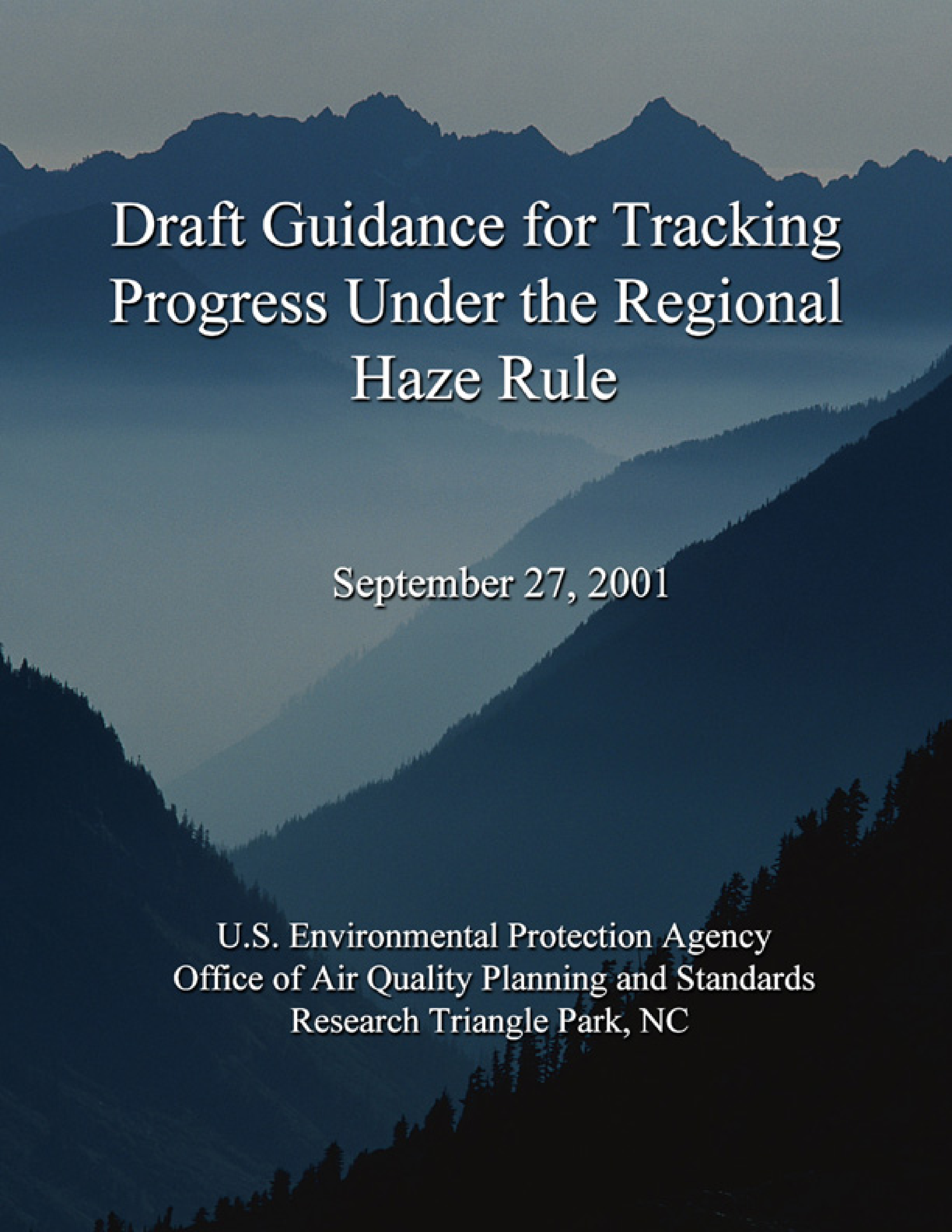

Draft Guidance for Tracking Progress Under the Regional Haze Rule

September 27, 2001

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC

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Abbreviations and Acronyms

b_{ag} - Light extinction coefficient associated with the absorption by gases

b_{ap} - Light extinction coefficient associated with the absorption by particles

b_{ext} - Total light extinction coefficient

b_{sg} - Light extinction coefficient associated with the scattering by gases

b_{sp} - Light extinction coefficient associated with the scattering by particles

BART - best available retrofit technology

CAA – Clean Air Act

CAAA – 1990 Clean Air Act Amendments

CASTNet - Clean Air Status and Trends Network

CIRA – Cooperative Institute for Research in the Atmosphere, Colorado State University

CM - Coarse mass

dv - Deciview haze index

EC - Elemental carbon (also referred to as light absorbing carbon, LAC)

EPA – United States Environmental Protection Agency

f(RH) – Relative humidity adjustment factor

GCVTC – Grand Canyon Visibility Transport Commission

IMPROVE – Interagency Monitoring of PROtected Visual Environments

LAC - Light absorbing carbon (also referred to as elemental carbon, EC)

Mm^{-1} - Inverse megameter (10^{-6} m^{-1})

MARAMA - Mid-Atlantic Regional Air Management Association

NAAQS – National Ambient Air Quality Standards

NESCAUM - Northeast States for Coordinated Air Use Management

NO_2 – Nitrogen dioxide

NOAA - National Oceanic and Atmospheric Administration

NPS – United States Department of the Interior, National Park Service

OC - Organic carbon

OMC - Organic carbon mass

OP - Pyrolized organics

PIXE - Proton induced x-ray emission spectroscopy

PM – Particulate matter

$PM_{2.5}$ – Particulate matter with an aerodynamic diameter less than 2.5 microns

PM_{10} – Particulate matter with an aerodynamic diameter less than 10 microns

RH - Relative humidity

RPO - Regional Planning Organization

SIP – State Implementation Plan

STAPPA - State and Territorial Air Program Administrators

TDMA - Tandem differential mobility analyzers

TIP - Tribal implementation plan

TOR - Thermal optical reflectance

WESTAR - Western States Air Resources Council

Glossary of Terms

Aerosols – Tiny liquid and/or solid particles dispersed in the air.

Coarse mass – Mass of particulate matter with an aerodynamic diameter greater than 2.5 microns but less than 10 microns.

Crustal material – Solid particulate matter represented by the sum of the soil mass and coarse mass.

Deciview haze index (*dv*) – Derived from calculated light extinction measurements so 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 directly from the total light extinction coefficient (b_{ext} expressed in inverse megameters [Mm^{-1}]):

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

Elemental carbon (EC)– Often referred to as soot or light-absorbing carbon (LAC). Ambient elemental carbon measurements represent the carbon that was not converted to carbon dioxide or carbon monoxide during complete combustion processes.

Fine particulate matter – particulate matter with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$).

Least-impaired days – Data representing a subset of the annual measurements that correspond to the clearest, or least hazy, days of the year.

Light extinction - A measure of how much light is absorbed or scattered as it passes through a medium, such as the atmosphere. The aerosol light extinction refers to the absorption and scattering by aerosols, and the total light extinction refers to the sum of the aerosol light extinction, the absorption of gases (such as NO_2), and the atmospheric light extinction (Rayleigh scattering).

Mandatory Federal Class I area - Certain national parks (over 6,000 acres), wