Maine	Fish and Wildlife Service	Wilderness Area of Wildlife Refuge	1970 (Edmunds Unit) 1975 (Baring Unit)	2,780 4,680
Roosevelt Campobello	New Brunswick	Roosevelt Campobello International Park Commission	International Park	1964	2,800
Great Gulf	New Hampshire	Forest Service	Wilderness Area of National Forest	1975	5,552
Presidential Range – Dry River	New Hampshire	Forest Service	Wilderness Area of National Forest	1975	27,380
Brigantine	New Jersey	Fish and Wildlife Service	Wilderness Area of Wildlife Refuge	1975	6,603
Lye Brook	Vermont	Forest Service	Wilderness Area of National Forest	1975	15,680

A.1 National Parks

President Woodrow Wilson established the National Park Service (NPS) in 1916 under the Department of the Interior. At the time, 40 areas of historical, natural or recreational significance were identified for protection under one managing agency. Today the national park system encompasses more than 370 areas designated by Congress or the President. The role of the NPS is:

> "To promote and regulate the use of Federal areas known as national parks, monuments and reservations… by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (National Park Service Organic Act, 16 U.S.C.1.)

A wide range of recreational activities are permitted on NPS lands. The use of motorized vehicles, prohibited in many wildlife refuge and wilderness areas, is allowed in many national parks, which support the use of cars, snowmobiles, mountain bikes, and recreational vehicle (RV) camping. Parks with sensitive natural and cultural areas may restrict these activities if they adversely affect or threaten park resources.

Consistent with a national trend toward increased outdoor recreation, visits to national parks rose from 246 million in 1987 to 275 million in 1996. In that same period, the number of overnight visitors grew from 16.6 million to 18.3 million (Van Horne, 1999). As a result, some of the more popular parks now require reservations for overnight visits, or limit the number of visitors.

Acadia National Park in Maine is the only Class I areas in the Northeast under the jurisdiction of the NPS. This area is described in Box IX-1. The scenic qualities of this park is adversely affected by regional haze. For example, Acadia National Park has air pollution levels similar to those found in Philadelphia, PA, during the summer months when visitation is highest (Mardock et al, 1999).

Box IX-1: Class I National Parks in the Northeast.

Acadia National Park, ME

When Acadia National Park was designated in 1919, it was called Lafayette National Park and was the first national park designated east of the Mississippi River. Created with 6,000 acres of land, the park changed its name in 1929 and now encompasses about 40,000 acres of mixed ecology including Atlantic shoreline, mixed hardwood forests, spruce and fir forests, mountains, lakes and islands. Facilities at the park include 45 miles of carriage roads for walking and biking with 27 miles of scenic driving, plus 120 miles of hiking only trails, 2 campgrounds, a restaurant and 3 gift shops. Acadia averages 3 million visitors each year with the majority visiting during July and August (almost 700,000 visitors per month) and the fewest during December, January, and February (almost 38,000 visitors per month). Open year round, Acadia provides an abundance of recreational opportunities. Fees are $10 per vehicle or $5 per motorbike for 7 days. Additional fees for camping apply and vary from $12-$18 per day throughout the year. The average park visitor stays at Acadia 1-4 days. (http://www.nps.gov.acad)

A.2 Wilderness Areas Managed by the Forest Service

Wilderness areas are managed by the U.S. Forest Service, which is part of the Department of Agriculture. The Forest Service is primarily responsible for managing national forests and grasslands. It was established by Congress in 1905 to manage the multiple uses and benefits of public lands. The self-described mission of the Forest Service is "Caring for the Land and Serving People," a formulation that suggests a balance between protecting environmental values and managing commercial and recreational interests.

Any federally protected land can be designated as a wilderness area under the guidelines of the Wilderness Act of 1964 which describes such areas as:

> "Administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness…A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." (The Wilderness Act, 16 U.S.C. 1 1 21)

In wilderness areas, recreation is secondary to preservation. Only those activities that do not threaten the wild integrity of the area are permitted. Travel is universally limited to non-mechanical means such as on foot or by horseback. To protect ecosystems, groups are limited to ten people and quotas or reservation systems may be imposed to limit visitor impacts. Low-impact recreation is supported within wilderness areas with designated trails and camping areas. People visit these areas to experience wilderness and to enjoy year-round activities such as hiking, rock climbing, bird and wildlife watching, hunting, fishing, cross country skiing and snow shoeing. Since wilderness areas are usually part of larger managed areas, no direct fees are charged for their use (http://www.wilderness.net).

In the Northeast, the Forest Service manages three Class I wilderness areas: the Great Gulf and Presidential-Dry River Wilderness areas in New Hampshire's White Mountain National Forest and the Lye Brook Wilderness area in Vermont's Green Mountain National Forest. Box IX-2 describes these areas.

Class I areas in the White Mountain National Forest are especially affected by poor visibility. Mt. Washington, the highest mountain in the Northeast, attracts visitors (who can climb, drive, or ride to the summit) in large part because of the breathtaking views from its summit. Any action taken to improve visibility in the adjacent Great Gulf and Presidential-Dry River wilderness areas will affect the vistas from the summit of Mt. Washington. The White Mountain National Forest is the main tourist attraction in New Hampshire and ranks among the most popular National Forests in the country with over 6 million visitors annually (U. S. Forest Service, 2000).

Vermont's rustic mountain landscapes and quaint New England towns also attract throngs of visitors each year that support an important tourist-based economy. The Class I Lye Brook Wilderness area is part of the Green Mountain National Forest, which attracts many of Vermont's visitors. Haze reductions targeted at Lye Brook will increase visibility throughout the Green Mountain National Forest and beyond.

Box IX-2: Class I Wilderness Areas Managed by the Forest Service.

Great Gulf Wilderness Area, NH

The Great Gulf Wilderness is located in a unique mountain valley surrounded by the Presidential Mountain Range. The valley has steep walls rising from 1,100 feet to 1,600 feet above the valley floor. The area includes many rivulets that drain eastward to the West Fork of the Peabody River. For visitors, the Great Gulf offers 21.3 miles of marked trails, which offer some of the best views of the ridges and summits of the Presidential Range -- including Mt. Washington, the tallest peak in the Northeast. Great Gulf averages 20,128 visitors annually. The area is open for camping below the tree line most of the year; however, camping is prohibited during the winter when weather conditions make camping unsafe.

Presidential Range – Dry River Wilderness Area, NH

The Presidential Range-Dry River Wilderness is a rugged expanse of mountains and valleys located south of Mt. Washington and other peaks in the Presidential Range, including Mt. Eisenhower and Mt. Monroe. The Wilderness extends over and beyond the central valley of the Dry River to the Saco River, encompassing numerous brooks and smaller, heavily forested mountains. As the name suggests, the Dry River is almost without water by late summer but swells quickly during heavy rains. There are only ten trails in the wilderness area totaling 46.1 miles in length. This area receives fewer visitors than Great Gulf (about 7,000 annually), mostly due to its more remote location. Its southern portion has almost no trails, is very steep and rugged, and offers a rare degree of solitude.

Lye Brook Wilderness Area, VT

At 15,680 acres, Lye Brook is the second largest wilderness area within the Green Mountain National Forest. Its main attraction is the series of cascades that make up Lye Brook Falls, but the surrounding area also has much to offer. Lye Brook features a diversity of habitats from northern hardwood forests to grassy meadows, and a scattering of lakes, streams, and bogs. Prospect Rock, a series of cliffs, is popular spot offering breathtaking views of the whole wilderness. Intertwined with the pristine natural beauty are remnants of the heavy logging that occurred in the area during the early 1900s. Lye Brook offers a variety of recreational activities despite the limitations of its wilderness designation. With only three hiking trails, much of the land is available for backcountry exploring. Other popular activities are wildlife watching, hunting (for wild turkey, white tailed deer, black bear and beaver) and, in the winter, cross-country skiing and snowshoeing.

A.3 Wilderness Areas Managed by the Fish and Wildlife Service

Wildlife refuges are managed by the Fish and Wildlife Service (FWS). FWS was created when the Bureau of Fisheries and the Biological Survey merged in 1940. The Wildlife Refuge System was established by the National Wildlife Refuge Administration Act of 1966 to conserve, protect, and enhance fish and wildlife and their habitats. However, the specific mission of FWS in managing the refuge system remained undefined for more than 30 years. The National Wildlife Refuge System Improvement Act of 1997 finally defined the FWS's role as follows:

> "To administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans." (NWRI Act 1997)

The National Refuge System has grown since its inception to include over 500 refuges, several thousand Waterfowl Production Areas, and 50 Coordination Areas, that attract nearly 30 million visitors each year. In recent years, growing interest in these areas has prompted debate over the role of recreation within the refuge system. The National Wildlife Refuge Administration Act limits public use within refuges to activities "compatible" with the management of the refuge, but does not clearly define "appropriate compatible use." The debate was addressed by the National Wildlife Refuge System Improvement Act of 1997, which defined "compatible uses" as those that "will not materially interfere with or detract from the fulfillment of the mission of the [Refuge] System or the purposes of a refuge." Recreation within a wildlife refuge is limited to "wildlife-dependent recreation" such as hunting, fishing, wildlife observation and photography, and environmental education and interpretation.

Because the primary purpose of the refuge system is to protect the habitat of plant and animal species, recreational opportunities at specific refuges may be restricted. Two percent of national wildlife refuges are closed to the public. The Class I areas within wildlife refuges in the Northeast and Mid-Atlantic are free and open to the public and provide opportunities for some of the most popular and visibility dependent recreational activities such as bird watching (U.S. Fish and Wildlife Service, 2000).

Box IX-3: Class I Wilderness Areas Managed by the Fish and Wildlife Service.

Brigantine – Edwin B. Forsythe Wildlife Refuge, NJ

Until 1984, the Brigantine – Edwin B. Forsythe Wildlife Refuge existed as two distinct refuges. Today, the combined refuge encompasses 42,000 acres of coastal habitat, over 90 percent of which consists of tidal marshes and meadows. About 6,600 acres of the refuge have been designated Class I wilderness area. The refuge serves as an important resting and feeding spot for migratory waterfowl including the endangered piping plover, black skimmer, and least tern; it also provides an ideal spawning ground and nursery for native fish. The remaining area of the refuge is dominated by pitch pine, oak forest, and white cedar-red maple swamps which are home to songbirds, white-tailed deer, box turtles, and other woodland creatures.

The Forsythe Refuge is nationally recognized as one of the East Coast's premier birding spots, and hosts around 200,000 visitors each year. In addition, it supports hiking, biking, and scenic driving with eight miles of roadway, and three groomed trails. Saltwater fishing, crabbing, clamming from boats, surf fishing, and deer and waterfowl hunting are allowed during appropriate seasons. The refuge's visitor center also serves as a community resource for environmental education programs. Plans have been made to increase visitor access through the development of new foot trails, docks, observation platforms, and an updated visitors' center (http://www2.nature.nps.gov/ard/fws/brig/forsyth.htm).

Moosehorn Wildlife Refuge, ME

Two units, the Baring Unit (17,200 acres) and the Edmunds Unit (7,200 acres), make up the Moosehorn Wildlife Refuge, which was officially established in 1937. Within the refuge, a combined 7,460 acres of land (2780 acres from the Edmunds Unit and 4680 acres from the Baring Unit) are protected as Class I wilderness area. The refuge includes rocky shores, rolling forested hills, lakes, bogs, and marshes that provide protected habitat and breeding grounds for migratory land and water birds. Moosehorn was the first migratory bird refuge to be established in what is now a chain of refuges extending south to Florida. It features American bald eagles, and the American woodcock among the more than 220 species of birds that have been spotted here. While birding is the primary attraction of Moosehorn Refuge, visitors also utilize over 50 miles of roads and trails for hiking, biking, cross country skiing, and snowmobiling. Non-motorized boats are also allowed access to streams and lakes in the refuge for fishing. In November, the refuge is open for white-tailed deer hunting. Education programs also draw visitors to the refuge, where wildlife biologists invite visitors to join them on bird banding operations .(http://www.mainebirding.net/moosehorn/).

A.4 International Parks

Only one international park exists and that is Roosevelt Campobello International Park which is located in New Brunswick, Canada. Because this park is jointly administered by the U.S. and Canada, its protection falls under the jurisdiction of both countries. International parks are designated as Class I areas by statute in the regional haze rule and thus are afforded the same protection as other Class I areas throughout the country. A description of Roosevelt Campobello International Park is given in Box IX-4.

Box IX-4: International Parks.

Roosevelt Campobello International Park, ME

Roosevelt Campobello International Park is the only international park in the world. The park is located on Campobello island in Canada, but is of historical significance to the U.S. as the life-long summer home of President Franklin Delano Roosevelt. U.S. President Lyndon Johnson and Canadian Prime Minister Lester Pearson established the park on January 22, 1964 by international agreement. The park remains a symbol of neighborly relations between the U.S. and Canada, and of the importance of FDR's achievements to both nations. The Roosevelt Campobello International Commission manages the park. Commission members are appointed by the Governor General of the Council of Canada and by the U.S. President. The agreement splits equally all costs of development, operation, and management (www.fdr.net).

The park itself is a mixture of historic cottages and scenic natural landscapes. There are 8.4 miles of scenic roads in the park and 8 miles of walking paths. The grounds of the park include coastal headlands, rocky shores, beaches, wetlands, fields, forest, and the landscaped gardens of the cottages. The mix of habitat is excellent for a variety of migratory and shore birds (Roosevelt Campobello International Park Commission, 2000). While the historic cottages are only open from Memorial Day to Columbus Day, the natural areas and visitor center are open year round. This unique historic, natural area attracts approximately 150,000 visitors annually, with most arriving in August. The National Park Service recommends visitors plan on 2 to 4 hours to view the cottages, and 8 or more hours for full appreciation of the natural areas. In addition to the historic setting, several recreational activities are permitted on the island. There are no admission fees for this park, although donations are encouraged and accepted.

B. Economic Benefits of Outdoor Recreation

Since its inception in 1960, the National Survey on Recreation and the Environment (NSRE) has offered the most complete information regarding outdoor recreation trends in the U.S. In 1960, the survey estimated that 131 million individuals over the age of 12 participated in outdoor activities. By 1994-5, this number had increased by 65 percent to 216 million

people (Cordell et al., 1999). Of 29 activities covered by the NSRE survey, 23 reported increased levels of participation since the last survey in 1982-3. For example, the number of individuals bicycling and skiing more than doubled in a decade. Technology has encouraged this trend with innovations in sporting equipment allowing people easier access to, and enhanced enjoyment of, their favorite outdoor activities (Cordell et al., 1999).

Although the aggregate economic impact of outdoor recreation is difficult to calculate, estimates for specific activities suggest overall trends. Bird watching, for example, has experienced the greatest gain in participant days of all the activities surveyed in 1982-3 and 1994-5. Birders in the U.S. are estimated to spend $2.5 billion annually on feeders, seed, baths, nest boxes, binoculars, and field guides. Although many may not leave their backyards, an estimated 24.7 million birders travel to recreational and wilderness areas in an attempt to catch glimpses of their favorite species. An avid birder is estimated to spend approximately $2,000 annually on this hobby, of which half goes toward travel. With about 123,500 serious birders in the U.S., this equates to a minimum "dedicated birder GNP" of $247 million (Baicich et al., 1999). Recreational spending of this type can be significant to the economy of localities near parks or refuge areas. For example, with the influx of 100,000 birders annually to Cape May, NJ, "avitourism" contributes nearly $10 million dollars to the local economy. At Hawk Mountain, PA, a "hotspot" for raptor migration viewing, some 500,000 visitors annually bring $4 million into the local economy.

The following are estimates of activity-specific expenditures related to the use of public lands (Stegner, 1999a):

- $67.9 billion spent by hunters and anglers in 1996
- $29 billion spent by bird watchers in 1996
- $17.8 billion retail spending on new and used boats and related goods and services in 1996
- $9.4 billion spent on snow sport-related expenditures annually
- $6.5 billion spent on food and lodging while visiting national wildlife refuges yearly
- $2.0 billion spent for rentals at commercial campgrounds in 1995

Communities surrounding protected areas often benefit tremendously from the jobs and income created by the outdoor recreation industry. Non-resident visitors typically contribute to the local economy in four distinct sectors: lodging, food, retail, and recreation/amusement services. English and Marcoullier (1999) conducted a study to determine the benefits, by region, that outdoor recreation contributes to jobs and income for each of these economic sectors. In the Northeast, 3 percent of all jobs and 1.3 percent of income are related to recreation. Of all non-local recreational visitor-supported jobs in the U.S., the Northeast accounts for 40 percent of all jobs in eating and drinking establishments, 36 percent of all lodging jobs, 38 percent of all retail jobs, and 41 percent of all jobs in recreation services. Rural counties near Acadia National Park, White Mountain National Forest, and Green

Mountain National Forest owe more than 6 percent (double the national average) of jobs in the area to recreational visitors. A recent study by Abt Associates (2000) estimates that a 10 percent increase in park visitation at Acadia would lead to a $20 million increase in local sales, $2 million in increased tax revenue and approximately 800 new jobs.

Outdoor recreation on federally managed lands also draws foreign visitors to the U.S. Surveys of international travelers identified "outdoor-related activities," and particularly "visiting parks and forests" as common reasons for coming to the U.S. International travelers ranked parks, forests, and historic places as highly important factors to consider when planning their trip, with responses ranging from 91 percent of Venezuelan visitors to 70 percent of Japanese visitors. International travel to the U.S. has grown 66 percent in the past decade to become an $89 billion industry (O'Leary, 1999). Interest in natural areas and outdoor recreation plays an important role in the growth of the tourist industry. In the northeastern U.S., states with Class I areas attract large numbers of international visitors. In 1995, Maine ranked 14th in the nation for attracting international visitors with Vermont, New Jersey, and New Hampshire ranking 15th, 17th and 27th, respectively (O'Leary, 1999).

As interest in outdoor activities grows, demands on public land increase. Between 1986 and 1996, there was a 40 percent increase in visitors to federally managed public lands (Stenger, 1999b). This increase reflects not only additional people seeking outdoor settings, but also the expectation visitors have of the quality of the environment managed by federal agencies. The role of Federal Land Managers (FLMs) is to maintain or improve the quality of the lands they manage, thereby enhancing park enjoyment and use.

C. Public Perceptions of Visual Air Quality

The benefits of improved visibility in Class I areas depend in part on the public's ability to perceive such improvements. Conditions such as object/sky contrast, solar angle, sky color, cloud cover, and landscape features can all affect an individual's ability to perceive changes in visual quality. A layered haze with defined edges affecting only part of the view may be easier to detect than a uniform haze that has no boundaries and uniformly impairs visibility. Effective means to quantify discernible visibility change and communicate the link between pollution levels and visual air quality are needed to generate public support and appreciation of efforts to address regional haze.

As described in Chapter III, the deciview (dv) is a unit of measure which tends to be linear with perceived changes in visibility; thus a 1 dv change in visibility reflects a change in visibility that is just perceptible to the human eye.[86] However, the measure itself does not quantify human responses to perceived visibility changes. For example, studies have shown that a 1 dv reduction in visibility elicits a different response on hazy days, when overall contrast is low, than when the same change occurs on a clear day with high overall contrast. Human judgments about scenic quality are often referred to as perceived visual air quality (PVAQ). Studies of PVAQ can help researchers to understand those aspects of haze that most

[86] There is some controversy, however, whether this statement holds for all distances. Certainly there is evidence that a 1 dv change is perceptible for a target at the distance of the visual range.

influence an individual's assessment of scenic quality and assess the level of visibility change needed to affect visitor enjoyment.

PVAQ can be measured using a series of photographs and a ranking scale (e.g., from 1 to 10) to rate visual air quality. The pictures show the same scene under various pollutant levels and different background conditions. This technique allows researchers to relate perceptions of visibility to quantifiable differences in pollutant levels, relative humidity, lighting conditions, etc. Ideally, such studies would allow researchers to define one parameter that would produce equal PVAQ, regardless of other background conditions.

In a study by the National Park Service (Malm, 2000), multiple slides representing best, worst, and intermediate levels of air quality with various conditions of cloud, snow cover, and sun angle were shown to volunteer visitor participants. The 10 slides in random order were shown once to the participant in order to become familiar with the slides and then shown again to evaluate them. Participants used a scale from poor (1) to good (10) to evaluate the scenes. As a control to test for accuracy, 15 identical slides were mixed with the evaluation slides. The results were controlled for factors such as the participant's education level, age, sex and location of residence.

The results show a simple linear relationship between the level of scenic contrast and PVAQ (See Figure IX-1) regardless of the size of the distant feature. This same relationship held under different lighting conditions (e.g. cloud cover and sun angle). Visitors are just as likely to notice changes in air quality in the morning as in the afternoon, or on a cloudy day as on a clear day although ratings of the scenery are generally lower for mornings and cloudy periods.

When PVAQ is compared to actual particulate concentrations, perceptions of visual impairment appear to be most sensitive to low concentrations, or when the air is cleaner (see Figure IX-2). As the air gets dirtier, the PVAQ rating changes little. When distance to the viewed object is taken into account, the sensitivity of the PVAQ rating in a cleaner environment is even higher. This suggests that maintaining current visibility conditions on the 20 percent best days may be a challenge, given that some Class I areas experience near pristine conditions on these days. While comprising only 10 to 15 percent of all people who participate in outdoor activities, outdoor enthusiasts account for 60 to 90 percent of all visitor days in federal lands (English et al, 1999). Enthusiasts who repeatedly visit the same area for recreation may perceive small changes in visibility more readily, and may find anything less than the visual quality typical of the 20 percent best days to be unacceptable.

PVAQ ratings for photographs of layered haze and plumes show that the color and position of haze in relation to scenic features can affect perceptions of visual air quality. The position of plumes in the sky, however, tends to affect perception only when the haze is dark in color (Malm, 2000).

Figure IX-1: Perceived Visual Air Quality (PVAQ) versus contrast (Malm, 2000).

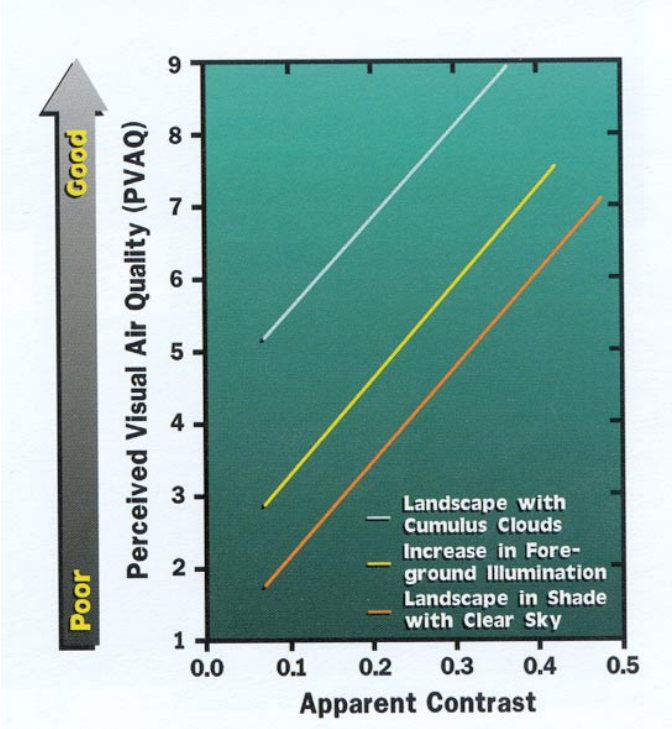
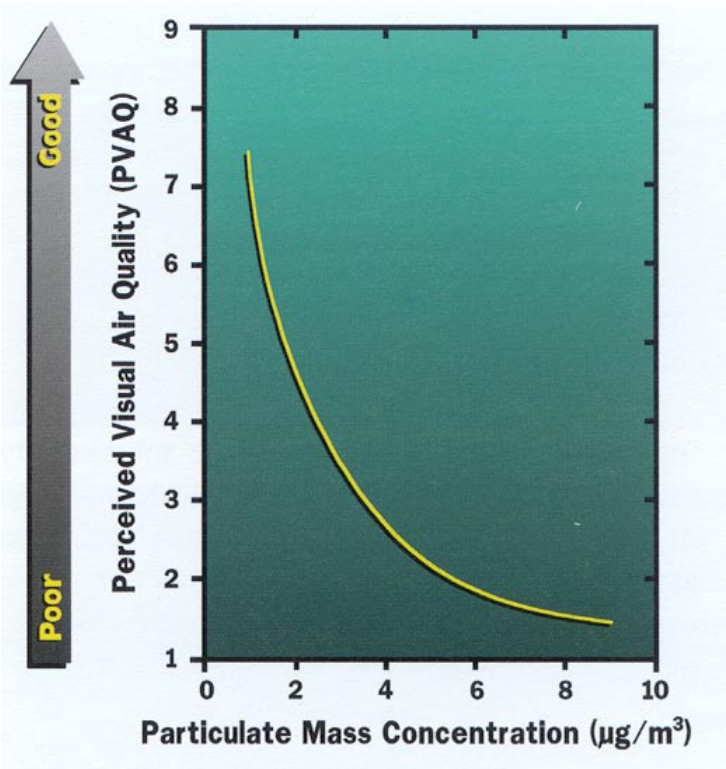


Figure IX-2: Sensitivity of PVAQ to different pollutant levels (Malm 2000).



Information garnered by PVAQ surveys regarding human perception of visible air quality can assist researchers in designing studies to value these changes. Researchers can use photographs of the same view at the same time of day to control for external factors that may affect PVAQ, thus limiting the possibility that the value assigned to specific visibility improvements (e.g. in willingness to pay studies) is representative of anything but air quality. These studies also give federal land managers information on how visitors perceive the 20 percent best visibility days. The best visibility days tend to get poorer ratings when conditions are cloudy or when features are shaded.

D. Non-Valued Benefits of Visibility to Outdoor Recreation

The preferences people have for clean air and unhindered visibility represent the kind of social value that is difficult to translate into dollar figures. Nevertheless, such preferences play an important role in decisions to visit, stay, or return to Class I areas. The NSRE identified the most popular outdoor activities as walking/hiking (66.7 percent), viewing a beach or waterside (62.1 percent), family gatherings (61.8 percent), and sightseeing (56.6 percent). Three of these top four activities are directly affected by visibility. In choosing an "ideal" outdoor setting for their recreation, almost 80 percent of Americans surveyed responded that the "quality of scenery" is extremely important. The majority of Americans (almost 90 percent) agree that scenic beauty is an "important" or "extremely important" value of wilderness (Cordell et al., 1997). These statistics support the notion that visual quality is a fundamental component of the value placed by society on maintaining national parks and wilderness areas.

The Customer Use and Survey Techniques for Operations, Management, Evaluations, and Research (CUSTOMER) study (Tarrant et al, 1999) measures visitor preferences and perceptions at a variety of recreational sites in terms of demographic and trip characteristics (day vs. overnight, first time or repeat visit, etc). Northeastern and mid-Atlantic Class I areas include the range of settings surveyed in this study, including developed areas (i.e., areas with services for RVs, picnics, and driving), dispersed areas (i.e., areas that are primarily roadless), water areas (i.e., lakes, rivers and streams), roadside areas (i.e., areas within 0.5 mile of roads), and winter settings (i.e., areas with snow and ice-based recreational opportunities). When asked about visibility (or other visibility related characteristics such as "quality of the scenery") respondents consistently identified visibility attributes as among the most important characteristics of their visit. This finding was independent of trip characteristics or demographic group (although individuals with high income/education levels tended to give the highest ratings to visual quality).

Multiple studies at individual national parks corroborate these findings. A survey of summer visitors to the Grand Canyon, Mesa Verde, Mount Rainier, Great Smoky Mountains, and Everglades National Parks between 1983 and 1985 asked respondents to rank the importance of a list of both general and site specific park features (USNPS, 2000). "Clean, clear air" was rated among the four most important features at all five parks. Additionally, other scenery related features were rated as "very important." Overall, the study pointed out that the visitors to national parks expect first to experience a natural setting, free of pollution,

and second, to enjoy the unique features of that park. If park attributes such as "clean, clear air" deteriorate, so presumably would visitor satisfaction and ultimately visitor attendance.

This NPS 2000 study also asked visitors if they noticed any haze during their stay at the park and if so, how much. Researchers found that on days when visual range was impaired (as measured by teleradiometer readings), visitors reported they did notice haze. Visitors who reported the view to be "very" or "extremely" hazy ranked their satisfaction with the view and their overall park experience lower than those who noticed only "slight" to "moderate" haze. Studies of the Great Gulf Wilderness (Hill et al, 2000) found that there is a level at which visitors find the haze to be "unacceptable." Most respondents indicated that visibility of 20 deciviews or greater was "unacceptable" for the view from Mt. Jefferson. Researchers have postulated that the deciview level of unacceptability is relatively high at this site because the scene depth at Mt. Jefferson is comparatively short at five miles. Visitors at areas with views spanning a greater distance may have a lower tolerance for haze since distant features would disappear into the haze much sooner than a scenic feature at close range.

Recently, Acadia National Park conducted a visitor study to: (1) determine visitor demographics and activity preferences; (2) identify favorable features or qualities of the park; and (3) solicit public input on Acadia's primary mission (Littlejohn, 1999). Among other questions, visitors were asked which activities they had participated in during their visit. Not unlike the previous studies mentioned, park visitors overwhelmingly cited sightseeing/pleasure driving (86 percent) and hiking (72 percent). Visitors were asked to rank scenic views, native plants and animals, recreational opportunities, solitude/quiet, wildness, cultural/historical sites and resources, clean air, and clean water on a scale from 1 to 5 representing varying levels of importance from "extremely important" to "not important." Scenic views (99 percent), clean air (97 percent), and clean water (96 percent) received the highest ratings of "extremely" or "very" important. Respondents also indicated that "scenic views" were the most enjoyed features of their visit from a long list that included both park amenities and specific natural features. Furthermore, visitors consistently replied that they thought the mission of Acadia National Park is to "preserve, protect, and maintain the natural beauty."

Finally, this study also found that most visitors receive information about the park from previous visits (51 percent), travel/guide books (41 percent), and from friends (40 percent). This suggests that perceptions of poor visibility can affect not only return trips by the visitors who experience haze, but their recommendations to friends. This finding is especially troubling for parks such as Acadia, where the peak visitor season coincides with the worst season for regional haze.

E. Valuation of Visibility and Related Attributes

Various methods have been developed to assess the economic value of resources such as forests, biodiversity, clean air and clean water. For example, the worth of a forest could be calculated as the total market value of the timber it contains. This method is helpful in measuring the potential use value of an environmental resource, but it is less helpful in quantifying the value of non-use goods (such as species protection) or indirect use goods (such as clean air). A technique that is frequently used to quantify the economic value of such goods

is called the Contingent Valuation Method (CVM). CVM studies frequently rely on surveys of the public's willingness to pay (WTP) to keep a resource or, alternatively, its willingness to accept compensation (WTA) for the loss of the resource. The results of these surveys can be highly sensitive to the formulation of survey questions; hence survey instruments must be carefully designed and tested to limit uncertainties and potential biases. Lack of familiarity with the resource to be valued, difficulty in understanding the questions, or lack of effort on the part of respondents can all distort survey results. Despite these difficulties, USEPA, the Interior Department, and the U.S. Court of Appeals have supported CVM as a viable and legitimate method for calculating the value of societal benefits associated with environmental protection (McClelland et al., 1993). Moreover, researchers have found that willingness to pay estimates generated by the CVM approach are comparable to estimates produced through other non-use and/or indirect use valuation techniques and can successfully predict actual purchase behavior (McClelland et al., 1993).

Various CVM studies have been conducted to value changes in air quality, including the specific attribute of visibility. These studies have been closely scrutinized to assess uncertainties associated with the survey methods. Chestnut and Rowe (1990) designed a study to value visibility at different national parks, across multiple regions. The study focuses on national parks in the Southwest, California, and the Southeast. Participants were asked about national parks and their personal experiences with them, general attitudes toward environmental issues, and the importance of visibility specifically. They were also asked how different visibility conditions would affect their enjoyment of national parks and whether they would be willing to pay higher prices or taxes to support specific measures to improve visibility.

Protecting visibility from further degradation ranked as a "high priority" for 72 percent of respondents. The study also found that 95 percent of respondents believed that their enjoyment of national parks would increase with improved visibility conditions. The findings of this study suggest a high level of public support for protecting and preserving "non-use" resources such as visibility. The following ranked highest among reasons to protect visibility and other natural values:

- "So there will be areas preserved in their natural condition, even if no one ever goes there."
- "To preserve our national heritage."
- "So there is not development everywhere."

The study found that the individuals willing to pay for visibility improvement was correlated with their income level and past or expected visits to the park. The mean per household value for all of the visibility improvement scenarios presented was $40-$60 annually. The mean is higher for residents of the state where the park is located. The Chestnut and Rowe study suggests that visual quality is important, not only to park visitors but also to those who never plan to visit a park themselves. This finding is important, since the economic burden of implementing control measures is likely to be borne equally by all citizens or ratepayers in a given region, regardless of whether they use Class I areas or not.

A similar study specific to the Great Gulf Wilderness in New Hampshire was conducted during the summer of 1998 (Hill et al., 2000). Individuals both on and off-site were surveyed to determine their willingness to accept compensation for worse visibility conditions. Only 20 percent of the respondents were willing to accept lower electricity costs for hazier conditions, suggesting that they placed a high value on visual quality. Significantly, 66 percent of respondents reported that they would cancel future plans to visit the White Mountains if visibility conditions worsened significantly.

USEPA used Chestnut and Rowe's estimates of visibility values to calculate the economic benefits associated with SO_2 emission reductions being considered by the Western Regional Air Partnership (WRAP)(USEPA, 2000). These emissions represent the total reductions that could be achieved by applying BART controls to all eligible sources in the WRAP region in order to achieve the region's 2018 visibility goals. The results of the Chestnut and Rowe study were transferred to Class I areas in other parts of the country using a "benefits transfer methodology" that adjusted WTP measures for other populations using baseline visibility, magnitude of visibility improvement, and household income. The results suggested that a 170,000 ton reduction in SO_2 emissions in the WRAP region would translate to an annual national willingness to pay of $320 million (1997 dollars). This estimate assumed higher reported WTP values for states with a Class I area, and lower estimates for states without a Class I area. USEPA's conclusions acknowledge that total economic benefit may be higher because this estimate did not include the benefits of improved visibility in residential areas around the Class I areas. The analysis also did not account for potential benefits in terms of reduced damage to structures and materials or ecosystem benefits. Therefore, the total economic benefit would be likely to exceed $320 million.

Abt Associates (2000) recently completed a study using WTP valuations and an economic utility function (which balances the tradeoff between household income and willingness to pay for visibility improvements) to assess the benefit of eliminating emissions from electric utility generators in terms of visibility improvement. The study found that the elimination of SO_2 and NO_X emissions from U.S. power plants would produce $7.7 billion in national visibility benefits alone. The economic benefit to Maine specifically was estimated to be $327.8 million, to New Hampshire, $6.0 million, and to Vermont, $600,000 (Abt Associates, 2000). These figures were based on enhanced recreational value, they do not take into account other indirect benefits, such as the increase in property values that may accrue to regions with improved visibility.

F. Related Public Health and Ecosystem Benefits of Reducing Fine Particle Pollution

As noted in the introduction to this chapter, the potential benefits of improving visibility in the eastern U.S. are fundamentally intertwined with the benefits of reducing fine particle pollution more generally, and ambient sulfate levels in particular. Federal visibility goals cannot be practically achieved – given the regional nature of haze in the eastern U.S. – without broad-based reductions in fine particles and their precursors. Such reductions will affect a much larger area than the Class I areas alone, both in terms of human exposure to fine particle pollution and in terms of ecosystem exposure to acid deposition, nitrogen-related

eutrophication, and other environmental impacts associated with haze-forming pollutants. Further, visibility improvements will accrue at other treasured areas of the region that are not designated as Class I areas including the Adirondack Mountains, the Allegheny Mountains, the Cape Cod National Seashore, and beach resorts throughout the region.

Fine particle pollution has been linked by a variety of epidemiological studies to direct impacts on human health, including premature mortality and morbidity. A number of studies have demonstrated that elevated levels of fine particle pollution are associated with increased emergency room and hospital visits, increased respiratory and cardiovascular illness (including chronic bronchitis and asthma), and increased risk of death. These studies formed the basis of USEPA's recent proposal to establish a new NAAQS for fine particulate matter, specifically particles with a diameter less than 2.5 micrometers or $PM_{2.5}$. That standard is now under review by the Supreme Court. Meanwhile, additional studies continue to add weight to the existing evidence for a direct and substantial relationship between health risks and fine particle pollution (HEI, 2000).

Importantly, the available epidemiological evidence suggests that there is no concentration threshold below which fine particle pollution is harmless to human health. Rather, the relationship between fine particle concentrations and health risks appears to be linear over the range of concentrations commonly experienced in the eastern U.S. In other words, a given increase or decrease in fine particle concentrations produces a commensurate increase or decrease in associated health risks. This finding suggests that any additional reductions in fine particle pollution that result from efforts to improve visibility conditions in Class I areas will produce public health benefits, even in areas where particulate levels are below a future $PM_{2.5}$ NAAQS. In short, broader public health benefits could add substantially, in economic terms, to the value placed on visibility improvement at Class I sites per se.

For example, USEPA's examination of the economic benefits of achieving a 170,000-ton reduction in SO_2 emissions in the WRAP region included an assessment of associated health benefits. Using concentration-response functions from published epidemiological studies to estimate the resulting avoidance of premature mortality, chronic bronchitis, respiratory and cardiovascular hospital admissions, asthma-related emergency room visits, lower and upper respiratory symptoms and care, asthma attacks, and lost days of work, the Agency arrived at a figure of roughly $1.3 billion in avoided health costs.[87]

Another recent study by Abt Associates for the Clean Air Task Force examined the health benefits of achieving substantial additional reductions in SO_2 and NO_x emissions from power plants nationwide (Clean Air Task Force, 2000). The study concluded that reducing these emissions by 75 percent from 1997 levels could reduce the annual number of premature deaths associated with current levels of fine particle pollution in the U.S. by 18,000.

Further SO_2 and NO_x reductions would also have multiple ecosystem benefits. There is evidence that acid deposition continues to be a problem for sensitive ecosystems in several northeastern states and that the acid neutralizing capacity (ANC) of soils is continuing to

[87] Note that possible effects on infant mortality, low birth weight, changes in pulmonary function, chronic respiratory diseases other than chronic bronchitis, morphological changes, altered host defense mechanisms, cancer, and non-asthma related respiratory emergency room visits were not considered.

decline in many parts of the region (Likens et al., 1996). Meanwhile, nitrate deposition has been associated with increases in nitrogen-saturated soils, increased toxicity of fish habitats, impaired health of several plant and tree species, and the proliferation of oxygen-depleting algae in sensitive bays and estuaries. Finally, further reductions in both NO_x and VOC emissions can help to reduce ozone formation and transport. Ozone has its own human health and ecosystem impacts; these include decreased lung function and eye irritation in humans, as well as damage to structures and vegetation.

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X. Summary and Recommendations

A. The Problem

Visibility is impaired when particles in the atmosphere scatter and absorb light. A new regional haze rule issued by the USEPA in 1999 addresses visibility impairment caused by air pollutants from numerous sources located over a wide geographic area. The goal of the program is to reduce manmade emissions and incrementally restore visibility in national parks and wilderness areas to natural conditions no later than 2064.

There are seven Class I areas in the Northeast and Mid-Atlantic covered under the regional haze rule: Acadia National Park, ME; Brigantine Wildlife Refuge, NJ; Great Gulf Wilderness Area, NH; Lye Brook Wilderness Area, VT; Moosehorn Wildlife Refuge, ME; Presidential Range – Dry Gulf Wilderness Area, NH; and the Roosevelt Campobello International Park, ME. Under natural atmospheric conditions, visibility in the East would be about 8 deciviews, which is equivalent to a visual range of 60 to 80 miles. Currently, on the worst 20 percent days, visibility at the Class I areas in New England is about 25 deciviews and about 30 deciviews at the New Jersey site, which is equivalent to visual range of about 15 to 30 miles. The deciview is the metric used in USEPA's regional haze rule to characterize visual quality and track reasonable progress due to its mostly linear relationship to perceived changes in visibility.

Due to the relatively short length of time that visibility data have been collected in most areas, it is difficult to determine whether visibility is improving or worsening at Class I areas in the Northeast and Mid-Atlantic. Acadia National Park, where data has been collected for the longest period, shows a modest level of improvement for both the 20 percent best and worst visibility days. A similar trend has been observed at the Washington, DC IMPROVE site.

Sulfates, organic carbon, nitrates, elemental carbon and crustal material are the main constituents of light-attenuating particles in the atmosphere. Particles can be directly emitted from industrial, transportation and agricultural sources or formed in the atmosphere by precursor species that are chemically transformed into the building blocks of fine particulate matter. In the East, sulfates are the predominant contributor to haze. Power plants and other industrial facilities are the primary sources of SO_2 and NO_x, the precursors for sulfates and nitrates. Highway vehicles and non-road equipment are a significant source of NO_x, organic matter and elemental carbon. Natural contributions to visibility include crustal materials (e.g., soil dust and sea salt) and biogenic organic hydrocarbons emitted by vegetation.

The presence of ammonia in the atmosphere aids the formation of sulfate and nitrate particles and increases the efficiency with which they grow in size. On a per mass unit basis, sulfates and nitrates are much greater contributors to visibility degradation than other haze constituents due, in part, to their affinity for water vapor. Under high relative humidity conditions, these particles can grow rapidly and change from solid to

liquid phase, significantly enhancing their ability to scatter light and degrade visibility. Ammonium sulfate accounts for 70 percent to 80 percent of the light extinction occurring at Class I areas on the worst visibility days in the Northeast and Mid-Atlantic. Under certain winter conditions, ammonium ion can be preferentially attracted to NO_x rather than SO_2, resulting in increased nitrate formation. Even under such winter conditions, however, sulfates remain the most important source of light extinction at all Class I locations in the Northeast and Mid-Atlantic.

Organic compounds comprise a significant mass fraction of aerosol particles and are an important contributor to visibility impairment even though they are assumed to have a low affinity for water vapor. Better understanding of the composition of organic aerosol particles remains a key focus for further research and may have a significant impact on the selection of haze control strategies depending on whether the majority of organic aerosols found at Class I sites are related to emissions from the transportation sector or from biogenic sources. Organic aerosol is more prevalent in urban locations, as evidenced by results from the IMPROVE monitor located in Washington D.C. where the relative contribution of organics to overall particulate matter is greater than at any of the Class I areas in the Northeast or Mid-Atlantic. This suggests an important anthropogenic contribution in urban areas.[88]

The long range transport of pollutants such as SO_2 and NO_x in the atmosphere is a well-established phenomenon with important implications for the regional haze program. As exemplified by the haze event described in Chapter III, visibility impairment can be exacerbated by the transport of SO_2 and NO_x emissions into the Northeast, where they are chemically transformed into haze constituents.

B. The Importance of Visibility

The sweeping views from the summit of Stratton Mountain in Vermont (overlooking the Lye Brook Wilderness area to the west) are said to have inspired Benton MacKaye when he conceived the idea of a scenic hiking route spanning the length of the Appalachian Mountains along the East Coast (Green Mountain Club, 1999). While the Appalachian Trail, which extends from Georgia to Maine, might have been created without the pristine views MacKaye must have experienced that day, this anecdote speaks to the importance of preserving and improving visibility conditions across the northeastern U.S.

Over $150 billion are spent annually in the U.S. on recreational activities in or near federally protected lands. National surveys indicate that 80 percent of Americans feel that the "quality of scenery" is an extremely important factor in choosing locations for their outdoor recreational activities. In addition to the psychological impact on

[88] Note that in the summertime, anthropogenic organic carbon emissions in urban areas combine with NO_x to create tropospheric ozone (smog). Ozone promotes the oxidation of biogenic hydrocarbons into light-scattering secondary organic aerosols. In this way, anthropogenic organic carbon emissions can also have an indirect effect on the biogenic contribution to visibility impairment in more rural Class I areas.

visitors at parks and wilderness areas, efforts to improve visibility will provide attendant public health and environmental benefits throughout the region. Reducing visibility impairing particulate matter will decrease the incidence of heart and respiratory ailments and associated premature morbidity and mortality across broad regions of the country (HEI, 2000). The USEPA estimates that $1.4 billion in public health-related savings would be realized in the western U.S. if BART controls were implemented consistent with the 2018 visibility milestone targets for that region (USEPA, 2000). Given higher pollutant levels and population density, far greater health benefits would be expected from similar controls on large stationary sources affecting visibility in the East.

Contributors to regional haze including NO_x and VOCs, also contribute to photochemical smog, a pollutant with significant health and welfare implications in the eastern U.S. The same meteorological processes responsible for secondary aerosol formation can lead to the photochemical transformation of these precursor species into ozone and other smog constituents. Even after three decades of emission control programs, the Northeast and Mid-Atlantic states still suffer from unacceptably high levels of ozone under certain meteorological conditions. Due to the predominance of photochemical smog events during summer months, NO_x controls for many large point sources are currently in place from May to September. Nitrates represent a more significant source of visibility impairment during the winter months in the East. Since some of the 20 percent worst days occur during the winter at Class I areas in the Northeast and Mid-Atlantic, examination of conditions leading to wintertime visibility impairment will have to be considered in order to achieve visibility goals.

The benefits of controlling pollutants that degrade visibility are significant in terms of other air pollution-related environmental problems. Sulfates and nitrates cause acid rain which results in: (1) the acidification of surface waters and soils through wet and dry deposition processes; (2) the depletion of soils' acid neutralizing capacity as stored base cations are replaced with acidic ions; and (3) soils suffering from nitrogen saturation, where the supply of nitrates received through atmospheric deposition overwhelms the natural ability of plants and microorganisms to utilize it. Dry and wet nitrate deposition also contributes to nitrification, algal blooms and eutrophication in critical marine bays and estuaries. For example, Chesapeake Bay receives almost 6 kilograms per hectare per year of wet nitrate deposition from airborne NO_x to the serious detriment of the ecosystem and wildlife within the bay (Cimorelli, 1999).

C. Recommendations

One of the primary goals of this analysis was to identify haze-related issues needing further research prior to the development of state and tribal implementation plans. This section summarizes the technical recommendations made in the body of this report and will help inform the research agenda of the OTC regional planning organization in the coming years. The recommendations are sorted into the following categories: basic science, modeling and data analysis, air quality monitoring and measurement, emission inventories, communication and education, and regulatory

efforts. It should be noted that these recommendations reflect the views of NESCAUM and MARAMA staff as members of the OTC RPO and may not accurately represent the views of individual state agencies or tribes within the RPO.

C.1 Basic Science

Natural background visibility conditions

In order to adequately characterize natural background conditions at Class I areas and establish viable rate-of-progress goals, forthcoming USEPA guidance on the subject should address natural variability in a more precise manner. Estimates in this report are largely based on a study by Federal Land Managers that do not account for the natural range of particulate forming emissions, meteorological conditions, and relative humidity experienced in the Northeast and Mid-Atlantic. We encourage the USEPA to develop a method for calculating the 20 percent best and worst natural visibility conditions for each Class I area based on monitored relative humidity over an extended period of time. A 20 percent best and 20 percent worst relative humidity value for each season should be considered. Additional work is also recommended to explore the magnitude of seasonal changes in biogenic emissions under natural conditions and the resulting impact on visibility. Finally, further research is needed to better assess the visibility impacts of marine aerosols on natural conditions at Class I areas in coastal locations.

Calculating baseline conditions

USEPA also plans to release guidance on tracking reasonable progress toward visibility goals. This guidance should contain a sensitivity analysis that details the range of potential errors introduced by the various assumptions that go into the calculation of reconstructed light extinction.

For example, in calculating visibility conditions from monitored data, it is recognized that relative humidity plays a significant role in the determination of the 20 percent best and worst visibility days. Monthly relative humidity values should be developed for each Class I area for both the 20 percent best and worst monitored days. Data from within the region suggest that using a single monthly average relative humidity value may bias the selection of the 20 percent best visibility days. Given the strong influence that humidity has on the optical properties of fine particles, further research should be focused on determining the accuracy of the relative humidity adjustment factor assumed in the forthcoming guidance.

Uncertainties also exist with regard to the relationship between the operationally defined term “organic carbon” (OC) and total organic mass as determined by organic carbon (OMC). The factor of 1.4 currently used by the IMPROVE program to define this relationship is based on empirical data. USEPA should evaluate the validity of this factor. USEPA should also look at the uncertainty introduced by assuming a constant size distribution, fixed dry scattering coefficients, and a single representative wavelength.

Secondary Organic Aerosols

Further study is needed to resolve the current uncertainty regarding the composition of secondary organic aerosol (SOA) and the relative fraction from anthropogenic versus biogenic sources. The USEPA, through the RPO structure, should encourage research into the role of biogenic organic compounds in SOA formation. This may include supporting basic research as well as emission inventory/emission factor work. Research in this area should also address the affinity of organic fine particulate matter for water vapor. The hygroscopicity of organic aerosol particles strongly influences their optical properties and, as the second most abundant constituent of fine particles in the East, warrant attention. During summer in rural eastern locations, organics may contribute up to 50 percent of fine particle mass; however, the current assumption that this fraction of aerosol composition is non-hygroscopic may underestimate its contribution to visibility degradation during these time periods.

C.2 Modeling and Data Analysis

Computer modeling

Computer model simulations of future fine particle levels will serve as the basis of state planning efforts. In order to ascertain as much useful information as possible, a regional modeling strategy is recommended that takes advantage of the multiple analytical techniques that are or will be available and is coordinated in cooperation with other regional planning organizations. This strategy is consistent with the approach used by the OTC modeling committee who, therefore, may be the appropriate group to develop a regional modeling strategy for haze.

An initial goal of the RPO's modeling effort will be to establish preliminary transport source regions for each of the relevant pollutants with regard to each of the Class I areas in or affected by the Northeast and Mid-Atlantic States. Work is also needed to evaluate seasonal variability caused by differences in weather patterns, sunlight and the availability of reactants. While similar work has been done to quantify transport of acid rain and ozone precursors, this work needs to be updated and refined for the purposes of the regional haze program.

REMSAD is appropriate for this preliminary work based on the availability of input data and the relatively short computational time required by this tool compared to other available models. The computational efficiency of REMSAD is critical given that the annual, as opposed to episodic, nature of the regional haze problem will require analyzing entire seasons. In addition, the RPO should develop "in-house" modeling capabilities with technically superior models (e.g. Models-3/CMAQ) in order to support the future needs of the member states. This effort will complement fine particle work being conducted or contemplated by participating states using other models such as UAM-V, CAMx-AERO, URM, CALPUFF, etc.

Assess differences in source contributions on best and worst days

Standard trajectory techniques (such as HYSPLIT) should be investigated and utilized to bundle air trajectories associated with good and poor visibility days as part of the effort to identify source regions for visibility-impairing pollutants. The National Park Service has previously performed such an analysis for Acadia National Park. This work needs to be updated to reflect changes in source region emissions due to new regulatory requirements and the closure of major sources such as the nickel smelter in Sudbury Ontario. A similar analysis is needed for other Class I areas in the Northeast and Mid-Atlantic that may be affected by different source regions than Acadia. Given its location as the southern-most Class I area in the OTC RPO region, future work should focus on the Brigantine Wildlife Refuge in New Jersey. The combined source regions for Acadia and Brigantine should reasonably bound the area of influence for haze-forming pollutants that affect visibility in Class I areas of the Northeast and Mid-Atlantic. This information is critical to establishing appropriate modeling domains.

GIS mapping of haze-related data

To make haze related data more accessible, this information should be mapped and displayed using geographic information systems. This approach will: (1) enable assessments of spatial and temporal variation in emissions and ambient fine particle concentrations; (2) provide a means for displaying a range of visibility metrics simultaneously and provide a better understanding of the relationship among the different ways of quantifying visual quality; and (3) make these data more accessible to both policymakers and the public. Ultimately, this technique should prove useful in explaining the linkages between regional haze and related public health and environmental issues.

C.3 Air Quality Monitoring and Measurement

A regional monitoring strategy must be developed which focuses on maintaining existing visibility records and identifying new monitoring activities that can add to these records. The regional monitoring strategy will necessarily address coordination with the FLM monitoring programs and provide the basis for SIP development in the future.

Dealing with incomplete monitoring data

Due to instrumentation problems with nitrate measurement, IMPROVE data on some high particle days is “thrown out” as incomplete. These days are not subsequently included in the 20 percent worst day calculations. Since nitrates are a relatively small contributor on most worst-case days, a weighted average nitrate concentration should be used and the resulting data should be retained as valid. Weighted average nitrate values can be derived from measured nitrate values on high mass particle days for which valid data exist.

Sorting IMPROVE data

Total particle weight is not always the best indicator of light extinction. IMPROVE data should be sorted according to reconstructed total particle light extinction

rather than gravimetric or reconstructed fine mass. Because of the disproportionate visibility impairment caused by sulfates and nitrates, a grouping of the best and worst visibility days may not correspond exactly to a grouping based on mass concentrations. For example, even though sulfate is the generally the dominant contributor to haze on the 20 percent worst days, sulfate mass on some of those days may be less than that of other particle constituents, such as organic carbon. In this case, a grouping based on mass sorting may miss some of the poorest visibility days.

Compile and evaluate regional PM2.5 monitoring data for haze purposes

The IMPROVE network provides a wealth of particulate data for assessing source contributions and long-term trends. In addition, states are now collecting new $PM_{2.5}$ data from an extensive monitoring network, and researchers are establishing new "supersites" for assessing particulate health impacts in New York City, Baltimore and Pittsburgh. All these data collection efforts will serve as important sources of information for assessing speciated particulate compositions, source contributions, and visibility improvement trends. As such, they will be part of a continuing effort by the RPO to assess $PM_{2.5}$ in the context of regional haze. Our regional database should be enhanced by adding these additional data.

Translate PM-fine data into deciview increments

The OTC RPO's database of speciated aerosol and relative humidity data in the Northeast and Mid-Atlantic states should be updated to include calendar year 2000 data. Sources of relative humidity data and procedures for using those data to calculate visibility metrics should continue to be explored. Adding relative humidity sensors to the required instrumentation package at each IMPROVE site is highly recommended. Deciviews and visual ranges need to be calculated for each aerosol sampling day and averaged into the appropriate time periods.

Assessment of marine aerosols

A field study is needed to better quantify the role of marine aerosols in haze formation. The information from such a study would aid in more accurately calculating natural background conditions at Class I areas at or near the coast. Initial studies should focus on Acadia National Park, Maine, Moosehorn Wilderness, Maine or Brigantine Wilderness, New Jersey.

Visibility cameras

The CAMNET initiative involves placing cameras at locations where visual quality is important. The pictures from these cameras provide an important resource for educating the public about regional haze. This network must be maintained and should be expanded to cover all Class I areas in the Northeast and Mid-Atlantic. Additional effort is needed to maximize the use of the images available from the network. At a minimum, these sites must be linked to the OTC RPO website. The data from continuous fine particle monitors should be used in conjunction with the camera images to evaluate and illustrate the relationship between ambient fine particle concentrations and visibility throughout the region.

C.4 Emission Inventories

Ammonia

Given the important role that it plays in the transformation of SO_2 and NO_x into sulfate and nitrate, better estimates of ammonia emissions are needed. The regional ammonia inventory being developed by researchers at Carnegie Mellon University, under a grant from NESCAUM and MARAMA, is a critical first step in overcoming this deficiency. The results from this analysis need to be translated into a format useful for SIP inventories and modeling purposes. State and local air quality agencies should compare available information for point sources to the CMU inventory and update the inventory with the most accurate information.

SO_2, VOC, and $PM_{2.5}$

In order to improve modeled estimates of SOA, as discussed above, emission inventories of VOC, SO_2 and $PM_{2.5}$ must be improved. This report demonstrates the dominant role of sulfates on both worst and best days. Inventories will need to be especially sensitive and accurate for modeling the 20 percent best visibility days when $PM_{2.5}$ concentrations are only about 2-4 $\mu g/m^3$ in the Northeastern Class I areas. Given the importance of sulfate aerosols (for both worst and best days), refinements in SO_2 emissions (especially quality assuring the 1999 NET emissions) will be needed. Similarly, improving biogenic and anthropogenic VOC emissions estimates, improving primary $PM_{2.5}$ emissions estimates, and obtaining speciated organic carbon (OC) measurements will be required.

It appears that better spatial and temporal allocation of emissions as well as more detailed speciation will be important for regional haze analysis. These aspects of the inventory are often handled in the emissions modeling or preprocessing phase of air quality modeling. Increased capability in this area is needed and a distributed approach may be the best model. As recommended for modeling activities, various states (or possibly the OTC RPO) should share the responsibility of developing the capability for emissions modeling and preprocessing.

The OTC RPO should stay abreast of efforts by EPA and other states and regions to improve estimates of biogenic emissions so that we have access to the best data available. This can be achieved through coordination with other regional planning organizations to develop a work plan for improving emissions inventories for regional planning purposes.

Mobile sources

Highway vehicles and nonroad equipment are significant sources of haze precursor species. The benefits of the Tier II motor vehicle emission control program, the 2004 heavy-duty engine rule, and the low sulfur gasoline and diesel regulations with regard to regional haze must be evaluated and quantified. While the NO_x, VOC and PM benefit projections have been quantified, the impact of these future controls on SO_2 and organic emissions from mobile sources must be better understood.

Quantification of current emission inventories should be improved by using MOBILE6 and by improving estimates of particulate emissions from mobile sources. Improvements in calculation and allocation of vehicle miles traveled (VMT) also need to be addressed in a regionally coordinated manner.

C.5 Communication and Education

The OTC RPO and states will need to develop communication programs to educate policymakers, affected industry and the public about the adverse impacts of regional haze and its linkages with other important public health and environmental issues. Such outreach will be important to build the political support necessary to achieve the aggressive visibility goals established by Congress.

C.6 Regulatory Efforts

A detailed technical analysis of USEPA's proposed BART guidance should be performed. This analysis should include: (1) a preliminary assessment of source regions influencing visibility at one or more of Class I areas in the Northeast; (2) an initial identification of potentially BART-eligible sources; (3) a summary of existing information regarding SO_2 and NO_X emissions from these sources; (4) an assessment of potential control options; and (5) a preliminary analysis of the reductions that might be achieved from these sources.

D. Conclusion

While regional haze is a new regulatory initiative in the eastern U.S. with relatively long planning and compliance horizons, much is already known about the causes of visibility impairment at Class I areas. As detailed in this report, sulfates are far and away the most significant component of regional haze in this part of the country and coal-fired utility boilers are the predominant source of sulfate precursor emissions.

The OTC RPO and its counterparts in other regions are tasked with orchestrating the technical assessment needed to develop cost-effective state and tribal implementation plans to comply with the regional haze rule. The RPOs, states, and tribes will need several years of coordinated research to better understand visibility problems and develop viable solutions. Nevertheless, we start with a reasonably strong understanding of the major causes of visibility impairment throughout the Northeast and Mid-Atlantic region and regulatory actions that will likely be needed to remedy the problem. Preliminary efforts to control SO_2 sources that contribute to sulfate aerosol formation in the Northeast and Mid-Atlantic should not be constrained by the relatively small uncertainties in quantifying secondary causes of visibility impairment in the region. At the same time, achieving the ultimate goal of eliminating the impact of manmade pollutants on visibility in all Class I areas will necessitate a far deeper understanding of the multitude of sources and the complicated chemistry at play. Developing this level of understanding represents a significant technical challenge to the RPOs and the individual states and tribes. Similarly, RPOs and states must effectively educate policymakers, affected industry and

the public about the adverse impacts of regional haze and its linkages with other important public health and environmental issues in order to build the understanding necessary to achieve the aggressive goals established by Congress.

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Appendix A – Full Text of the Regional Haze Rule

[Code of Federal Regulations]
[Title 40, Volume 2, Parts 50 to 51]
[Revised as of July 1, 1997]
From the U.S. Government Printing Office via GPO Access
[CITE: 40CFR51]

TITLE 40--PROTECTION OF ENVIRONMENT

CHAPTER I--ENVIRONMENTAL PROTECTION AGENCY

PART 51--REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMITTAL OF IMPLEMENTATION PLANS--Table of Contents

Subpart P--Protection of Visibility

Authority: Secs. 110, 114, 121, 160-169, 169A, 169B, 301, and 302 of the Clean Air Act, (42 U.S.C. 7410, 7414, 7421, 7470-7479, 7491, 7492, 7601, and 7602).

Sec. 51.300 Purpose and applicability.

(a) Purpose. The primary purposes of this subpart are (1) to require States to develop programs to assure reasonable progress toward meeting the national goal of preventing any future, and remedying any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from man-made air pollution, and (2) to establish necessary additional procedures for new source permit applicants, States, and Federal Land Managers to use in conducting the visibility impact analysis required for new sources under §51.166. This subpart sets forth requirements addressing visibility impairment in its two principal forms: “reasonably attributable” impairment (i.e., impairment attributable to a single source or small group of sources) and regional haze (i.e. widespread haze from a multitude of sources which impairs visibility in multiple direction over a large area).

(b) Applicability. (1) General Applicability. The provisions of this subpart are applicable to:

(i) Each State which has a mandatory Class I Federal area

identified in part 81, subpart D, of this title, and

(ii) Each State in which there is any source the emissions from which may reasonably be anticipated to cause or contribute to any impairment of visibility in any such area.

(2) The provisions of this subpart pertaining to implementation plans to address reasonably attributable visibility impairment are applicable to the following States:

(i) Alabama
(ii) Alaska
(iii) Arizona
(iv) Arkansas
(v) California
(vi) Colorado
(vii) Florida
(viii) Georgia
(ix) Hawaii
(x) Idaho
(xi) Kentucky
(xii) Louisiana
(xiii) Maine
(xiv) Michigan
(xv) Minnesota
(xvi) Missouri
(xvii) Montana
(xviii) Nevada
(xix) New Hampshire
(xx) New Jersey
(xxi) New Mexico
(xxii) North Carolina
(xxiii) North Dakota
(xxiv) Oklahoma
(xxv) Oregon
(xxvi) South Carolina
(xxvii) South Dakota
(xxviii) Tennessee
(xxix) Texas
(xxx) Utah
(xxxi) Vermont
(xxxii) Virginia
(xxxiii) Virgin Islands
(xxxiv) Washington
(xxxv) West Virginia
(xxxvi) Wyoming

(3) The provisions of this subpart pertaining to implementation

plans to address regional haze visibility impairment are applicable to all States as defined in section 302(d) of the Clean Air Act except Guam, Puerto Rico, American Samoa, and the Northern Mariana Islands.

Sec. 51.301 Definitions.

For purposes of this subpart:

(a) Adverse impact on visibility means, for purposes of section 307, visibility impairment which interferes with the management, protection, preservation, or enjoyment of the visitor's visual experience of the Federal Class I area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of visibility impairments, and how these factors correlate with (1) times of visitor use of the Federal Class I area, and (2) the frequency and timing of natural conditions that reduce visibility. This term does not include effects on integral vistas.

(b) Agency means the U.S. Environmental Protection Agency.

(c) Best Available Retrofit Technology (BART) means an emission limitation based on the degree of reduction achievable through the application of the best system of continuous emission reduction for each pollutant which is emitted by an existing stationary facility. The emission limitation must be established, on a case-by-case basis, taking into consideration the technology available, the costs of compliance, the energy and nonair quality environmental impacts of compliance, any pollution control equipment in use or in existence at the source, the remaining useful life of the source, and the degree of improvement in visibility which may reasonably be anticipated to result from the use of such technology.

(d) Building, structure, or facility means all of the pollutant-emitting activities which belong to the same industrial grouping, are located on one or more contiguous or adjacent properties, and are under the control of the same person (or persons under common control). Pollutant-emitting activities must be considered as part of the same industrial grouping if they belong to the same Major Group (i.e., which have the same two-digit code) as described in the Standard Industrial Classification Manual, 1972 as amended by the 1977 Supplement (U.S. Government Printing Office stock numbers 4101-0066 and 003-005-00176-0 respectively).

(e) Existing stationary facility means any of the following stationary sources of air pollutants, including any reconstructed source, which was not in operation prior to August 7, 1962, and was in existence on August 7, 1977, and has the potential to emit 250 tons per year or more of any air pollutant. In determining potential to emit, fugitive emissions, to the extent quantifiable, must be counted.

(1) Fossil-fuel fired steam electric plants of more than 250 million British thermal units per hour heat input,
(2) Coal cleaning plants (thermal dryers),
(3) Kraft pulp mills,
(4) Portland cement plants,
(5) Primary zinc smelters,
(6) Iron and steel mill plants,
(7) Primary aluminum ore reduction plants,
(8) Primary copper smelters,
(9) Municipal incinerators capable of charging more than 250 tons of refuse per day,
(10) Hydrofluoric, sulfuric, and nitric acid plants,
(11) Petroleum refineries,
(12) Lime plants,
(13) Phosphate rock processing plants,
(14) Coke oven batteries,
(15) Sulfur recovery plants,
(16) Carbon black plants (furnace process),
(17) Primary lead smelters,
(18) Fuel conversion plants,
(19) Sintering plants,
(20) Secondary metal production facilities,
(21) Chemical process plants,
(22) Fossil-fuel boilers of more than 250 million British thermal units per hour heat input,
(23) Petroleum storage and transfer facilities with a capacity exceeding 300,000 barrels,
(24) Taconite ore processing facilities,
(25) Glass fiber processing plants, and
(26) Charcoal production facilities.

(f) Federal Class I area means any Federal land that is classified or reclassified Class I.

(g) Federal Land Manager means the Secretary of the department with authority over the Federal Class I area (or the Secretary’s designee) or, with respect to Roosevelt-Campobello International Park, the Chairman of the Roosevelt-Campobello International Park Commission.

(h) Federally enforceable means all limitations and conditions which are enforceable by the Administrator under the Clean Air Act including those requirements developed pursuant to parts 60 and 61 of this title, requirements within any applicable State Implementation Plan, and any permit requirements established pursuant to §51.163 of this chapter or under regulations approved pursuant to part 51, 52, or 60 of this title.

(i) Fixed capital cost means the capital needed to provide all of the depreciable components.

(j) Fugitive Emissions means those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening.

(k) In existence means that the owner or operator has obtained all necessary preconstruction approvals or permits required by Federal, State, or local air pollution emissions and air quality laws or regulations and either has (1) begun, or caused to begin, a continuous program of physical on-site construction of the facility or (2) entered into binding agreements or contractual obligations, which cannot be canceled or modified without substantial loss to the owner or operator, to undertake a program of construction of the facility to be completed in a reasonable time.

(l) Installation means an identifiable piece of process equipment.

(m) In operation means engaged in activity related to the primary design function of the source.

(n) Integral vista means a view perceived from within the mandatory Class I Federal area of a specific landmark or panorama located outside the boundary of the mandatory Class I Federal area.

(o) Mandatory Class I Federal Area means any area identified in part 81, subpart D of this title.

(p) Major Stationary Source and major modification mean major stationary source and major modification, respectively, as defined in §51.166.

(q) Natural conditions includes naturally occurring phenomena that reduce visibility as measured in terms of light extinction, visual range, contrast, or coloration.

(r) Potential to emit means the maximum capacity of a stationary source to emit a pollutant under its physical and operational design. Any physical or operational limitation on the capacity of the source to emit a pollutant including air pollution control equipment and restrictions on hours of operation or on the type or amount of material combusted, stored, or processed, shall be treated as part of its design if the limitation or the effect it would have on emissions is federally enforceable. Secondary emissions do not count in determining the potential to emit of a stationary source.

(s) Reasonably attributable means attributable by visual observation or any other technique the State deems appropriate.

(t) Reconstruction will be presumed to have taken place where the fixed capital cost of the new component exceeds 50 percent of the fixed capital cost of a comparable entirely new source. Any final decision as to whether reconstruction has occurred must be made in accordance with the provisions of Sec. 60.15 (f) (1) through (3) of this title.

(u) Secondary emissions means emissions which occur as a result of the construction or operation of an existing stationary facility but do not come from the existing stationary facility. Secondary emissions may include, but are not limited to, emissions from ships or trains coming to or from the existing stationary facility.

(v) Significant impairment means, for purposes of section 303, visibility impairment which, in the judgment of the Administrator, interferes with the management, protection, preservation, or enjoyment of the visitor's visual experience of the mandatory Class I Federal area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of the visibility impairment, and how these factors correlate with (1) times of visitor use of the mandatory Class I Federal area, and (2) the frequency and timing of natural conditions that reduce visibility.

(w) Stationary Source means any building, structure, facility, or installation which emits or may emit any air pollutant.

(x) Visibility impairment means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

(y) Visibility in any mandatory Class I Federal area includes any integral vista associated with that area.

(z) Reasonably attributable visibility impairment means visibility impairment that is caused by the emission of air pollutants from one, or a small number of sources.

(aa) Regional haze means visibility impairment that is caused by the emission of air pollutants from numerous sources located over a wide geographic area. Such sources include, but are not limited to, major and minor stationary sources, mobile sources, and area sources.

(bb) Deciview means a measurement of visibility impairment. A deciview is a haze index derived from calculated light extinction, such that uniform changes in haziness correspond to uniform incremental changes in perception across the entire range of conditions, from pristine to highly impaired. The deciview haze index is calculated based on the following equation:

deciview haze index = $10 \ln_e(b_{ext}/10 \text{ Mm}^{-1})$.

where b_{ext} = atmospheric light extinction coefficient

For the purposes of calculating deciview for this regulation, the atmospheric light extinction coefficient must be calculated from aerosol measurements.

(cc) State means “State” as defined in section 302(d) of the Clean Air Act.

(dd) Most impaired days means the average visibility impairment (measured in deciviews) for the twenty percent of monitored days in a calendar year with the highest amount of visibility impairment.

(ee) Least impaired days means the average visibility impairment (measured in deciviews) for the twenty percent of monitored days in a calendar year with the lowest amount of visibility impairment.

(ff) Implementation plan means, for the purposes of this part, any State Implementation Plan, Federal Implementation Plan, or Tribal Implementation Plan.

(gg) Indian tribe or Tribe means any Indian tribe, band, nation, or other organized group or community, including any Alaska Native village, which is federally recognized as eligible for the special programs and services provided by the United States to Indians because of their status as Indians.

(hh) BART-eligible source means an existing stationary facility as defined in section 51.301(e).

(ii) Geographic enhancement for the purpose of section 308 means a method, procedure, or process to allow a broad regional strategy, such as an emissions trading program designed to achieve greater reasonable progress than BART for regional haze, to accomodate BART for reasonably attributable impairment.

Sec. 51.302 Implementation control strategies for reasonably attributable visibility impairment.

(a) Plan Revision Procedures. (1) Each State identified in section 300(b)(2) must have submitted, not later than September 2, 1981, an implementation plan meeting the requirements of this subpart pertaining to reasonably attributable visibility impairment.

(2) (i) The State, prior to adoption of any implementation plan to address reasonably attributable impairment required by this subpart, must conduct one or more public hearings on such plan in accordance with §51.102.

(ii) In addition to the requirements in §51.102, the State must provide written notification of such hearings to each affected Federal Land Manager, and other affected States, and must state where the public can inspect a summary prepared by the Federal Land Managers of their conclusions and recommendations, if any, on the proposed plan revision.

(3) Submission of plans as required by this subpart must be conducted in accordance with the procedures in §51.103.

(b) State and Federal Land Manager Coordination. (1) The State must identify to the Federal Land Managers, in writing and within 30 days of the promulgation of these regulations, the title of the official to which the Federal Land Manager of any mandatory Class I Federal area can submit a recommendation on the implementation of this subpart including, but not limited to:

(i) A list of integral vistas that are to be listed by the State for the purpose of implementing section 304,

(ii) Identification of impairment of visibility in any mandatory Class I Federal area(s), and

(iii) Identification of elements for inclusion in the visibility monitoring strategy required by §51.305.

(2) The State must provide opportunity for consultation, in person and at least 60 days prior to holding any public hearing on the plan, with the Federal Land Manager on the proposed SIP revision required by this subpart. This consultation must include the opportunity for the affected Federal Land Managers to discuss their:

(i) Assessment of impairment of visibility in any mandatory Class I Federal area, and

(ii) Recommendations on the development of the long-term strategy.

(3) The plan must provide procedures for continuing consultation between the State and Federal Land Manager on the implementation of the visibility protection program required by this subpart.

(c) General Plan Requirements for reasonably attributable visibility impairment.

(1) The affected Federal Land Manager may certify to the State, at any time, that there exists reasonably attributable impairment of visibility in any mandatory Class I Federal area.

(2) The plan must contain the following to address reasonably attributable impairment:

(i) A long-term (10-15 years) strategy, as specified in section 305 and section 306, including such emission limitations, schedules of compliance, and such other measures including schedules for the implementation of the elements of the long-term strategy as may be necessary to make reasonable progress toward the national goal specified in section 300(a).

(ii) An assessment of visibility impairment and a discussion of how each element of the plan relates to the preventing of future or remedying of existing impairment of visibility in any mandatory Class I Federal area within the State.

(iii) Emission limitations representing BART and schedules for compliance with BART for each existing stationary facility identified according to paragraph (c)(4) of this section.

(3) The plan must require each source to maintain control equipment required by this subpart and establish procedures to ensure such control equipment is properly operated and maintained.

(4) For any existing reasonably attributable visibility impairment the Federal Land Manager certifies to the State under paragraph (c)(1) of this section, at least 6 months prior to plan submission or revision:

(i) The State must identify and analyze for BART each existing stationary facility which may reasonably be anticipated to cause or contribute to impairment of visibility in any mandatory Class I Federal area where the impairment in the mandatory Class I Federal area is reasonably attributable to that existing stationary facility. The State need not consider any integral vista the Federal Land Manager did not identify pursuant to section 304(b) at least 6 months before plan submission.

(ii) If the State determines that technological or economic limitations on the applicability of measurement methodology to a particular existing stationary facility would make the imposition of an emission standard infeasible it may instead prescribe a design, equipment, work practice, or other operational standard, or combination thereof, to require the application of BART. Such standard, to the degree possible, is to set forth the emission reduction to be achieved by implementation of such design, equipment, work practice or operation, and must provide for compliance by means which achieve equivalent results.

(iii) BART must be determined for fossil-fuel fired generating plants having a total generating capacity in excess of 750 megawatts pursuant to ``Guidelines for Determining Best Available Retrofit Technology for Coal-fired Power Plants and Other Existing Stationary Facilities'' (1980), which is incorporated by reference, exclusive of appendix E, which was published in the Federal Register on February 6, 1980 (45 FR 8210). It is EPA publication No. 450/3-80-009b and is for sale from the U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. It is also available for inspection at the Office of the Federal Register Information Center, 800 North Capitol NW., suite 700, Washington, DC.

(iv) The plan must require that each existing stationary facility required to install and operate BART do so as expeditiously as practicable but in no case later than five years after plan approval or revision.

(v) The plan must provide for a BART analysis of any existing stationary facility that might cause or contribute to impairment of visibility in any mandatory Class I Federal area identified

under this paragraph (c)(4) at such times, as determined by the Administrator, as new technology for control of the pollutant becomes reasonably available if:

(A) The pollutant is emitted by that existing stationary facility,

(B) Controls representing BART for the pollutant have not previously been required under this subpart, and

(C) The impairment of visibility in any mandatory Class I Federal area is reasonably attributable to the emissions of that pollutant.

Sec. 51.303 Exemptions from control.

(a) (1) Any existing stationary facility subject to the requirement under §51.302 to install, operate, and maintain BART may apply to the Administrator for an exemption from that requirement.

(2) An application under this section must include all available documentation relevant to the impact of the source's emissions on visibility in any mandatory Class I Federal area and a demonstration by the existing stationary facility that it does not or will not, by itself or in combination with other sources, emit any air pollutant which may be reasonably anticipated to cause or contribute to a significant impairment of visibility in any mandatory Class I Federal area.

(b) Any fossil-fuel fired power plant with a total generating capacity of 750 megawatts or more may receive an exemption from BART only if the owner or operator of such power plant demonstrates to the satisfaction of the Administrator that such power plant is located at such a distance from all mandatory Class I Federal areas that such power plant does not or will not, by itself or in combination with other sources, emit any air pollutant which may reasonably be anticipated to cause or contribute to significant impairment of visibility in any such mandatory Class I Federal area.

(c) Application under this §51.303 must be accompanied by a written concurrence from the State with regulatory authority over the source.

(d) The existing stationary facility must give prior written notice to all affected Federal Land Managers of any application for exemption under this §51.303.

(e) The Federal Land Manager may provide an initial recommendation or comment on the disposition of such application. Such recommendation, where provided, must be part of the exemption application. This recommendation is not to be construed as the concurrence required under paragraph (h) of this section.

(f) The Administrator, within 90 days of receipt of an application for exemption from control, will provide notice of receipt of an exemption application and notice of opportunity for public hearing on the application.

(g) After notice and opportunity for public hearing, the Administrator may grant or deny the exemption. For purposes of judicial review, final EPA action on an application for an exemption under this §51.303 will not occur until EPA approves or disapproves the State Implementation Plan revision.

(h) An exemption granted by the Administrator under this §51.303 will be effective only upon concurrence by all affected Federal Land Managers with the Administrator's determination.

Sec. 51.304 Identification of integral vistas.

(a) On or before December 31, 1985 the Federal Land Manager may identify any integral vista. The integral vista must be identified according to criteria the Federal Land Manager develops. These criteria must include, but are not limited to, whether the integral vista is important to the visitor's visual experience of the mandatory Class I Federal area. Adoption of criteria must be preceded by reasonable notice and opportunity for public comment on the proposed criteria.

(b) The Federal Land Manager must notify the State of any integral vistas identified under paragraph (a) of this section, and the reasons therefor.

(c) The State must list in its implementation plan any integral vista the Federal Land Manager identifies at least six months prior to plan submission, and must list in its implementation plan at its earliest opportunity, and in no case later than at the time of the periodic review of the SIP required by section 306(c), any integral vista the Federal Land Manager identifies after that time.

(d) The State need not in its implementation plan list any integral vista the identification of which was not made in accordance with the criteria in paragraph (a) of this section. In making this finding, the State must carefully consider the

expertise of the Federal Land Manager in making the judgments called for by the criteria for identification. Where the State and the Federal Land Manager disagree on the identification of any integral vista, the State must give the Federal Land Manager an opportunity to consult with the Governor of the State.

Sec. 51.305 Monitoring for Reasonably Attributable Visibility Impairment.

(a) For the purposes of addressing reasonably attributable visibility impairment, each State containing a mandatory Class I Federal area must include in the plan a strategy for evaluating reasonably attributable visibility impairment in any mandatory Class I Federal area by visual observation or other appropriate monitoring techniques. Such strategy must take into account current and anticipated visibility monitoring research, the availability of appropriate monitoring techniques, and such guidance as is provided by the Agency.

(b) The plan must provide for the consideration of available visibility data and must provide a mechanism for its use in decisions required by this subpart.

Sec. 51.306 Long-term strategy requirements for reasonably attributable visibility impairment.

(a) (1) For the purposes of addressing reasonably attributable visibility impairment, each plan must include a long-term (10-15 years) strategy for making reasonable progress toward the national goal specified in section 300(a). This strategy must cover any existing impairment the Federal Land Manager certifies to the State at least 6 months prior to plan submission, and any integral vista of which the Federal Land Manager notifies the State at least 6 months prior to plan submission.

(2) A long-term strategy must be developed for each mandatory Class I Federal area located within the State and each mandatory Class I Federal area located outside the State which may be affected by sources within the State. This does not preclude the development of a single comprehensive plan for all such areas.

(3) The plan must set forth with reasonable specificity why the long-term strategy is adequate for making reasonable progress toward the national visibility goal, including remedying existing and preventing future impairment.

(b) The State must coordinate its long-term strategy for an

area with existing plans and goals, including those provided by the affected Federal Land Managers, that may affect impairment of visibility in any mandatory Class I Federal area.

(c) The plan must provide for periodic review and revision, as appropriate, of the long-term strategy for addressing reasonably attributable visibility impairment. The plan must provide for such periodic review and revision not less frequently than every three years until the date of submission of the State's first plan addressing regional haze visibility impairment in accordance with sections 51.308(b) and (c). On or before this date, the State must revise its plan to provide for review and revision of a coordinated long-term strategy for addressing reasonably attributable and regional haze visibility impairment, and the State must submit the first such coordinated long-term strategy. Future coordinated long-term strategies must be submitted consistent with the schedule for periodic progress reports set forth in section 51.308(g). Until the State revises its plan to meet this requirement, the State must continue to comply with existing requirements for plan review and revision, and with all emission management requirements in the plan to address reasonably attributable impairment. This requirement does not affect any pre-existing deadlines for State submittal of a long-term strategy review (or element thereof) between [the date of promulgation of regional haze rules] and the date required for submission of the State's first regional haze plan. In addition, the plan must provide for review of the long-term strategy as it applies to reasonably attributable impairment, and revision as appropriate, within 3 years of State receipt of any certification of reasonably attributable impairment from a Federal land manager. The review process must include consultation with the appropriate Federal Land Managers, and the State must provide a report to the public and the Administrator on progress toward the national goal. This report must include an assessment of:

(1) The progress achieved in remedying existing impairment of visibility in any mandatory Class I Federal area;

(2) The ability of the long-term strategy to prevent future impairment of visibility in any mandatory Class I Federal area;

(3) Any change in visibility since the last such report, or, in the case of the first report, since plan approval;

(4) Additional measures, including the need for SIP revisions, that may be necessary to assure reasonable progress toward the national visibility goal;

(5) The progress achieved in implementing BART and meeting other schedules set forth in the long-term strategy;

(6) The impact of any exemption granted under §51.303;

(7) The need for BART to remedy existing visibility impairment of any integral vista listed in the plan since the last such report, or, in the case of the first report, since plan approval.

(d) The long-term strategy must provide for review of the impacts from any new major stationary source or major modifications on visibility in any mandatory Class I Federal area. This review of major stationary sources or major modifications must be in accordance with §51.307, §51.166, and §51.160 and any other binding guidance provided by the Agency insofar as these provisions pertain to protection of visibility in any mandatory Class I Federal areas.

(e) The State must consider, at a minimum, the following factors during the development of its long-term strategy:

(1) Emission reductions due to ongoing air pollution control programs,

(2) Additional emission limitations and schedules for compliance,

(3) Measures to mitigate the impacts of construction activities,

(4) Source retirement and replacement schedules,

(5) Smoke management techniques for agricultural and forestry management purposes including such plans as currently exist within the State for these purposes, and

(6) Enforceability of emission limitations and control measures.

(f) The plan must discuss the reasons why the above and other reasonable measures considered in the development of the long-term strategy were or were not adopted as part of the long-term strategy.

(g) The State, in developing the long-term strategy, must take into account the effect of new sources, and the costs of compliance, the time necessary for compliance, the energy and

nonair quality environmental impacts of compliance, and the remaining useful life of any affected existing source and equipment therein.

Sec. 51.307 New source review.

(a) For purposes of new source review of any new major stationary source or major modification that would be constructed in an area that is designated attainment or unclassified under section 107(d)(1)(D) or (E) of the Clean Air Act, the State plan must, in any review under §51.166 with respect to visibility protection and analyses, provide for:

(1) Written notification of all affected Federal Land Managers of any proposed new major stationary source or major modification that may affect visibility in any Federal Class I area. Such notification must be made in writing and include a copy of all information relevant to the permit application within 30 days of receipt of and at least 60 days prior to public hearing by the State on the application for permit to construct. Such notification must include an analysis of the anticipated impacts on visibility in any Federal Class I area,

(2) Where the State requires or receives advance notification (e.g. early consultation with the source prior to submission of the application or notification of intent to monitor under § 51.166) of a permit application of a source that may affect visibility the State must notify all affected Federal Land Managers within 30 days of such advance notification, and

(3) Consideration of any analysis performed by the Federal Land Manager, provided within 30 days of the notification and analysis required by paragraph (a)(1) of this section, that such proposed new major stationary source or major modification may have an adverse impact on visibility in any Federal Class I area. Where the State finds that such an analysis does not demonstrate to the satisfaction of the State that an adverse impact will result in the Federal Class I area, the State must, in the notice of public hearing, either explain its decision or give notice as to where the explanation can be obtained.

(b) The plan shall also provide for the review of any new major stationary source or major modification:

(1) That may have an impact on any integral vista of a mandatory Class I Federal area, if it is identified in accordance with §51.304 by the Federal Land Manager at least 12 months before submission of a complete permit application, except where

the Federal Land Manager has provided notice and opportunity for public comment on the integral vista in which case the review must include impacts on any integral vista identified at least 6 months prior to submission of a complete permit application, unless the State determines under section §51.304(d) that the identification was not in accordance with the identification criteria, or

(2) That proposes to locate in an area classified as nonattainment under section 107(d)(1)(A), (B), or (c) of the Clean Air Act that may have an impact on visibility in any mandatory Class I Federal area.

(c) Review of any major stationary source or major modification under paragraph (b) of this section, shall be conducted in accordance with paragraph (a) of this section, and §51.166(o), (p) (1) through (2), and (q). In conducting such reviews the State must ensure that the source's emissions will be consistent with making reasonable progress toward the national visibility goal referred to in §51.300(a). The State may take into account the costs of compliance, the time necessary for compliance, the energy and nonair quality environmental impacts of compliance, and the useful life of the source.

(d) The State may require monitoring of visibility in any Federal Class I area near the proposed new stationary source or major modification for such purposes and by such means as the State deems necessary and appropriate.

§51.308 Regional Haze Program Requirements

(a) <u>What is the purpose of this section?</u> This section establishes requirements for implementation plans, plan revisions, and periodic progress reviews to address regional haze.

(b) <u>When are the first implementation plans due under the regional haze program</u>? Except as provided in sections 51.308(c) and 51.309(c), each State identified in section 51.300(b)(3) must submit an implementation plan for regional haze meeting the requirements of sections 51.308(d) and (e) by the following dates:

(1) For any area designated as attainment or unclassifiable for the national ambient air quality standard (NAAQS) for fine particulate matter ($PM_{2.5}$), the State must submit a regional haze implementation plan to EPA within 12 months after the date of designation.

(2) For any area designated as nonattainment for the $PM_{2.5}$ NAAQS, the State must submit a regional haze implementation plan to EPA at the same time that the State's plan for implementation of the $PM_{2.5}$ NAAQS must be submitted under section 172 of the Clean Air Act, that is, within 3 years after the area is designated as nonattainment, but not later than December 31, 2008.

(c) Options for regional planning. If at the time the SIP for regional haze would otherwise be due, a State is working with other States to develop a coordinated approach to regional haze by participating in a regional planning process, the State may choose to defer addressing the core requirements for regional haze in section 51.308(d) and the requirements for BART in section 51.308(e). If a State opts to do this, it must meet the following requirements:

(1) The State must submit an implementation plan by the earliest date by which an implementation plan would be due for any area of the State under section 51.308(b). This implementation plan must contain the following:

(i) A demonstration of ongoing participation in a regional planning process to address regional haze, and an agreement by the State to continue participating with one or more other States in such a process for the development of this and future implementation plan revisions;

(ii) A showing, based on available inventory, monitoring, or modeling information, that emissions from within the State contribute to visibility impairment in a mandatory Class I Federal Area outside the State, or that emissions from another State contribute to visibility impairment in any mandatory Class I Federal area within the State.

(iii) A description of the regional planning process, including a list of the States which have agreed to work together to address regional haze in a region (i.e. the regional planning group), the goals, objectives, management, and decisionmaking structure of the regional planning group, deadlines for completing significant technical analyses and developing emission management strategies, and a schedule for State review and adoption of regulations implementing the recommendations of the regional group;

(iv) A commitment by the State to submit an implementation plan revision addressing the requirements in sections 51.308(d) and(e) by the date specified in section 51.308(c)(2). In

addition, the State must commit to develop its plan revision in coordination with the other States participating in the regional planning process, and to fully address the recommendations of the regional planning group.

(v) A list of all BART-eligible sources within the State.

(2) The State must submit an implementation plan revision addressing the requirements in sections 51.308(d) and (e) by the latest date an area within the planning region would be required to submit an implementation plan under section 51.308(b), but in any event, no later than December 31, 2008.

(d) What are the core requirements for the implementation plan for regional haze? The State must address regional haze in each mandatory Class I Federal area located within the State and in each mandatory Class I Federal area located outside the State which may be affected by emissions from within the State. To meet the core requirements for regional haze for these areas, the State must submit an implementation plan containing the following plan elements and supporting documentation for all required analyses:

(1) Reasonable progress goals. For each mandatory Class I Federal area located within the State, the State must establish goals (expressed in deciviews) that provide for reasonable progress towards achieving natural visibility conditions. The reasonable progress goals must provide for an improvement in visibility for the most impaired days over the period of the implementation plan and ensure no degradation in visibility for the least impaired days over the same period.

(i) In establishing a reasonable progress goal for any mandatory Class I Federal area within the State, the State must:

(A) Consider the costs of compliance, the time necessary for compliance, the energy and non-air quality environmental impacts of compliance, and the remaining useful life of any potentially affected sources, and include a demonstration showing how these factors were taken into consideration in selecting the goal.

(B) Analyze and determine the rate of progress needed to attain natural visibility conditions by the year 2064. To calculate this rate of progress, the State must compare baseline visibility conditions to natural visibility conditions in the mandatory Federal Class I area and determine the uniform rate of visibility improvement (measured in deciviews) that would need to be maintained during each implementation period in order to

attain natural visibility conditions by 2064. In establishing the reasonable progress goal, the State must consider the uniform rate of improvement in visibility and the emission reduction measures needed to achieve it for the period covered by the implementation plan.

(ii) For the period of the implementation plan, if the State establishes a reasonable progress goal that provides for a slower rate of improvement in visibility than the rate that would be needed to attain natural conditions by 2064, the State must demonstrate, based on the factors in section 51.308(d)(1)(i)(A) above, that the rate of progress for the implementation plan to attain natural conditions by 2064 is not reasonable; and that the progress goal adopted by the State is reasonable. The State must provide to the public for review as part of its implementation plan an assessment of the number of years it would take to attain natural conditions if visibility improvement continues at the rate of progress selected by the State as reasonable.

(iii) In determining whether the State’s goal for visibility improvement provides for reasonable progress towards natural visibility conditions, the Administrator will evaluate the demonstrations developed by the State pursuant to sections 51.308(d)(1)(i) and 51.308(d)(1)(ii).

(iv) In developing each reasonable progress goal, the State must consult with those States which may reasonably be anticipated to cause or contribute to visibility impairment in the mandatory Class I Federal area. In any situation in which the State cannot agree with another such State or group of States that a goal provides for reasonable progress, the State must describe in its submittal the actions taken to resolve the disagreement. In reviewing the State’s implementation plan submittal, the Administrator will take this information into account in determining whether the State’s goal for visibility improvement provides for reasonable progress towards natural visibility conditions.

(v) The reasonable progress goals established by the State are not directly enforceable but will be considered by the Administrator in evaluating the adequacy of the measures in the implementation plan to achieve the progress goal adopted by the State.

(vi) The State may not adopt a reasonable progress goal that represents less visibility improvement than is expected to result from implementation of other requirements of the Clean Air Act during the applicable planning period.

(2) Calculations of baseline and natural visibility conditions. For each mandatory Class I Federal area located within the State, the State must determine the following visibility conditions (expressed in deciviews):

(i) Baseline visibility conditions for the most impaired and least impaired days. The period for establishing baseline visibility conditions is 2000 to 2004. Baseline visibility conditions must be calculated, using available monitoring data, by establishing the average degree of visibility impairment for the most and least impaired days for each calendar year from 2000 to 2004. The baseline visibility conditions are the average of these annual values. For mandatory Class I Federal areas without onsite monitoring data for 2000-2004, the State must establish baseline values using the most representative available monitoring data for 2000-2004, in consultation with the Administrator or his or her designee;

(ii) For an implementation plan that is submitted by 2003, the period for establishing baseline visibility conditions for the period of the first long term strategy is the most recent 5-year period for which visibility monitoring data are available for the mandatory Class I federal areas addressed by the plan. For mandatory Class I Federal areas without onsite monitoring data, the State must establish baseline values using the most representative available monitoring data, in consultation with the Administrator or his or her designee;

(iii) Natural visibility conditions for the most impaired and least impaired days. Natural visibility conditions must be calculated by estimating the degree of visibility impairment existing under natural conditions for the most impaired and least impaired days, based on available monitoring information and appropriate data analysis techniques; and

(iv)(A) for the first implementation plan addressing the requirements of section 51.308(d) and (e),the number of deciviews by which baseline conditions exceed natural visibility conditions for the most impaired and least impaired days; or

(B) for all future implementation plan revisions, the number of deciviews by which current conditions, as calculated under section 51.308(f)(1), exceed natural visibility conditions for the most impaired and least impaired days.

(3) Long-term strategy for regional haze. Each State listed in §51.300(b)(3) must submit a long-term strategy that addresses regional haze visibility impairment for each mandatory Class I

Federal area within the State and for each mandatory Class I Federal area located outside the State which may be affected by emissions from the State. The long-term strategy must include enforceable emissions limitations, compliance schedules, and other measures as necessary to achieve the reasonable progress goals established by States having mandatory Class I Federal areas. In establishing its long-term strategy for regional haze, the State must meet the following requirements:

(i) Where the State has emissions that are reasonably anticipated to contribute to visibility impairment in any mandatory Class I Federal area located in another State or States, the State must consult with the other State(s) in order to develop coordinated emission management strategies. The State must consult with any other State having emissions that are reasonably anticipated to contribute to visibility impairment in any mandatory Class I Federal area within the State.

(ii) Where other States cause or contribute to impairment in a mandatory Class I Federal area, the State must demonstrate that it has included in its implementation plan all measures necessary to obtain its share of the emission reductions needed to meet the progress goal for the area. If the State has participated in a regional planning process, the State must ensure it has included all measures needed to achieve its apportionment of emission reduction obligations agreed upon through that process.

(iii) The State must document the technical basis, including modeling, monitoring and emissions information, on which the State is relying to determine its apportionment of emission reduction obligations necessary for achieving reasonable progress in each mandatory Class I Federal area it affects. The State may meet this requirement by relying on technical analyses developed by the regional planning organization and approved by all State participants. The state must identify the baseline emissions inventory on which its strategies are based. The baseline emissions inventory year is presumed to be the most recent year of the consolidate periodic emissions inventory.

(iv) The State must identify all anthropogenic sources of visibility impairment considered by the State in developing its long-term strategy. The State should consider major and minor stationary sources, mobile sources, and area sources.

(v) The State must consider, at a minimum, the following factors in developing its long-term strategy:

(A) Emission reductions due to ongoing air pollution control

programs, including measures to address reasonably attributable visibility impairment;

(B) Measures to mitigate the impacts of construction activities;

(C) Emissions limitations and schedules for compliance to achieve the reasonable progress goal

(D) Source retirement and replacement schedules

(E) Smoke management techniques for agricultural and forestry management purposes including plans as currently exist within the State for these purposes;

(F) Enforceability of emissions limitations and control measures; and

(G) The anticipated net effect on visibility due to projected changes in point, area, and mobile source emissions over the period addressed by the long-term strategy.

(4) Monitoring strategy and other implementation plan requirements. The State must submit with the implementation plan a monitoring strategy for measuring, characterizing, and reporting of regional haze visibility impairment that is representative of all mandatory Class I Federal areas within the State. This monitoring strategy must be coordinated with the monitoring strategy required in section 51.305 for reasonably attributable visibility impairment. Compliance with this requirement may be met through participation in the Interagency Monitoring of Protected Visual Environments network. The implementation plan must also provide for the following:

(i) The establishment of any additional monitoring sites or equipment needed to assess whether reasonable progress goals to address regional haze for all mandatory Class I Federal areas within the State are being achieved.

(ii) Procedures by which monitoring data and other information are used in determining the contribution of emissions from within the State to regional haze visibility impairment at mandatory Class I Federal areas both within and outside the State.

(iii) For a State with no mandatory Class I Federal areas, procedures by which monitoring data and other information are used in determining the contribution of emissions from within the State to regional haze visibility impairment at mandatory Class I Federal areas in other States.

(iv) The implementation plan must provide for the reporting of all visibility monitoring data to the Administrator at least annually for each mandatory Class I Federal area in the State.

To the extent possible, the State should report visibility monitoring data electronically.

(v) A statewide inventory of emissions of pollutants that are reasonably anticipated to cause or contribute to visibility impairment in any mandatory Class I Federal area. The inventory must include emissions for a baseline year, emissions for the most recent year for which data are available, and estimates of future projected emissions. The State must also include a commitment to update the inventory periodically.

(vi) Other elements, including reporting, recordkeeping, and other measures, necessary to assess and report on visibility.

(e) Best Available Retrofit Technology (BART) requirements for regional haze visibility impairment. The State must submit an implementation plan containing emission limitations representing BART and schedules for compliance with BART for each BART-eligible source that may reasonably be anticipated to cause or contribute to any impairment of visibility in any mandatory Class I Federal area, unless the State demonstrates that an emissions trading program or other alternative will achieve greater reasonable progress toward natural visibility conditions.

(1) To address the requirements for BART, the State must submit an implementation plan containing the following plan elements and include documentation for all required analyses:

(i) A list of all BART-eligible sources within the State.

(ii) A determination of BART for each BART-eligible source in the State that emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility in any mandatory Class I Federal area. All such sources are subject to BART. This determination must be based on the following analyses:

(A) An analysis of the best system of continuous emission control technology available and associated emission reductions achievable for each BART-eligible source within the State subject to BART. In this analysis, the State must take into consideration the technology available, the costs of compliance, the energy and nonair quality environmental impacts of compliance, any pollution control equipment in use at the source, and the remaining useful life of the source; and

(B) An analysis of the degree of visibility improvement that would be achieved in each mandatory Class I Federal area as a

result of the emission reductions achievable from all sources subject to BART located within the region that contributes to visibility impairment in the Class I area, based on the analysis conducted under section 51.308(e)(1)(ii)(A).

(iii) If the State determines in establishing BART that technological or economic limitations on the applicability of measurement methodology to a particular source would make the imposition of an emission standard infeasible, it may instead prescribe a design, equipment, work practice, or other operational standard, or combination thereof, to require the application of BART. Such standard, to the degree possible, is to set forth the emission reduction to be achieved by implementation of such design, equipment, work practice or operation, and must provide for compliance by means which achieve equivalent results.

(iv) A requirement that each source subject to BART be required to install and operate BART as expeditiously as practicable, but in no event later than 5 years after approval of the implementation plan revision.

(v) A requirement that each source subject to BART maintain the control equipment required by this subpart and establish procedures to ensure such equipment is properly operated and maintained.

(2) A State may opt to implement an emissions trading program or other alternative measure rather than to require sources subject to BART to install, operate, and maintain BART. To do so, the State must demonstrate that this emissions trading program or other alternative measure will achieve greater reasonable progress than would be achieved through the installation and operation of BART. To make this demonstration, the State must submit an implementation plan containing the following plan elements and include documentation for all required analyses:

(i) A demonstration that the emissions trading program or other alternative measure will achieve greater reasonable progress than would have resulted from the installation and operation of BART at all sources subject to BART in the State. This demonstration must be based on the following:

(A) A list of all BART-eligible sources within the State.

(B) An analysis of the best system of continuous emission control technology available and associated emission reductions

achievable for each source within the State subject to BART. In this analysis, the State must take into consideration the technology available, the costs of compliance, the energy and nonair quality environmental impacts of compliance, any pollution control equipment in use at the source, and the remaining useful life of the source. The best system of continuous emission control technology and the above factors may be determined on a source category basis. The State may elect to consider both source-specific and category-wide information, as appropriate, in conducting its analysis.

(C) An analysis of the degree of visibility improvement that would be achieved in each mandatory Class I Federal area as a result of the emission reductions achievable from all such sources subject to BART located within the region that contributes to visibility impairment in the Class I area, based on the analysis conducted under section 51.308(e)(2)(i)(B).

(ii) A demonstration that the emissions trading program or alternative measures will apply, at a minimum, to all BART-eligible sources in the State. Those sources having a federally enforceable emission limitation determined by the State and approved by EPA as meeting BART in accordance with section 51.302(c) or 51.308(e)(1) do not need to meet the requirements of the emissions trading program or alternative measure, but may choose to participate if they meet the requirements of the emissions trading program or alternative measure.

(iii) A requirement that all necessary emission reductions take place during the period of the first long-term strategy for regional haze. To meet this requirement, the State must provide a detailed description of the emissions trading program or other alternative measure, including schedules for implementation, the emission reductions required by the program, all necessary administrative and technical procedures for implementing the program, rules for accounting and monitoring emissions, and procedures for enforcement.

(iv) A demonstration that the emission reductions resulting from the emissions trading program or other alternative measure will be surplus to those reductions resulting from measures adopted to meet requirements of the Clean Air Act as of the baseline date of the SIP.

(v) At the State’s option, a provision that the emissions trading program or other alternative measure may include a geographic enhancement to the program to address the requirement under §51.302(c) related to BART for reasonably attributable

impairment from the pollutants covered under the emissions trading program or other alternative measure.

(3) After a State has met the requirements for BART or implemented emissions trading program or other alternative measure that achieve more reasonable progress than the installation and operation of BART, BART-eligible sources will be subject to the requirements of section 51.308(d) in the same manner as other sources.

(4) Any BART-eligible facility subject to the requirement under section 51.308(e) to install, operate, and maintain BART may apply to the Administrator for an exemption from that requirement. An application for an exemption will be subject to the requirements of section 51.303(a)(2)-(h).

(f) Requirements for comprehensive periodic revisions of implementation plans for regional haze. Each State identified in section 51.300(b)(3) must revise and submit its regional haze implementation plan revision to EPA by July 31, 2018 and every ten years thereafter. In each plan revision, the State must evaluate and reassess all of the elements required in section 51.308(d), taking into account improvements in monitoring data collection and analysis techniques, control technologies, and other relevant factors. In evaluating and reassessing these elements, the State must address the following:

(1) Current visibility conditions for the most impaired and least impaired days, and actual progress made towards natural conditions during the previous implementation period. The period for calculating current visibility conditions is the most recent five year period preceding the required date of the implementation plan submittal for which data are available. Current visibility conditions must be calculated based on the annual average level of visibility impairment for the most and least impaired days for each of these five years. Current visibility conditions are the average of these annual values.

(2) The effectiveness of the long-term strategy for achieving reasonable progress goals over the prior implementation period(s); and

(3) Affirmation of, or revision to, the reasonable progress goal in accordance with the procedures set forth in section 51.308(d)(1). If the State established a reasonable progress goal for the prior period which provided a slower rate of progress than that needed to attain natural conditions by the year 2064, the State must evaluate and determine the

reasonableness, based on the factors in section 51.308(d)(1)(i)(A), of additional measures that could be adopted to achieve the degree of visibility improvement projected by the analysis contained in the first implementation plan described in section 51.308(d)(1)(i)(B).

(g) Requirements for periodic reports describing progress towards the reasonable progress goals. Each State identified in section 51.300(b)(3) must submit a report to the Administrator every 5 years evaluating progress towards the reasonable progress goal for each mandatory Class I Federal area located within the State and in each mandatory Class I Federal area located outside the State which may be affected by emissions from within the State. The first progress report is due 5 years from submittal of the initial implementation plan addressing sections 51.308(d) and (e). The progress reports must be in the form of implementation plan revisions that comply with the procedural requirements of sections 51.102 and 51.103. Periodic progress reports must contain at a minimum the following elements:

(1) A description of the status of implementation of all measures included in the implementation plan for achieving reasonable progress goals for mandatory Class I Federal areas both within and outside the State.

(2) A summary of the emissions reductions achieved throughout the State through implementation of the measures described in section 51.308(g)(1).

(3) For each mandatory Class I Federal area within the State, the State must assess the following visibility conditions and changes, with values for most impaired and least impaired days expressed in terms of five-year averages of these annual values.

(i) the current visibility conditions for the most impaired and least impaired days;

(ii) the difference between current visibility conditions for the most impaired and least impaired days and baseline visibility conditions;

(iii) the change in visibility impairment for the most impaired and least impaired days over the past five years;

(4) An analysis tracking the change over the past 5 years in emissions of pollutants contributing to visibility impairment from all sources and activities within the State. Emissions changes should be identified by type of source or activity. The

analysis must be based on the most recent updated emissions inventory, with estimates projected forward as necessary and appropriate, to account for emissions changes during the applicable 5-year period.

(5) An assessment of any significant changes in anthropogenic emissions within or outside the State that have occurred over the past 5 years that have limited or impeded progress in reducing pollutant emissions and improving visibility.

(6) An assessment of whether the current implementation plan elements and strategies are sufficient to enable the State, or other States with mandatory Federal Class I areas affected by emissions from the State, to meet all established reasonable progress goals.

(7) A review of the State's visibility monitoring strategy and any modifications to the strategy as necessary.

(h) Determination of the adequacy of existing implementation plan. At the same time the State is required to submit any 5-year progress report to EPA in accordance with section 51.308(g), the State must also take one of the following actions based upon the information presented in the progress report:

(1) If the State determines that the existing implementation plan requires no further substantive revision at this time in order to achieve established goals for visibility improvement and emissions reductions, the State must provide to the Administrator a negative declaration that further revision of the existing implementation plan is not needed at this time.

(2) If the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from sources in another State(s) which participated in a regional planning process, the State must provide notification to the Administrator and to the other State(s) which participated in the regional planning process with the States. The State must also collaborate with the other State(s) through the regional planning process for the purpose of developing additional strategies to address the plan's deficiencies.

(3) Where the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from sources in another country, the State shall provide notification, along with available information, to the Administrator.

(4) Where the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from sources within the State, the State shall revise its implementation plan to address the plan's deficiencies within one year.

(i) What are the requirements for State and Federal Land Manager coordination?.

(1) By [insert date 90 days from the effective date of these regulations], the State must identify in writing to the Federal Land Managers the title of the official to which the Federal Land Manager of any mandatory Class I Federal area can submit any recommendations on the implementation of this subpart including, but not limited to:

(i) Identification of impairment of visibility in any mandatory Class I Federal area(s), and

(ii) Identification of elements for inclusion in the visibility monitoring strategy required by sections 51.305 and 51.308.

(2) The State must provide the Federal Land Manager with an opportunity for consultation, in person and at least 60 days prior to holding any public hearing on an implementation plan (or plan revision) for regional haze required by this subpart. This consultation must include the opportunity for the affected Federal Land Managers to discuss their:

(i) Assessment of impairment of visibility in any mandatory Class I Federal area, and

(ii) Recommendations on the development of the reasonable progress goal and on the development and implementation of strategies to address visibility impairment.

(3) In developing any implementation plan (or plan revision), the State must include a description of how it addressed any comments provided by the Federal Land Managers.

(4) The plan (or plan revision) must provide procedures for continuing consultation between the State and Federal Land Manager on the implementation of the visibility protection program required by this subpart, including development and review of implementation plan revisions and 5-year progress reports, and on the implementation of other programs having the potential to contribute to impairment of visibility in mandatory

Class I Federal areas.

§51.309 Requirements Related to the Grand Canyon Visibility Transport Commission.

(a) What is the purpose of this section?. This section establishes the requirements for the first regional haze implementation plan to address regional haze visibility impairment in the 16 Class I areas covered by the Grand Canyon Visibility Transport Commission Report. For the years 2003 to 2018, certain States (defined below as Transport Region States) may choose to implement the Commission's recommendations within the framework of the national regional haze program and applicable requirements of the Act by complying with the provisions of this section, as supplemented by an approvable Annex to the Commission Report as required by section 51.309(f). If a transport region state submits an implementation plan which is approved by EPA as meeting the requirements of this section, it will be deemed to comply with the requirements for reasonable progress for the period from approval of the plan to 2018.

(b) Definitions. For the purposes of this section:

(1) "16 Class I areas" means the following mandatory Class I Federal areas on the Colorado Plateau: Grand Canyon National Park, Sycamore Canyon Wilderness, Petrified Forest National Park, Mount Baldy Wilderness, San Pedro Parks Wilderness, Mesa Verde National Park, Weminuche Wilderness, Black Canyon of the Gunnison Wilderness, West Elk Wilderness, Maroon Bells Wilderness, Flat Tops Wilderness, Arches National Park, Canyonlands National Park, Capital Reef National Park, Bryce Canyon National Park, and Zion National Park.

(2) "Transport Region State" means one of the States that is included within the Transport Region addressed by the Grand Canyon Visibility Transport Commission (Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Wyoming).

(3) "Commission Report" means the report of the Grand Canyon Visibility Transport Commission entitled "Recommendations for Improving Western Vistas," dated June 10, 1996.

(4) "Fire" means wildfire, wildland fire (including prescribed natural fire) , prescribed fire, and agricultural burning conducted and occurring on Federal, State, and private wildlands and farmlands.

(5) “Milestone” means an average percentage reduction in emissions, expressed in tons per year, for a given year or for a period of up to five years ending in that year, compared to a 1990 actual emissions baseline.

(6) “Mobile Source Emission Budget” means the lowest level of VOC, NO_X, SO_2 elemental and organic carbon, and fine particles which are projected to occur in any area within the transport region from which mobile source emissions are determined to contribute significantly to visibility impairment in any of the 16 Class I areas.

(7) “Geographic enhancement” means a method, procedure, or process to allow a broad regional strategy, such as a milestone or backstop market trading program designed to achieve greater reasonable progress than BART for regional haze, to accommodate BART for reasonably attributable impairment.

(c) Implementation Plan Schedule. Each Transport Region State may meet the requirements of section 51.308(b)-(e) by electing to submit an implementation plan that complies with the requirements of section 51.309. Each Transport Region State must submit an implementation plan addressing regional haze visibility impairment in the 16 Class I areas no later than December 31, 2003. A Transport Region State that elects not to submit an implementation plan that complies with the requirements of section 51.309 (or whose plan does not comply with all of the requirements of 51.309) is subject to the requirements of section 51.308 in the same manner and to the same extent as any State not included within the Transport Region.

(d) Requirements of the first implementation plan for States electing to adopt all of the recommendations of the Commission Report. Except as provided for in §51.309(e), each Transport Region State must submit an implementation plan that meets the following requirements:

(1) Time period covered. The implementation plan must be effective for the entire time period between December 31, 2003 and December 31, 2018.

(2) Projection of visibility improvement. For each of the 16 mandatory Class I areas located within the Transport Region State, the plan must include a projection of the improvement in visibility conditions (expressed in deciviews, and in any additional ambient visibility metrics deemed appropriate by the State) expected through the year 2018 for the most impaired and least impaired days, based on the implementation of all measures

as required in the Commission report and the provisions in §51.309. The projection must be made in consultation with other Transport Region States with sources which may be reasonably anticipated to contribute to visibility impairment in the relevant Class I area. The projection may be based on a satisfactory regional analysis.

(3) Treatment of clean-air corridors. The plan must describe and provide for implementation of comprehensive emission tracking strategies for clean-air corridors to ensure that the visibility does not degrade on the least-impaired days at any of the 16 Class I areas. The strategy must include:

(i) An identification of clean-air corridors. The EPA will evaluate the State's identification of such corridors based upon the reports of the Commission's Meteorology Subcommittee and any future updates by a successor organization;

(ii) Within areas that are clean-air corridors, an identification of patterns of growth or specific sites of growth that could cause, or are causing, significant emissions increases that could have, or are having, visibility impairment at one or more of the 16 Class I areas.

(iii) In areas outside of clean-air corridors, an identification of significant emissions growth that could begin, or is beginning, to impair the quality of air in the corridor and thereby lead to visibility degradation for the least-impaired days in one or more of the 16 Class I areas.

(iv) If impairment of air quality in clean air corridors is identified pursuant to subsections 51.309(d)(3)(ii) and (iii), an analysis of the effects of increased emissions, including provisions for the identification of the need for additional emission reductions measures, and implementation of the additional measures where necessary.

(v) A determination of whether other clean air corridors exist for any of the 16 Class I areas. For any such clean air corridors, an identification of the necessary measures to protect against future degradation of air quality in any of the 16 Class I areas.

(4) Implementation of Stationary Source Reductions. The first implementation plan submission must include:

(i) Monitoring and reporting of sulfur dioxide emissions. The plan submission must include provisions requiring the

monitoring and reporting of actual stationary source sulfur dioxide emissions within the State. The monitoring and reporting data must be sufficient to determine whether a 13 percent reduction in actual stationary source sulfur dioxide emissions has occurred between the years 1990 and 2000, and whether milestones required by section 51.309(f)(ii) have been achieved for the transport region. The plan submission must provide for reporting of these data by the State to the Administrator. Where procedures developed under section 51.309(f)(2) and agreed upon by the State include reporting to a regional planning organization, the plan submission must provide for reporting to the regional planning body in addition to the Administrator.

(ii) Criteria and Procedures for a Market Trading Program. The plan must include the criteria and procedures for activating a market trading program or other program consistent with section 51.309(f)(2) if an applicable regional milestone is exceeded, procedures for operation of the program, and implementation plan assessments of the program in the years 2008, 2013, and 2018.

(iii) Provisions for activating a market trading program. Provisions to activate the market trading program or other program within 12 months after the emissions for the region are determined to exceed the applicable emission reduction milestone, and to assure that all affected sources are in compliance with allocation and other requirements within 5 years after the emissions for the region are determined to exceed the applicable emission reduction milestone.

(iv) Provisions for market trading program compliance reporting. If the market trading program has been activated, the plan submission must include provisions requiring the State to provide annual reports assuring that all sources are in compliance with applicable requirements of the market trading program.

(v) Provisions for stationary source NO_x and PM. The plan submission must include a report which assesses emissions control strategies for stationary source NO_x and PM, and the degree of visibility improvement that would result from such strategies. In the report, the State must evaluate and discuss the need to establish emission milestones for NO_x and PM to avoid any net increase in these pollutants from stationary sources within the transport region, and to support potential future development and implementation of a multipollutant and possibly multisource market-based program. The plan submission must provide for an implementation plan revision, containing any necessary long-term strategies and BART requirements for stationary source PM and NO_x

(including enforceable limitations, compliance schedules, and other measures) by no later than December 31, 2008.

(5) Mobile Sources. The plan submission must provide for:

(i) Statewide inventories of current annual emissions and projected future annual emissions of VOC, NO_X, SO_2, elemental and organic carbon, and fine particles from mobile sources for the years 2003 to 2018. The future year inventories must include projections for the year 2005, or an alternative year that is determined by the State to represent the year during which mobile source emissions will be at their lowest levels within the State.

(ii) A determination whether mobile source emissions in any areas of the State contribute significantly to visibility impairment in any of the 16 Class I Areas, based on the statewide inventory of current and projected mobile source emissions.

(iii) For States with areas in which mobile source emissions are found to contribute significantly to visibility impairment in any of the 16 Class I areas:

(A) The establishment and documentation of a mobile source emissions budget for any such area, including provisions requiring the State to restrict the annual VOC, Nox, SO_2, elemental and organic carbon, and/or fine particle mobile source emissions to their projected lowest levels, to implement measures to achieve the budget or cap, and to demonstrate compliance with the budget.

(B) An emission tracking system providing for reporting of annual mobile source emissions from the State in the periodic implementation plan revisions required by section 51.309(d)(10). The emission tracking system must be sufficient to determine the States' contribution toward the Commission's objective of reducing emissions from mobile sources by 2005 or an alternate year that is determined by the State to represent the year during which mobile source emissions will be at their lowest levels within the State, and to ensure that mobile source emissions do not increase thereafter.

(iv) Interim reports to EPA and the public in years 2003, 2008, 2013, and 2018 on the implementation status of the regional and local strategies recommended by the Commission Report to address mobile source emissions.

(6) Programs Related to Fire. The plan must provide for:

(i) Documentation that all Federal, State, and private prescribed fire programs within the State evaluate and address the degree visibility impairment from smoke in their planning and application. In addition the plan must include smoke management programs that include all necessary components including, but not limited to, actions to minimize emissions, evaluation of smoke dispersion, alternatives to fire, public notification, air quality monitoring, surveillance and enforcement, and program evaluation.

(ii) A statewide inventory and emissions tracking system (spatial and temporal) of VOC, NOx, elemental and organic carbon, and fine particle emissions from fire. In reporting and tracking emissions from fire from within the State, States may use information from regional data-gathering and tracking initiatives.

(iii) Identification and removal wherever feasible of any administrative barriers to the use of alternatives to burning in Federal, State, and private prescribed fire programs within the State.

(iv) Enhanced smoke management programs for fire that consider visibility effects, not only health and nuisance objectives, and that are based on the criteria of efficiency, economics, law, emission reduction opportunities, land management objectives, and reduction of visibility impact.

(v) Establishment of annual emission goals for fire, excluding wildfire, that will minimize emission increases from fire to the maximum extent feasible and that are established om cooperation with States, tribes, Federal land management agencies, and private entities.

(7) Area Sources of Dust Emissions from Paved and Unpaved Roads. The plan must include an assessment of the impact of dust emissions from paved and unpaved roads on visibility conditions in the 16 Class I Areas. If such dust emissions are determined to be a significant contributor to visibility impairment in the 16 Class I areas, the State must implement emissions management strategies to address the impact as necessary and appropriate.

(8) Pollution Prevention. The plan must provide for:

(i) An initial summary of all pollution prevention programs currently in place, an inventory of all renewable energy generation capacity and production in use, or planned as of the year 2002 (expressed in megawatts and megawatt-hours), the total

energy generation capacity and production for the State, the percent of the total that is renewable energy, and the State’s anticipated contribution toward the renewable energy goals for 2005 and 2015, as provided in section 51.309(d)(8)(vi).

(ii) Programs to provide incentives that reward efforts that go beyond compliance and/or achieve early compliance with air-pollution related requirements.

(iii) Programs to preserve and expand energy conservation efforts.

(iv) The identification of specific areas where renewable energy has the potential to supply power where it is now lacking and where renewable energy is most cost-effective.

(v) Projections of the short- and long-term emissions reductions, visibility improvements, cost savings, and secondary benefits associated with the renewable energy goals, energy efficiency and pollution prevention activities.

(vi) A description of the programs relied on to achieve the State's contribution toward the Commission's goal that renewable energy will comprise 10 percent of the regional power needs by 2005 and 20 percent by 2015, and a demonstration of the progress toward achievement of the renewable energy goals in the years 2003, 2008, 2013, and 2018. This description must include documentation of the potential for renewable energy resources, the percentage of renewable energy associated with new power generation projects implemented or planned, and the renewable energy generation capacity and production in use and planned in the State. To the extent that it is not feasible for a State to meet its contribution to the regional renewable energy goals, the State must identify in the progress reports the measures implemented to achieve its contribution and explain why meeting the State's contribution was not feasible.

(9) Implementation of Additional Recommendations. The plan must provide for implementation of all other recommendations in the Commission report that can be practicably included as enforceable emission limits, schedules of compliance, or other enforceable measures (including economic incentives) to make reasonable progress toward remedying existing and preventing future regional haze in the 16 Class I areas. The State must provide a report to EPA and the public in 2003, 2008, 2013, and 2018 on the progress toward developing and implementing policy or strategy options recommended in the Commission Report.

(10) Periodic Implementation Plan Revisions. Each Transport Region State must submit to the Administrator periodic reports in the years 2008, 2013, and 2018. The progress reports must be in the form of implementation plan revisions that comply with the procedural requirements of §51.102 and §51.103.

(i) The report will assess the area for reasonable progress as provided in §51.309 for mandatory Class I Federal area(s) located within the State and for mandatory Class I Federal area(s) located outside the State which may be affected by emissions from within the State. This demonstration may be based on assessments conducted by the States and/or a regional planning body. The progress reports must contain at a minimum the following elements:

(A) A description of the status of implementation of all measures included in the implementation plan for achieving reasonable progress goals for mandatory Class I Federal areas both within and outside the State.

(B) A summary of the emissions reductions achieved throughout the State through implementation of the measures described in §51.309(d)(10)(i)(A).

(C) For each mandatory Class I Federal area within the State, an assessment of the following: the current visibility conditions for the most impaired and least impaired days; the difference between current visibility conditions for the most impaired and least impaired days and baseline visibility conditions; the change in visibility impairment for the most impaired and least impaired days over the past five years.

(D) An analysis tracking the change over the past 5 years in emissions of pollutants contributing to visibility impairment from all sources and activities within the State. Emissions changes should be identified by type of source or activity. The analysis must be based on the most recent updated emissions inventory, with estimates projected forward as necessary and appropriate, to account for emissions changes during the applicable 5-year period.

(E) An assessment of any significant changes in anthropogenic emissions within or outside the State that have occurred over the past 5 years that have limited or impeded progress in reducing pollutant emissions and improving visibility.

(F) An assessment of whether the current implementation plan elements and strategies are sufficient to enable the State, or

other States with mandatory Federal Class I areas affected by emissions from the State, to meet all established reasonable progress goals.

(G) A review of the State's visibility monitoring strategy and any modifications to the strategy as necessary.

(ii) At the same time the State is required to submit any 5-year progress report to EPA in accordance with section 51.309(d)(10)(i), the State must also take one of the following actions based upon the information presented in the progress report:

(A) If the State determines that the existing implementation plan requires no further substantive revision at this time in order to achieve established goals for visibility improvement and emissions reductions, the State must provide to the Administrator a negative declaration that further revision of the existing implementation plan is not needed at this time.

(B) If the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from sources in another State(s) which participated in a regional planning process, the State must provide notification to the Administrator and to the other State(s) which participated in the regional planning process with the States. The State must also collaborate with the other State(s) through the regional planning process for the purpose of developing additional strategies to address the plan's deficiencies.

(C) Where the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from sources in another country, the State shall provide notification, along with available information, to the Administrator.

(D) Where the State determines that the implementation plan is or may be inadequate to ensure reasonable progress due to emissions from within the State, the State shall develop additional strategies to address the plan deficiencies and revise the implementation plan no later than one year from the date that the progress report was due.

(11) State Planning and Interstate Coordination. In complying with the requirements of section 309, States may include emission reductions strategies that are based on coordinated implementation with other States. Examples of these strategies include economic incentive programs and transboundary

emissions trading programs. The implementation plan must include documentation of the technical and policy basis for the individual State apportionment (or the procedures for apportionment throughout the trans-boundary region), the contribution addressed by the State's plan, how it coordinates with other State plans, and compliance with any other appropriate implementation plan approvability criteria. States may rely on the relevant technical, policy and other analyses developed by a regional entity (such as the Western Regional Air Partnership) in providing such documentation. Conversely, States may elect to develop their own programs without relying on work products from a regional entity.

(12) Tribal Implementation. Consistent with 40 CFR Part 49, Tribes within the Transport Region may implement the required visibility programs for the 16 Class I areas, in the same manner as States, regardless of whether such tribes have participated as members of a visibility transport commission.

(e) States Electing Not to Implement the Commission Recommendations. Any Transport Region State may elect not to implement the Commission recommendations set forth in paragraph (d) of this section. Such States are required to comply with the timelines and requirements of section 51.308. Any Transport Region state electing not to implement the Commission recommendations must advise the other states in the Transport Region of the nature of the program and the effect of the program on visibility-impairing emissions, so that other States can take this information into account in developing programs under section 51.309.

(f) Annex to the Commission Report.

(1) A Transport Region State may choose to comply with the provisions of this section and by doing so shall satisfy the requirements of section 51.308(b)-(e) only if the Grand Canyon Visibility Transport Commission (or a regional planning body formed to implement the Commission recommendations) submits a satisfactory annex to the Commission Report no later than October 1, 2000. To be satisfactory, the Annex must contain the following elements:

(i) The annex must contain quantitative emission reduction milestones for stationary source sulfur dioxide emissions for the reporting years 2003, 2008, 2013 and 2018. The milestones must provide for steady and continuing emission reductions for the 2003-2018 time period consistent with the Commission’s definition of reasonable progress, its goal of 50 to 70 percent reduction in

sulfur dioxide emissions from 1990 actual emission levels by 2040, applicable requirements under the Clean Air Act, and the timing of implementation plan assessments of progress and identification of deficiencies which will be due in the years 2008, 2013, and 2018. The emission reduction milestones must be shown to provide for greater reasonable progress than would be achieved by application of best available retrofit technology (BART) pursuant to section 51.308(e)(2) and would be approvable in lieu of BART.

(ii) The annex must contain documentation of the market trading program or other programs to be implemented pursuant to 51.309(d)(4)if current programs and voluntary measures are not sufficient to meet the required emission reduction milestones. This documentation must include model rules, memoranda of understanding, and other documentation describing in detail how emission reduction progress will be monitored, what conditions will require the market trading program to be activated, how allocations will be performed, and how the program will operate.

(2) The Commission may elect, at the same time it submits the annex, to make recommendations intended to demonstrate reasonable progress for other mandatory Class I areas (beyond the original 16) within the Transport Region States, including the technical and policy justification for these additional mandatory Class I Federal areas in accordance with the provisions of section 51.309(g).

(3) The EPA will publish the annex upon receipt. If EPA finds that the annex meets the requirements of §51.309(f)(1) and assures reasonable progress, then EPA, after public notice and comment, will amend the requirements of §51.309(d)(4) to incorporate the provisions of the annex within one year after EPA receives the annex. If EPA finds that the annex does not meet the requirements of §51.309(f)(1), or does not assure reasonable progress, or if EPA finds that the annex is not received, then each Transport Region State must submit an implementation plan for regional haze meeting all of the requirements of section 51.308.

(4) In accordance with the provisions under §51.309(f)(1), the annex may include a geographic enhancement to the program provided for in §51.309(d)(4) to address the requirement under §51.302(c) related to Best Available Retrofit Technology for reasonably attributable impairment from the pollutants covered by the milestones or the backstop market trading program. The geographic enhancement program may include an appropriate level of reasonably attributable impairment which may require

additional emission reductions over and above those achieved under the milestones defines in §51.309(f)(1)(i).

(g) Additional Class I Areas. The following submittals must be made by Transport Region States implementing the provisions of this section as the basis for demonstrating reasonable progress for additional Class I areas in the Transport Region States. If a Transport Region State submits an implementation plan which is approved by EPA as meeting the requirements of this section, it will be deemed to comply with the requirements for reasonable progress for the period from approval of the plan to 2018.

(1) In the plan submitted for the 16 Class I areas no later than December 31, 2003, a declaration indicating whether other Class I areas will be addressed under §51.308 or 51.309(g)(2) and (3).

(2) In a plan submitted no later than December 31, 2008, provide a demonstration of expected visibility conditions for the most impaired and least impaired days at the additional mandatory Class I Federal area(s) based on emissions projections from the long-term strategies in the implementation plan. This demonstration may be based on assessments conducted by the States and/or a regional planning body.

(3) In a plan submitted no later than December 31, 2008, provide revisions to the plan submitted under section 51.309(c), including provisions to establish reasonable progress goals and implement any additional measures necessary to demonstrate reasonable progress for the additional mandatory Federal Class I areas. These revisions must comply with the provisions of section 51.308(d)(1)-(4).

(4) The following provisions apply for Transport Region States establishing reasonable progress goals and adopting any additional measures for Class I areas other than the 16 Class I areas under section 51.309(g)(2)and(3).

(i) In developing long-term strategies pursuant to section 308(d)(3), the State may build upon the strategies implemented under section 51.309(d) and take full credit for the visibility improvement achieved through these strategies.

(ii) The requirement under section 51.308(e) related to Best Available Retrofit Technology for regional haze is deemed to be satisfied for pollutants addressed by the milestones and backstop trading program if, in establishing the emission reductions milestones under section 51.309(f), it is shown that greater

reasonable progress will be achieved for these Class I areas than would be achieved through the application of source-specific BART emission limitations under section 51.308(e)(1).

(iii) The Transport Region State may consider whether any strategies necessary to achieve the reasonable progress goals required by 51.309(g)(3) are incompatible with the strategies implemented under section 51.309(d) to the extent the State adequately demonstrates that the incompatibility is related to the costs of the compliance, the time necessary for compliance, the energy and no air quality environmental impacts of compliance, or the remaining useful life of any existing source subject to such requirements.

Appendix B - A Guide to Interpreting IMPROVE Monitoring Data

A GUIDE TO INTERPRETING IMPROVE MONITORING DATA
(The following text was provided by the University of California at Davis for the IMPROVE program.)

Introduction

The National Park Service (NPS) and other Federal Land Managers are required by the Clean Air Act to protect visibility at Class I areas, which include most national parks and wilderness areas. This is being accomplished through the Interagency Monitoring of Protected Visual Environments (IMPROVE) program, which has representatives from the NPS, the Forest Service (USFS), the Bureau of Land Management, the Fish and Wildlife Service (FWS), the Environmental Protection Agency, and regional-state organizations. The IMPROVE program includes the characterization of the haze by photography, the measurement of optical extinction with transmissometers and nephelometers, and the measurement of the composition and concentration of the fine particles that produce the extinction and the tracers that identify emission sources.

Figure 1 shows the locations of all particulate monitoring sites using IMPROVE samplers through August 1995. Funding agencies include the IMPROVE committee, the NPS, the USFS, the FSW, the Tahoe Regional Planning Agency, the Department of Energy, the Northeast States for Coordinated Air Use Management, the state of Vermont, and the Regional District of Fraser Cheam (British Columbia). All sites are operated by the University of California, Davis. Table 1 gives the start and end months for each site.

Figure 1. Particulate sampling sites using IMPROVE samplers through August 1995.

Table 1: Start and end dates of IMPROVE particulate sampling.

site name	start	end
Abbotsford, British Columbia	4/94	6/95
Acadia National Park	3/88	
Arches National Park	3/88	5/92
Badlands National Park	3/88	
Bandelier National Monument	3/88	
Big Bend National Park	3/88	
Bliss State Park, CA	11/90	
Boundary Waters Canoe Area	3/91	
Bridger Wilderness	3/88	
Bridgton, ME	9/88	11/93
Brigantine National Wildlife Refuge	3/91	
Brooklyn Lake, WY	4/94	
Bryce Canyon National Park	3/88	
Canyonlands National Park	3/88	
Cape Romain NWR	8/94	
Chassahowitzka NWR	3/93	
Chilliwack, British Columbia	4/94	6/95
Chiricahua National Monument	3/88	
Columbia River Gorge NSA	6/93	
Crater Lake National Park	3/88	
Craters of the Moon NM	5/92	
Death Valley National Monument	10/93	
Denali National Park	3/88	
Dolly Sods /Otter Creek Wilderness	3/91	
Dome Lands Wilderness	8/94	
Everglades National Park	9/88	
Gila Wilderness	4/94	
Glacier National Park	3/88	
Grand Canyon National Park		
Hopi Point	3/88	
Indian Gardens	10/89	
Great Basin National Park	5/92	
Great Gulf Wilderness	6/95	
Great Sand Dunes NM	5/88	
Great Smoky Mountains NP	3/88	
Guadalupe Mountains National Park	3/88	
Haleakala National Park	2/91	
Hawaii Volcanoes National Park	3/88	4/93
Isle Royale National Park	6/88	8/91
Jarbidge Wilderness	3/88	
Jefferson/James River Face Wild.	8/94	
Joshua Tree National Monument	9/91	9/92
Lassen Volcanic National Park	3/88	
Lone Peak Wilderness	11/93	
Lye Brook Wilderness	3/91	
Mammoth Cave National Park	3/91	
Meadview National Recreation Area	9/91	9/92
Mesa Verde National Park	3/88	
Mohawk Mountain, CT	9/88	11/93
Moosehorn NWR	12/94	
Mount Rainier National Park	3/88	
Mount Zirkel Wilderness	11/93	
Okefenokee NWR	3/91	
Petrified Forest National Park	3/88	
Pinnacles National Monument	3/88	
Point Reyes National Seashore	3/88	
Proctor Maple Research Farm, VT	09/88	
Quabbin Reservoir, MA	12/88	11/93
Redwood National Park	3/88	
Ringwood State Park, NJ	9/88	11/93
Rocky Mountain National Park	3/88	
Saguaro National Monument	6/88	
Salmon National Forest	11/93	
San Gorgonio Wilderness	3/88	
Sawtooth National Forest	1/94	
Scoville, ID	5/92	
Sequoia National Park	9/92	
Shenandoah National Park	3/88	
Shining Rock Wilderness	8/94	
Sipsy Wilderness	2/92	
Snoqualamie National Forest	7/93	
South Lake Tahoe, CA	3/89	
Sula (Selway Bitteroot Wilderness)	8/94	
Sunapee Mountain, NH	12/88	11/93
Sycamore Canyon Wilderness	9/91	9/92
Three Sisters Wilderness	7/93	
Tonto National Monument	3/88	
Upper Buffalo Wilderness	6/91	
Virgin Islands National Park	10/90	
Voyageurs National Park	3/88	
Washington D.C.	3/88	
Weminuche Wilderness	3/88	
Whiteface Mountain, NY	9/88	11/93
White River National Forest	7/93	
Yellowstone National Park	3/88	
Yosemite National Park	3/88	

Sample Collection and Analysis

The standard IMPROVE sampler has four sampling modules, listed in the Table 2: A, B, and C collect fine particles (0-2.5 µm), and D collects PM_{10} particles (0-10 µm). Module A Teflon is the primary filter, providing most of the fine particle data. Module B, with a denuder before the nylon filter to remove acidic gases, is used primarily for nitrate. Module C, with tandem quartz filters, measures carbon in eight temperature fractions. At many sites, the Module A or D Teflon filter is followed by a quartz filter impregnated with K_2CO_2 that converts SO_2 gas to sulfate on the filter. Some sites have a single Module A Teflon.

Table 2: Measurements by full IMPROVE sampler.

module:	A	B	C	D	A2 or D2
size:	fine	fine	fine	PM_{10}	gas
filter:	Teflon	nylon	quartz	Teflon	impregnated
analysis:	gravimetric PIXE/PESA XRF absorption	IC	TOR combustion	gravimetric	IC
variables:	mass H, Na - Pb b_{abs}	nitrate sulfate chloride	carbon in 8 temperature fractions	PM_{10} mass	SO_2

Each module is independent, with separate inlet, sizing device, flow measurement system, critical orifice flow controller, and pump. All modules have a common controller clock. The flow rate is measured before and after the collection by a primary method using an orifice meter system and a secondary method using the pressure drop across the filter and the equation of flow rate through a critical orifice. The particle sizing depends on the flow rate; the standard deviation of annual flow rates is 2% to 3%. The average particle cut point for the fine modules has averaged 2.6 µm, with a standard deviation of 0.2 µm. All concentrations are based on local volumes. Two 24-hour samples are collected each week, on Wednesday and Saturday (recently changed to 24-hour sample every three days). The filter cassettes are changed weekly by on-site personnel and shipped to Davis for processing and analysis. All filter handling is done in clean laboratory conditions. The recovery rate for validated data since 1991 has been 96%.

Teflon A and D: The five analytical methods used at Davis to analyze the Teflon A filters are listed in Table 3. All PM_{10} (Teflon D) filters were analyzed by gravimetric analysis; 4% were analyzed by all five methods. The elemental concentrations (H, Na-Pb) are obtained by PIXE, PESA and XRF. XRF was added for samples collected after May 1992; this affected the precision, MDLs and fraction found for elements between Fe and Pb.

The coefficient of absorption (b_{abs}) was measured either by an integrating plate or an integrating sphere system. Comparisons between the two methods verify that they accurately determine the absorption for the filter. However, because of shielding by other particles, this is less than the atmospheric coefficient. Based on separate experiments, an empirical equation has been derived using the areal density of all particles on the filter that corrects for the effect. The reported b_{abs}

and the precision include this correction factor. Collocated samplers with differing collection areas verify that the expression is reasonable. The coefficient of absorption is an optical measurement with units of 10^{-8} m^{-1} in the database. To convert to inverse megameters (10^{-6} m^{-1}), divide the value by 100. (For the seasonal summaries, the units are written in inverse megameters.)

Because of volatilization of nitrate and organics during sampling, the gravimetric mass measurements on Teflon filters may be slightly less than the actual mass. Studies comparing nitrate collected on Teflon filters with that collected on nylon indicate that one-half to three-quarters of the nitrate volatilizes from the Teflon filter during sampling. At most sites and seasons, ammonium nitrate is approximately 5% of the fine mass, so this loss is only a small fraction of the mass. At some western sites near major cities, such as San Gorgonio, the ammonium sulfate may be one-half of the fine mass in summer, resulting in major underestimates of fine mass.

Table 3. Analytical methods used for A and D Teflon filters.

gravimetric (electromicrobalance)	mass
LIPM: Laser Integrating Plate Method	coefficient of absorption (b_{abs})
PIXE: Particle Induced X-ray Emission XRF: X-ray Fluorescence	Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Pb
PESA: Proton Elastic Scattering Analysis	H

Nylon B: The nylon filters were analyzed by ion chromatography (IC) at Research Triangle Institute or Global GeoChemical for nitrate ($NO3^-$), chloride (CL-), sulfate (BSO4), and nitrite (NO2-). Nitrate vapors are removed prior to collection, so that the measured nitrate concentration represents only particulate nitrate. Chloride ion (CL-) is useful for sites near marine sources, but elsewhere the ambient concentrations are below the minimum detectable limit (MDL). Sulfate on nylon (BSO4) is used as a quality assurance check of the sulfur measured by PIXE on the Teflon A filter. However, we strongly recommend using the Teflon sulfur as the measurement of ambient sulfate, because of possible adsorption of SO_2 on the nylon filter. The nitrite concentrations are generally below the MDL.

Quartz C: The quartz filters were analyzed at Desert Research Institute for carbon using the Thermal Optical Reflectance (TOR) combustion method. The sample is heated in steps and the evolved CO_2 measured. The atmosphere is 100% He until part way through the 550°C step, when 2% O_2 is introduced. The reflectance of the sample is monitored throughout. It decreases at 120°C and returns to the initial value during the 550°C step after oxygen is added. All carbon before this return of initial reflectance is considered organic carbon and the remainder elemental carbon. The eight carbon fractions in the database are defined in Table 4. OP is the portion of E1, E2, or E3 before the reflectance returns to the initial value.

Table 4. Carbon components as a function of temperature and added oxygen.

Fraction	*pyrolized fraction*	*temperature range*	*atmosphere*	*reflectance vs. initial*
O1		ambient to 120°C	100% He	at initial
O2		120 - 250°C		under initial
O3		250 - 450°C		
O4		450 - 550°C		
E1	OP	remains at 550°C	98% He 2% O_2	
				over initial
E2		550 - 700°C		
E3		700 - 800°C		

The primary interest is in two fractions, organic carbon and elemental or light-absorbing carbon (LAC). The equations are:

total organic carbon = OC1+OC2+OC3+OC4+OP
total elemental carbon = EC1+EC2+EC3-OP

Preliminary statistical comparisons between the coefficient of absorption and the carbon measured by TOR suggest that the carbon evolved at 550°C without added oxygen (OC4) may be light-absorbing. The comparison also suggests that much of the OP may not be pyrolized organic. The carbon in question (OC4+OP) could be either light-absorbing organic carbon or elemental carbon. If it is organic, then the current organic and elemental measurements are correct, but there is approximately three times as much absorbing carbon than would be estimated by elemental carbon alone. If it is elemental, then the current organic carbon concentrations are approximately 30% too large. Until we determine otherwise, we will assume that the equations above correctly determine the organic and elemental fractions.

<u>SO_2 gas</u>: The sulfate on the impregnated quartz filter following a Teflon filters were analyzed by ion chromatography at Desert Research Institute or Research Triangle Institute to give the concentration of SO_2.

Concentration and Precision of Measured Variables

The general equation for the concentration of a given variable is

$$c = \frac{A - B}{V},$$

where A is the measured mass of the variable, 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. The artifact B may be produced by contamination in the filter material, and in handling and analysis, and by adsorption of gas during collection. The artifact is negligible for all Teflon measurements, including gravimetric analysis. It is determined from designated field blanks for ions and from secondary filters for carbon.

The precision in each concentration is included in the data base. The 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 an 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 organic, the uncertainties are less than would be estimated from the individual fractions. This will be discussed in the section of 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 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:

$$[\sigma(c)]^2 = [f_v c]^2 + [f_a c]^2 + \left[\frac{\sigma_a}{V}\right]^2 + \left[\frac{\sigma_{stat}}{V}\right]^2$$

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 MDL, the precision increases to 50%.

Table 5 separates the relative precisions of key measured variables into three groups. This 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%.

The average MDLs are provided with each concentration in the database. A concentration is assumed to be statistically significant only is if 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 MDL corresponds to twice the analytical precision determined by controls. For PIXE, XRF, and PESA, the MDL is based on the background under the peaks in the spectrum and is calculated separately for each case. The assumption for all elements except As is that there are no interference from other elements. Because the measurement for arsenic requires subtracting the value for lead, the MDL for As depends on the Pb concentration, and is generally larger than the value estimated from the background. When calculating averages, if the value is below the MDL, we use one-half of the MDL as the concentration and the precision in the concentration. In all cases, the relative precisions are around 50% at the MDL.

Table 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 6%	$PM_{2.5}$, 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 MDLs of many elements changed in June 1992, with the addition of XRF. Figure 2 shows the MDLs for each season for sulfur and selenium. The MDL for Fe decreased by a a factor of nearly 10, The MDLs for elements below Fe increased slightly, because of a reduction in cyclotron time to compensate for the extra cost of XRF analysis.

The MDLs of standard network samples for elements measured by PIXE and XRF are given in Table 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 7 separates these into four ranges. A significant change for aluminum occurred with samples beginning 2/93. Because of detector problems, Al, which is on the shoulder of the Si peak, was often not detected. Before this date, Al was observed on 65% of all samples; afterwards it was found on almost every sample. Sodium, chlorine, and chloride ion were observe in significant amounts only at sites with marine influences.

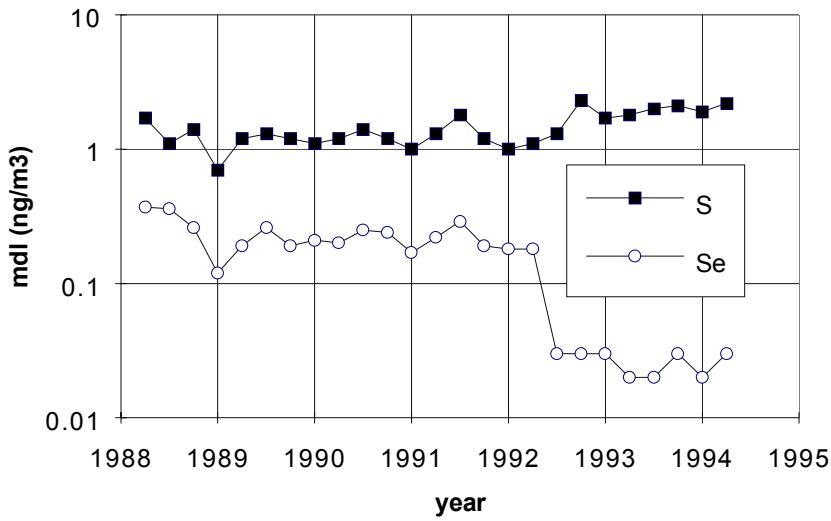

Figure 2: Minimum detectable limits (MDLs) of sulfur and selenium by season.

Table 6: Minimum detectable limits (MDLs) of elements in ng/m^3.

dates	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
6/88-5/92	8.7	2.9	1.8	1.4	1.3	1.2	1.3	0.83	0.64	0.57	0.50	0.41	0.39
6/92-5/94	13.	4.8	3.0	2.2	1.9	1.9	2.0	1.2	0.90	0.81	0.69	0.57	0.52
	Fe	Ni	Cu	Zn	Ga	Se	Br	Rb	Sr	Zr	Pb		
6/88-5/92	0.34	0.24	0.24	0.21	0.20	0.22	0.25	0.37	0.42	0.65	0.57		
6/92-5/94	0.11	0.05	0.05	0.05	0.03	0.03	0.03	0.06	0.07	0.11	0.06		

Table 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}, S, H, Si, K, Ca, Ti, Fe, Zn, Br, $SO_4^=$, NO_3^-, SO_2, OP, E1	$PM_{2.5}$, PM_{10}, S, H, 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
less than 40%	P, V, Ni, Se, As, Rb, Sr, Zr, O1, E3	P, V, Ni, Zr, O1, E3

Level I validation procedures for sample collection include comparison of the two measurements of flow rate. Level I validation procedures for sample analysis include comparison to recognized standards and periodic replicate measurements. Level II validation procedures include comparison of selected variables measured by different methods. This includes comparison of the PIXE and XRF measurements, comparison of sulfur by PIXE on Teflon with sulfate by ion chromatography on nylon, comparison of OMC and OMH, comparison of LAC and BABS, and comparison of MF with RCMA and RCMC.

Collocated sampling is an important part of the quality assurance program. These are conducted routinely at Davis and periodically at field locations. All collocated sampling has indicated that the precision estimates in the database are accurate representations of the actual differences.

Composite Variables

The database contains only measured variables. The composite variables listed in Table 8 can be derived from the measured variables based on reasonable assumptions.

Table 8: Composite Variables

NHSO	ammonium sulfate, $(NH_4)_2SO_2$: 4.125 * S
NHNO	ammonium nitrate, $(NH_4)NO_3$: 1.29 * $NO3^-$
OC	total organic carbon (quartz): OC1+OC2+OC3+OC4+OP
OMC	organic mass by carbon (quartz): 1.4 * OC
OMH	organic mass by hydrogen (Teflon): assumes all sulfur is ammonium sulfate and no there is hydrogen from nitrate 13.75 * (H - 0.25 * S)
LAC	light absorbing carbon (quartz): EC1+EC2+EC3-OP
TC	total carbon (quartz): OC1+OC2+OC3+OC4+EC1+EC2+EC3
SOOT	light absorbing carbon from optical measurement: If BABS in 10^{-8} m^{-1}, and SOOT and SOIL in ng/m^3, SOOT = BABS - 0.11 * SOIL
SOIL	soil: 2.20*Al + 2.49*Si + 1.63*Ca + 2.42*Fe + 1.94*Ti
KNON	nonsoil potassium: K - 0.6 * Fe
RCMC	reconstructed mass without nitrate, carbon from quartz filter C: NHSO + SOIL + 1.4*KNON + 2.5*Na + LAC + OMC
RCMA	reconstructed mass without nitrate, carbon from Teflon filter A: NHSO + SOIL + 1.4*KNON + 2.5*Na + BABS/2 + OMH

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

$$[\sigma(SOIL)]^2 = [2.20\ \sigma(Al)]^2 + [2.49\ \sigma(Si)]^2 + [1.63\ \sigma(Ca)]^2 + [2.42\ \sigma(Fe)]^2 + [1.94\ \sigma(Ti)]^2$$

Because of the fact that temperature separation plays a much larger role for carbon fractions than for the composites, and because the factions are not independent, we cannot follow the above method for OC, OMC, LAC, and TC. For these we recommend the following equations for 24-hour samples:

$$\sigma(OC) = \sqrt{(120)^2 + (0.05 * OC)^2} \qquad \sigma(OMC) = \sqrt{(168)^2 + (0.05 * OMC)^2}$$

$$\sigma(LAC) = \sqrt{(34)^2 + (0.07 * LAC)^2} \qquad \sigma(TC) = \sqrt{(133)^2 + (0.05 * TC)^2}$$

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 2.

<u>ammonium sulfate (NHSO)</u>: 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, we recommend multiplying the total carbon by 1.4, which assumes that carbon accounts for 71% of the organic mass. 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. We also assume that no significant hydrogen from nitrate remains. If we assume that the sulfate is fully neutralized ammonium sulfate, we can estimate the organic concentration by subtracting the hydrogen from sulfate and multiplying the difference by a constant representing the fraction of hydrogen. (We suggest a constant of 13.75. 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, as at sites near Los Angeles and San Francisco, 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 western sites except San Gorgonio, Sequoia, Pinnacles, Point Reyes, Redwoods, and Hawaii Volcanoes, the correlation coefficient (r^2) between OMH and OMC for the first two years was 0.89 and the slope was 0.98 ± 0.02. For 1992, r^2 was 0.87 and the slope was 1.07±0.01. The main advantage of using OMH at these sites is that its precision is better than that for OMC during periods of low organic, 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 organic. For 10 eastern sites in 1992, the average OMH was one-half the average OMC, and one-half of the OMH values were less than the minimum quantifiable limit.

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 MF (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.

light-absorbing carbon (LAC): This is the sum of elemental carbon fractions. The pyrolized fraction is subtracted. Preliminary analyses indicate that some of the O4 fraction may absorb light, and that OP may overestimate the pyrolytic mass.

light-absorbing carbon (SOOT): This is estimated from the coefficient of absorption assuming absorption efficiencies of 10 m^2/g for elemental carbon and 0.11 m^2/g for soil.

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. We have eliminated this from the calculation and used Fe 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 on 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 ratio of K/Fe of 0.6 measured on coarse samples (2.5 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 (say 0.5), 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 and RCMA): We use two estimates of reconstructed mass, which differ only in the estimation of organic mass and light-absorbing carbon. RCMC uses the quartz C measurements, while the RCMA uses the Teflon A measurements. The RCMC estimate should be used at sites where the OMH calculation is invalid, while the RCMA estimate should be used when the organic and LAC concentrations are small. It can also be used when there is no quartz measurement, as with a single Module A sampler.

Neither reconstructed mass estimate includes nitrates. The Teflon filter does not collect any nitrate in the vapor state, and loses one-half to three-quarters of the particulate nitrate by volatilization during sampling. At most sites this is a few percent 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.

Major Components of Fine Mass

ammonium sulfate: Sulfate is generally the major component of the fine mass throughout the United States, accounting for 20-40% of the mass in the West to 45-60% in the East. (It is less than organic at most sites in the Northwest and less than nitrate at San Gorgonio.) Sulfur primarily enters the atmosphere as SO_2 gas. The SO_2 converts in the atmosphere to sulfuric acid, which reacts with ammonia gas to form ammonium sulfate. There are periods at some sites when there is too much sulfuric acid to be neutralized by ammonia; some of it may remain as sulfuric acid. The rate of transformation and the size of the resulting particle depends on the relative humidity. This has a significant impact on visibility, because in high humidity the sulfate particles are larger and scatter light much more efficiently relative to the mass of sulfur. That is, the scattering per unit mass of sulfur is greater at high humidity than at low humidity. This growth can occur anytime during the lifetime of the particle. If the relative humidity later decreases the particle will shrink, but not immediately. Therefore the particle size and scattering efficiency depends on the relative humidity of the past as well as the present. The scattering efficiency for a small sulfate particle is less than that for a large one, but still significant. Because sulfate is such an efficient scatterer of light, its contribution to the extinction budget is even larger than its contribution to the mass budget.

ammonium nitrate: Nitrate is generally a minor component of the particulate mass and the extinction budget. At half of the sites, ammonium nitrate is less than 6% of the mass, compared to 32% for ammonium sulfate. The main exceptions are on the West Coast, where the average nitrate concentration can be more than the average sulfate concentration. In the east, it is 15% of ammonium sulfate.

soil: Most of this component is produced by soil dust. At some sites in the West, soil can be one of the largest components of the mass. Its effect on visibility is less per unit mass than sulfate, because the particles are generally larger than the optimum size. Soil emission is significantly enhanced by disturbances to the soil: off-road and dirt-road vehicular traffic, agricultural activities, bison stampedes. A smaller source of these elements can come from industrial and mining activities.

organic: Organic material is the largest component at most sites in the northwest, and elsewhere the second largest component. Possible sources are fires (wildfires, controlled burns, slash and field burning, incineration, household heating), industrial emissions, and biogenic emissions.

elemental carbon or light-absorbing carbon: This component accounts for 5% to 10% of the fine mass, depending on whether LAC or BABS is used.

reconstructed mass: The reconstructed mass by either definition generally correlates well with the gravimetric mass, accounting for almost all of the fine mass. About 20% of the unaccounted mass may be nitrate, with the remainder primarily residual water on the particles.

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Appendix C – IMPROVE Program Visibility Trend Tables

Table C-1. Annual trends of particle ambient mass for the 20% least impaired, 40-60% mid-range, and 20% most impaired days at Northeast IMPROVE monitor sites.

Acadia National Park, ME

SITE=ACAD GROUP=10

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
88	7.57	5.23	2.34	1.02	0.44	0.16	0.07	0.76	0.33	0.23	0.10	0.16	0.07
89	7.79	5.26	2.53	1.32	0.52	0.18	0.07	0.70	0.28	0.22	0.09	0.11	0.04
90	8.26	5.59	2.67	1.39	0.52	0.16	0.06	0.83	0.31	0.18	0.07	0.10	0.04
91	5.25	2.72	2.53	1.20	0.48	0.18	0.07	0.84	0.33	0.20	0.08	0.10	0.04
92	5.06	3.05	2.01	0.98	0.49	0.13	0.06	0.66	0.33	0.16	0.08	0.08	0.04
93	5.79	3.35	2.44	1.13	0.46	0.15	0.06	0.85	0.35	0.17	0.07	0.14	0.06
94	5.46	3.41	2.04	0.90	0.44	0.15	0.07	0.71	0.35	0.17	0.08	0.12	0.06
95	6.01	4.02	2.00	1.06	0.53	0.14	0.07	0.57	0.28	0.13	0.07	0.10	0.05
96	5.16	3.29	1.87	0.88	0.47	0.10	0.05	0.67	0.36	0.12	0.06	0.10	0.05
97	7.96	5.74	2.23	1.05	0.47	0.12	0.05	0.78	0.35	0.12	0.05	0.15	0.07
98	5.61	3.24	2.36	1.01	0.43	0.12	0.05	0.88	0.37	0.12	0.05	0.22	0.09

SITE=ACAD GROUP=50

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
88	7.14	2.26	4.88	2.41	0.49	0.46	0.09	1.36	0.28	0.40	0.08	0.25	0.05
89	8.41	2.55	5.86	3.24	0.55	0.65	0.11	1.31	0.22	0.45	0.08	0.21	0.04
90	8.82	4.06	4.76	2.89	0.61	0.26	0.06	1.11	0.23	0.31	0.06	0.19	0.04
91	10.87	5.90	4.97	2.72	0.55	0.34	0.07	1.42	0.29	0.30	0.06	0.18	0.04
92	7.68	3.05	4.63	2.39	0.52	0.32	0.07	1.37	0.30	0.39	0.08	0.16	0.04
93	8.46	3.74	4.71	2.48	0.53	0.38	0.08	1.40	0.30	0.26	0.06	0.19	0.04
94	9.68	4.92	4.77	2.40	0.50	0.44	0.09	1.46	0.31	0.27	0.06	0.20	0.04
95	9.05	4.95	4.10	2.09	0.51	0.41	0.10	1.19	0.29	0.21	0.05	0.20	0.05
96	9.13	4.89	4.25	2.41	0.57	0.30	0.07	1.15	0.27	0.21	0.05	0.18	0.04
97	7.99	3.96	4.03	2.34	0.58	0.24	0.06	1.08	0.27	0.19	0.05	0.17	0.04
98	7.73	3.70	4.03	2.01	0.50	0.24	0.06	1.34	0.33	0.21	0.05	0.23	0.06

SITE=ACAD GROUP=90

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
88	21.59	8.02	13.58	7.25	0.53	0.91	0.07	4.01	0.30	0.80	0.06	0.61	0.05
89	17.65	3.39	14.26	8.31	0.58	0.82	0.06	4.09	0.29	0.68	0.05	0.36	0.03
90	18.60	7.49	11.11	6.53	0.59	0.69	0.06	2.90	0.26	0.68	0.06	0.32	0.03
91	17.61	5.68	11.92	6.40	0.54	0.76	0.06	3.80	0.32	0.60	0.05	0.36	0.03
92	15.70	2.72	12.98	8.36	0.64	0.72	0.06	3.03	0.23	0.58	0.04	0.29	0.02
93	19.06	5.45	13.61	7.98	0.59	0.93	0.07	3.57	0.26	0.58	0.04	0.56	0.04
94	21.73	8.20	13.53	8.20	0.61	0.73	0.05	3.55	0.26	0.57	0.04	0.48	0.04
95	18.14	7.09	11.05	6.00	0.54	0.68	0.06	3.61	0.33	0.42	0.04	0.35	0.03
96	17.24	6.25	10.99	7.09	0.64	0.52	0.05	2.69	0.24	0.44	0.04	0.26	0.02
97	17.19	6.85	10.34	5.89	0.57	0.46	0.04	3.28	0.32	0.42	0.04	0.29	0.03
98	16.02	5.44	10.58	6.81	0.64	0.39	0.04	2.49	0.24	0.44	0.04	0.46	0.04

Brigantine Wilderness Area, NJ

SITE=BRIG GROUP=10

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	9.99	5.63	4.36	2.25	0.52	0.50	0.11	1.17	0.27	0.26	0.06	0.18	0.04
93	12.73	7.13	5.60	2.90	0.52	0.64	0.11	1.45	0.26	0.34	0.06	0.26	0.05
94	14.33	9.48	4.85	2.08	0.43	0.65	0.13	1.36	0.28	0.38	0.08	0.38	0.08
95	20.95	16.65	4.29	2.25	0.52	0.57	0.13	0.98	0.23	0.26	0.06	0.23	0.05
96	16.36	11.40	4.96	2.44	0.49	0.55	0.11	1.32	0.27	0.34	0.07	0.31	0.06
97	16.67	12.67	4.00	2.03	0.51	0.42	0.11	1.05	0.26	0.27	0.07	0.22	0.06
98	13.18	8.76	4.41	2.15	0.49	0.35	0.08	1.27	0.29	0.32	0.07	0.33	0.07

SITE=BRIG GROUP=50

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	14.55	5.59	8.96	5.07	0.57	1.00	0.11	2.13	0.24	0.54	0.06	0.23	0.03
93	18.16	7.96	10.20	5.59	0.55	1.25	0.12	2.43	0.24	0.55	0.05	0.38	0.04
94	21.03	10.61	10.42	4.99	0.48	1.76	0.17	2.45	0.24	0.64	0.06	0.58	0.06
95	19.85	11.32	8.52	4.24	0.50	1.55	0.18	1.79	0.21	0.50	0.06	0.45	0.05
96	22.19	13.12	9.07	5.30	0.58	0.91	0.10	2.08	0.23	0.45	0.05	0.32	0.04
97	20.97	12.73	8.23	4.81	0.58	0.71	0.09	1.90	0.23	0.45	0.05	0.36	0.04
98	21.65	13.79	7.86	4.06	0.52	0.70	0.09	2.18	0.28	0.51	0.06	0.41	0.05

SITE=BRIG GROUP=90

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	27.32	7.85	19.47	12.68	0.65	1.39	0.07	3.99	0.21	0.84	0.04	0.56	0.03
93	27.57	9.08	18.49	10.01	0.54	2.24	0.12	4.76	0.26	0.88	0.05	0.59	0.03
94	32.85	14.01	18.84	10.38	0.55	1.81	0.10	4.52	0.24	0.87	0.05	1.25	0.07
95	32.10	13.61	18.49	11.84	0.64	1.57	0.08	3.80	0.21	0.67	0.04	0.62	0.03
96	30.07	12.89	17.19	11.25	0.65	1.08	0.06	3.48	0.20	0.80	0.05	0.57	0.03
97	36.68	17.91	18.78	12.48	0.66	0.84	0.04	4.20	0.22	0.60	0.03	0.65	0.03
98	32.99	11.88	21.11	13.65	0.65	0.40	0.02	5.42	0.26	0.94	0.04	0.71	0.03

Lye Brook Wilderness Area, VT

SITE=LYBR GROUP=10

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	3.32	1.84	1.48	0.74	0.50	0.11	0.07	0.50	0.34	0.08	0.05	0.05	0.04
93	4.65	2.90	1.75	0.82	0.47	0.18	0.10	0.58	0.33	0.07	0.04	0.09	0.05
94	5.23	3.48	1.75	0.68	0.39	0.17	0.10	0.66	0.37	0.12	0.07	0.12	0.07
95	3.01	1.16	1.85	0.93	0.50	0.30	0.16	0.40	0.22	0.12	0.06	0.10	0.05
96	3.60	1.60	2.01	1.19	0.59	0.15	0.07	0.43	0.21	0.11	0.06	0.14	0.07
97	3.55	1.50	2.04	0.92	0.45	0.25	0.12	0.69	0.34	0.09	0.04	0.10	0.05
98	4.34	2.19	2.15	0.86	0.40	0.18	0.09	0.79	0.37	0.12	0.06	0.19	0.09

SITE=LYBR GROUP=50

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	6.36	1.91	4.45	2.33	0.52	0.56	0.13	1.15	0.26	0.23	0.05	0.17	0.04
93	7.12	3.34	3.78	1.84	0.49	0.39	0.10	1.16	0.31	0.19	0.05	0.19	0.05
94	9.88	5.24	4.64	2.16	0.47	0.59	0.13	1.32	0.28	0.26	0.06	0.32	0.07
95	6.69	2.41	4.27	2.27	0.53	0.51	0.12	1.05	0.25	0.24	0.06	0.20	0.05
96	6.80	2.01	4.79	2.83	0.59	0.38	0.08	1.15	0.24	0.22	0.05	0.22	0.05
97	7.01	2.84	4.17	2.27	0.55	0.34	0.08	1.19	0.29	0.19	0.05	0.18	0.04
98	7.74	2.26	5.47	2.46	0.45	0.66	0.12	1.61	0.29	0.26	0.05	0.49	0.09

SITE=LYBR GROUP=90

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
92	15.92	3.23	12.69	8.32	0.66	0.88	0.07	2.65	0.21	0.47	0.04	0.37	0.03
93	17.90	4.29	13.61	8.45	0.62	0.95	0.07	3.11	0.23	0.58	0.04	0.52	0.04
94	20.39	5.98	14.41	8.93	0.62	0.99	0.07	3.02	0.21	0.55	0.04	0.91	0.06
95	16.88	3.33	13.56	8.73	0.64	0.56	0.04	3.27	0.24	0.54	0.04	0.45	0.03
96	15.07	3.23	11.84	7.04	0.59	0.82	0.07	3.03	0.26	0.49	0.04	0.47	0.04
97	15.30	2.53	12.76	8.80	0.69	0.48	0.04	2.44	0.19	0.41	0.03	0.62	0.05
98	18.67	3.31	15.36	10.28	0.67	0.60	0.04	3.24	0.21	0.59	0.04	0.65	0.04

Moosehorn Wilderness Area, ME

SITE=MOOS GROUP=10

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
95	4.59	2.21	2.38	1.03	0.43	0.20	0.09	0.87	0.36	0.15	0.06	0.12	0.05
96	5.12	3.04	2.08	0.93	0.45	0.11	0.06	0.79	0.38	0.14	0.07	0.11	0.05
97	4.87	2.99	1.88	0.77	0.41	0.12	0.06	0.78	0.42	0.12	0.06	0.09	0.05
98	5.53	3.10	2.43	0.96	0.40	0.11	0.04	0.95	0.39	0.17	0.07	0.25	0.10

SITE=MOOS GROUP=50

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
95	7.39	2.87	4.52	2.20	0.49	0.38	0.08	1.48	0.33	0.25	0.05	0.21	0.05
96	9.22	4.87	4.36	2.04	0.47	0.24	0.06	1.63	0.37	0.27	0.06	0.18	0.04
97	9.33	5.04	4.29	2.08	0.48	0.26	0.06	1.53	0.36	0.23	0.05	0.19	0.05
98	8.81	4.56	4.25	1.87	0.44	0.30	0.07	1.54	0.36	0.26	0.06	0.29	0.07

SITE=MOOS GROUP=90

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
95	14.05	3.81	10.24	5.36	0.52	0.67	0.07	3.48	0.34	0.39	0.04	0.34	0.03
96	13.58	4.01	9.57	5.14	0.54	0.53	0.06	3.16	0.33	0.46	0.05	0.28	0.03
97	14.39	4.42	9.97	5.34	0.54	0.33	0.03	3.64	0.37	0.37	0.04	0.28	0.03
98	12.13	2.52	9.62	5.77	0.60	0.41	0.04	2.71	0.28	0.39	0.04	0.34	0.04

Washington, DC

SITE=WASH GROUP=10

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
89	16.80	7.82	8.98	3.69	0.41	1.20	0.13	2.45	0.27	1.15	0.13	0.49	0.05
90	30.72	22.31	8.40	3.55	0.42	1.15	0.14	2.21	0.26	1.07	0.13	0.42	0.05
91	13.88	5.17	8.71	3.89	0.45	1.33	0.15	2.19	0.25	0.87	0.10	0.43	0.05
92	13.91	4.96	8.95	4.30	0.48	0.95	0.11	2.31	0.26	0.89	0.10	0.49	0.06
93	15.88	5.26	10.62	4.95	0.47	1.34	0.13	2.78	0.26	0.92	0.09	0.62	0.06
94	16.55	7.63	8.92	3.49	0.39	1.45	0.16	2.35	0.26	0.97	0.11	0.65	0.07
95	11.11	4.56	6.55	3.23	0.49	0.78	0.12	1.50	0.23	0.62	0.10	0.42	0.06
96	13.87	6.27	7.60	3.61	0.48	0.98	0.13	1.83	0.24	0.71	0.09	0.47	0.06
97	11.64	4.64	7.00	3.64	0.52	0.56	0.08	1.66	0.24	0.63	0.09	0.51	0.07
98	11.37	4.18	7.19	2.93	0.41	0.73	0.10	2.08	0.29	0.77	0.11	0.68	0.09

SITE=WASH GROUP=50

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
89	25.93	10.16	15.77	6.63	0.42	2.45	0.16	4.10	0.26	1.69	0.11	0.91	0.06
90	41.66	27.09	14.57	5.94	0.41	2.44	0.17	3.83	0.26	1.72	0.12	0.63	0.04
91	24.00	6.06	17.93	8.98	0.50	2.42	0.13	4.27	0.24	1.54	0.09	0.73	0.04
92	24.00	6.81	17.19	8.20	0.48	2.65	0.15	4.06	0.24	1.51	0.09	0.77	0.04
93	26.79	8.30	18.49	8.62	0.47	2.81	0.15	4.80	0.26	1.52	0.08	0.75	0.04
94	24.13	7.69	16.44	6.99	0.43	2.25	0.14	4.49	0.27	1.71	0.10	0.99	0.06
95	19.04	6.23	12.81	6.05	0.47	2.01	0.16	3.02	0.24	1.07	0.08	0.66	0.05
96	20.03	6.44	13.58	5.99	0.44	1.91	0.14	3.69	0.27	1.08	0.08	0.91	0.07
97	16.77	3.90	12.87	5.88	0.46	2.00	0.16	3.37	0.26	1.00	0.08	0.62	0.05
98	16.38	4.20	12.18	5.71	0.47	1.47	0.12	3.19	0.26	1.05	0.09	0.76	0.06

SITE=WASH GROUP=90

SYEAR	TMASS	CM	FMASS	SO4	F_SO4	NO3	F_NO3	OC	F_OMC	LAC	F_LAC	SOIL1	F_SOIL
89	37.35	13.50	23.85	11.62	0.49	3.20	0.13	5.47	0.23	2.17	0.09	1.38	0.06
90	58.77	35.92	22.85	9.24	0.40	3.00	0.13	6.89	0.30	2.72	0.12	1.01	0.04
91	40.24	9.08	31.16	18.58	0.60	2.87	0.09	6.78	0.22	1.91	0.06	1.01	0.03
92	41.17	9.30	31.87	18.47	0.58	3.74	0.12	6.20	0.19	2.04	0.06	1.42	0.04
93	43.08	10.39	32.69	15.34	0.47	4.12	0.13	8.93	0.27	2.33	0.07	1.97	0.06
94	37.44	9.26	28.18	14.43	0.51	2.56	0.09	7.62	0.27	2.34	0.08	1.23	0.04
95	31.61	7.29	24.32	12.72	0.52	2.79	0.11	6.20	0.26	1.69	0.07	0.92	0.04
96	30.88	5.97	24.90	15.17	0.61	1.51	0.06	5.59	0.22	1.74	0.07	0.90	0.04
97	30.08	5.72	24.36	13.61	0.56	2.49	0.10	5.90	0.24	1.36	0.06	1.00	0.04
98	27.80	2.94	24.87	14.94	0.60	0.41	0.02	6.67	0.27	1.74	0.07	1.11	0.04

Key:
GROUP 10 = 20% least impaired visibility days
GROUP 50 = 40 – 60% mid-range visibility days
GROUP 90 = 20% most impaired visibility days
SYEAR = Sample year (March – February)
TMASS = Total mass ($\mu g/m^3$)
CM = Coarse mass ($PM_{10} – PM_{2.5}$) ($\mu g/m^3$)
FMASS = Reconstructed fine particle mass ($\mu g/m^3$)
SO4 = Ammonium sulfate ($\mu g/m^3$)
NO3 = Ammonium nitrate ($\mu g/m^3$)
OC = Organic carbon ($\mu g/m^3$)
LAC = Light absorbing carbon ($\mu g/m^3$)
SOIL1 = Fine soil ($\mu g/m^3$)
F_*** = Mass fraction of speciated particle relative to reconstructed fine particle
Data from IMPROVE, http://alta_vista.cira.colostate.edu/
NOTE: Great Gulf Wilderness Area data tables not available from IMPROVE web site.

Table C-2. Annual trends of particle light extinction for the 20% least impaired, 40-60% mid-range, and 20% most impaired days at Northeast IMPROVE monitor sites.

Acadia National Park, ME

SITE=ACAD GROUP=10

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
88	126	11	21.04	10.66	0.51	1.70	0.08	3.06	0.15	2.33	0.11	3.30	0.16
89	115	12	23.91	13.75	0.58	1.93	0.08	2.80	0.12	2.17	0.09	3.27	0.14
90	112	13	24.77	14.48	0.58	1.67	0.07	3.32	0.13	1.84	0.07	3.46	0.14
91	124	12	21.55	12.53	0.58	1.87	0.09	3.37	0.16	2.04	0.09	1.73	0.08
92	141	10	17.75	10.26	0.58	1.32	0.07	2.64	0.15	1.63	0.09	1.91	0.11
93	128	11	20.59	11.73	0.57	1.59	0.08	3.40	0.17	1.71	0.08	2.15	0.10
94	141	10	17.65	9.42	0.53	1.51	0.09	2.82	0.16	1.73	0.10	2.17	0.12
95	137	11	18.56	11.00	0.59	1.46	0.08	2.28	0.12	1.31	0.07	2.51	0.14
96	149	10	16.16	9.17	0.57	1.05	0.07	2.66	0.16	1.21	0.07	2.08	0.13
97	130	11	20.12	10.98	0.55	1.23	0.06	3.12	0.16	1.19	0.06	3.60	0.18
98	136	11	18.80	10.58	0.56	1.28	0.07	3.54	0.19	1.24	0.07	2.16	0.12

SITE=ACAD GROUP=50

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
88	77	16	40.97	25.14	0.61	4.78	0.12	5.44	0.13	4.00	0.10	1.61	0.04
89	63	18	52.02	33.80	0.65	6.76	0.13	5.22	0.10	4.50	0.09	1.74	0.03
90	74	17	43.00	30.14	0.70	2.74	0.06	4.43	0.10	3.06	0.07	2.63	0.06
91	72	17	44.33	28.38	0.64	3.55	0.08	5.70	0.13	2.98	0.07	3.72	0.08
92	79	16	39.60	24.96	0.63	3.30	0.08	5.49	0.14	3.86	0.10	1.99	0.05
93	77	16	40.49	25.82	0.64	4.00	0.10	5.62	0.14	2.63	0.06	2.43	0.06
94	76	16	41.33	25.04	0.61	4.61	0.11	5.83	0.14	2.70	0.07	3.14	0.08
95	85	15	36.10	21.83	0.60	4.25	0.12	4.74	0.13	2.11	0.06	3.17	0.09
96	81	16	38.01	25.07	0.66	3.14	0.08	4.59	0.12	2.09	0.06	3.12	0.08
97	85	15	35.74	24.43	0.68	2.51	0.07	4.31	0.12	1.94	0.05	2.55	0.07
98	90	15	33.32	20.93	0.63	2.49	0.07	5.36	0.16	2.08	0.06	2.46	0.07

SITE=ACAD GROUP=90

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
88	31	25	114.4	75.58	0.66	9.44	0.08	16.04	0.14	7.96	0.07	5.42	0.05
89	30	26	120.8	86.61	0.72	8.55	0.07	16.37	0.14	6.84	0.06	2.39	0.02
90	36	24	98.40	68.04	0.69	7.18	0.07	11.60	0.12	6.76	0.07	4.81	0.05
91	36	24	99.59	66.67	0.67	7.91	0.08	15.22	0.15	6.02	0.06	3.77	0.04
92	31	25	114.5	87.12	0.76	7.52	0.07	12.12	0.11	5.78	0.05	1.92	0.02
93	31	25	116.7	83.13	0.71	9.65	0.08	14.29	0.12	5.81	0.05	3.82	0.03
94	30	26	118.4	85.50	0.72	7.58	0.06	14.22	0.12	5.67	0.05	5.40	0.05
95	38	23	92.78	62.54	0.67	7.05	0.08	14.43	0.16	4.16	0.04	4.61	0.05
96	36	24	98.36	73.85	0.75	5.40	0.05	10.74	0.11	4.35	0.04	4.01	0.04
97	40	23	87.88	61.35	0.70	4.84	0.06	13.13	0.15	4.15	0.05	4.40	0.05
98	38	23	93.03	70.95	0.76	4.04	0.04	9.96	0.11	4.36	0.05	3.72	0.04

Brigantine Wilderness Area, NJ

SITE=BRIG GROUP=10

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	78	16	40.22	24.02	0.60	5.32	0.13	4.68	0.12	2.64	0.07	3.56	0.09
93	63	18	51.62	31.00	0.60	6.82	0.13	5.80	0.11	3.45	0.07	4.54	0.09
94	72	17	44.53	22.23	0.50	6.97	0.16	5.45	0.12	3.81	0.09	6.07	0.14
95	69	17	46.92	24.09	0.51	6.05	0.13	3.92	0.08	2.64	0.06	10.22	0.22
96	68	18	47.75	26.06	0.55	5.89	0.12	5.27	0.11	3.37	0.07	7.15	0.15
97	77	16	40.95	21.73	0.53	4.52	0.11	4.22	0.10	2.65	0.06	7.83	0.19
98	77	16	40.54	22.97	0.57	3.75	0.09	5.08	0.13	3.15	0.08	5.59	0.14

SITE=BRIG GROUP=50

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	42	22	82.27	54.15	0.66	10.66	0.13	8.50	0.10	5.37	0.07	3.59	0.04
93	38	23	93.47	59.74	0.64	13.35	0.14	9.74	0.10	5.49	0.06	5.16	0.06
94	37	24	95.32	53.30	0.56	18.83	0.20	9.81	0.10	6.43	0.07	6.95	0.07
95	43	22	81.25	45.31	0.56	16.57	0.20	7.15	0.09	4.99	0.06	7.24	0.09
96	40	23	87.44	56.63	0.65	9.77	0.11	8.32	0.10	4.53	0.05	8.20	0.09
97	44	22	79.10	51.42	0.65	7.54	0.10	7.61	0.10	4.52	0.06	8.00	0.10
98	47	21	73.37	43.35	0.59	7.51	0.10	8.73	0.12	5.10	0.07	8.68	0.12

SITE=BRIG GROUP=90

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	21	29	180.1	135.5	0.75	14.89	0.08	15.97	0.09	8.43	0.05	5.27	0.03
93	22	29	164.9	107.0	0.65	23.92	0.15	19.04	0.12	8.85	0.05	6.04	0.04
94	22	29	166.8	111.0	0.67	19.32	0.12	18.08	0.11	8.74	0.05	9.66	0.06
95	21	29	173.9	126.5	0.73	16.73	0.10	15.19	0.09	6.66	0.04	8.78	0.05
96	23	28	162.0	120.2	0.74	11.59	0.07	13.93	0.09	7.95	0.05	8.31	0.05
97	21	29	176.6	133.3	0.76	9.03	0.05	16.82	0.10	5.99	0.03	11.40	0.06
98	20	30	189.0	145.9	0.77	4.23	0.02	21.67	0.11	9.37	0.05	7.84	0.04

Lye Brook Wilderness Area, VT

SITE=LYBR GROUP=10

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	171	8	12.81	7.71	0.60	1.16	0.09	2.00	0.16	0.78	0.06	1.16	0.09
93	154	9	15.35	8.55	0.56	1.90	0.12	2.33	0.15	0.73	0.05	1.83	0.12
94	157	9	14.90	7.11	0.48	1.74	0.12	2.62	0.18	1.21	0.08	2.21	0.15
95	148	10	16.44	9.66	0.59	3.18	0.19	1.61	0.10	1.20	0.07	0.79	0.05
96	140	10	17.83	12.39	0.69	1.53	0.09	1.71	0.10	1.11	0.06	1.09	0.06
97	146	10	16.83	9.57	0.57	2.59	0.15	2.75	0.16	0.91	0.05	1.00	0.06
98	146	10	16.74	8.96	0.54	1.91	0.11	3.17	0.19	1.19	0.07	1.51	0.09

SITE=LYBR GROUP=50

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	81	16	38.42	24.35	0.63	5.89	0.15	4.59	0.12	2.27	0.06	1.32	0.03
93	93	14	32.06	19.19	0.60	4.08	0.13	4.66	0.15	1.93	0.06	2.20	0.07
94	78	16	39.98	22.58	0.56	6.12	0.15	5.27	0.13	2.55	0.06	3.46	0.09
95	83	16	37.28	23.70	0.64	5.32	0.14	4.22	0.11	2.38	0.06	1.65	0.04
96	76	16	41.69	29.50	0.71	3.96	0.09	4.60	0.11	2.21	0.05	1.42	0.03
97	85	15	35.77	23.72	0.66	3.52	0.10	4.77	0.13	1.88	0.05	1.88	0.05
98	73	17	43.41	25.67	0.59	6.87	0.16	6.42	0.15	2.60	0.06	1.85	0.04

SITE=LYBR GROUP=90

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
92	32	25	113.6	86.79	0.76	9.23	0.08	10.61	0.09	4.71	0.04	2.31	0.02
93	30	26	119.5	88.21	0.74	9.93	0.08	12.44	0.10	5.84	0.05	3.09	0.03
94	29	26	125.6	93.23	0.74	10.34	0.08	12.08	0.10	5.48	0.04	4.50	0.04
95	31	26	117.9	91.14	0.77	5.88	0.05	13.10	0.11	5.36	0.05	2.44	0.02
96	35	24	101.4	73.45	0.72	8.51	0.08	12.12	0.12	4.86	0.05	2.41	0.02
97	32	25	113.0	91.89	0.81	5.02	0.04	9.77	0.09	4.15	0.04	2.14	0.02
98	27	27	135.0	107.3	0.79	6.21	0.05	12.95	0.10	5.93	0.04	2.64	0.02

Moosehorn Wilderness Area, ME

SITE=MOOS GROUP=10

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
95	133	11	19.30	10.76	0.56	2.12	0.11	3.47	0.18	1.51	0.08	1.45	0.08
96	143	10	17.32	9.67	0.56	1.19	0.07	3.17	0.18	1.35	0.08	1.93	0.11
97	153	9	15.51	8.07	0.52	1.25	0.08	3.13	0.20	1.18	0.08	1.88	0.12
98	136	11	18.72	10.02	0.54	1.14	0.06	3.78	0.20	1.67	0.09	2.11	0.11

SITE=MOOS GROUP=50

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
95	83	16	37.25	22.94	0.62	4.00	0.11	5.91	0.16	2.46	0.07	1.93	0.05
96	85	15	36.06	21.22	0.59	2.55	0.07	6.52	0.18	2.67	0.07	3.10	0.09
97	85	15	36.01	21.68	0.60	2.73	0.08	6.11	0.17	2.26	0.06	3.22	0.09
98	88	15	34.35	19.46	0.57	3.15	0.09	6.15	0.18	2.55	0.07	3.03	0.09

SITE=MOOS GROUP=90

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
95	42	22	83.33	55.92	0.67	6.98	0.08	13.90	0.17	3.92	0.05	2.62	0.03
96	44	22	79.03	53.55	0.68	5.53	0.07	12.63	0.16	4.63	0.06	2.69	0.03
97	43	22	80.40	55.67	0.69	3.47	0.04	14.58	0.18	3.75	0.05	2.93	0.04
98	43	22	80.98	60.15	0.74	4.22	0.05	10.83	0.13	3.93	0.05	1.85	0.02

Washington, D.C.

SITE=WASH GROUP=10

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
89	50	21	68.34	31.55	0.46	10.28	0.15	9.81	0.14	11.52	0.17	5.18	0.08
90	47	21	73.60	30.41	0.41	9.86	0.13	8.85	0.12	10.69	0.15	13.81	0.19
91	52	20	65.66	33.30	0.51	11.40	0.17	8.76	0.13	8.67	0.13	3.53	0.05
92	51	20	66.53	36.77	0.55	8.10	0.12	9.26	0.14	8.93	0.13	3.47	0.05
93	44	22	77.95	42.31	0.54	11.49	0.15	11.13	0.14	9.24	0.12	3.78	0.05
94	51	20	66.60	29.88	0.45	12.40	0.19	9.40	0.14	9.69	0.15	5.23	0.08
95	66	18	49.66	27.62	0.56	6.66	0.13	5.99	0.12	6.23	0.13	3.16	0.06
96	58	19	57.91	30.91	0.53	8.39	0.14	7.33	0.13	7.05	0.12	4.23	0.07
97	63	18	52.15	31.10	0.60	4.82	0.09	6.65	0.13	6.29	0.12	3.30	0.06
98	65	18	50.56	25.08	0.50	6.24	0.12	8.31	0.16	7.74	0.15	3.19	0.06

SITE=WASH GROUP=50

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
89	31	26	117.9	56.70	0.48	20.93	0.18	16.39	0.14	16.92	0.14	7.00	0.06
90	30	26	121.1	50.79	0.42	20.83	0.17	15.34	0.13	17.25	0.14	16.89	0.14
91	27	27	134.3	76.79	0.57	20.70	0.15	17.07	0.13	15.40	0.11	4.37	0.03
92	28	26	129.1	70.15	0.54	22.68	0.18	16.23	0.13	15.15	0.12	4.85	0.04
93	26	27	137.8	73.73	0.53	24.01	0.17	19.19	0.14	15.15	0.11	5.73	0.04
94	30	26	119.8	59.81	0.50	19.27	0.16	17.98	0.15	17.12	0.14	5.60	0.05
95	37	24	96.11	51.72	0.54	17.20	0.18	12.08	0.13	10.71	0.11	4.40	0.05
96	36	24	97.91	51.24	0.52	16.34	0.17	14.77	0.15	10.78	0.11	4.78	0.05
97	38	23	93.93	50.33	0.54	17.13	0.18	13.48	0.14	10.03	0.11	2.95	0.03
98	40	23	87.95	48.86	0.56	12.55	0.14	12.77	0.15	10.49	0.12	3.28	0.04

SITE=WASH GROUP=90

SYEAR	SVR	DV	TBEXT	ESO4	F_ESO4	ENO3	F_ENO3	EOC	F_EOC	ELAC	F_ELAC	ECM	F_ECM
89	21	29	179.9	99.44	0.55	27.34	0.15	21.88	0.12	21.73	0.12	9.49	0.05
90	20	30	182.0	79.03	0.43	25.63	0.14	27.56	0.15	27.23	0.15	22.56	0.12
91	16	32	236.2	159.0	0.67	24.52	0.10	27.12	0.11	19.14	0.08	6.46	0.03
92	16	32	242.2	158.0	0.65	32.00	0.13	24.82	0.10	20.40	0.08	6.99	0.03
93	16	32	233.6	131.2	0.56	35.21	0.15	35.74	0.15	23.29	0.10	8.21	0.04
94	18	31	206.0	123.5	0.60	21.86	0.11	30.49	0.15	23.39	0.11	6.78	0.03
95	21	29	179.7	108.8	0.61	23.86	0.13	24.80	0.14	16.88	0.09	5.29	0.03
96	20	30	186.9	129.8	0.69	12.90	0.07	22.35	0.12	17.38	0.09	4.48	0.02
97	21	29	179.3	116.4	0.65	21.27	0.12	23.62	0.13	13.58	0.08	4.43	0.02
98	21	29	178.2	127.8	0.72	3.53	0.02	26.69	0.15	17.37	0.10	2.87	0.02

Key:
GROUP 10 = 20% least impaired visibility days
GROUP 50 = 40 – 60% mid-range visibility days
GROUP 90 = 20% most impaired visibility days
SYEAR = Sample year (March – February)
SVR = Standard visual range (kilometers)
DV = Deciviews (includes Rayleigh scattering of 10 Mm^{-1})
TBEXT = Reconstructed particle mass extinction (Mm^{-1}), which excludes Rayleigh scattering
ESO4 = Ammonium sulfate extinction (Mm^{-1})
ENO3 = Ammonium nitrate extinction (Mm^{-1})
EOC = Organic carbon extinction (Mm^{-1})
ELAC = Light absorbing carbon extinction (Mm^{-1})
ECM = Crustal material extinction (fine and coarse soil) (Mm^{-1})
F_*** = Extinction fraction of speciated particle relative to reconstructed particle mass extinction
Data from IMPROVE, http://alta_vista.cira.colostate.edu/
NOTE: Great Gulf Wilderness Area data tables not available from IMPROVE web site.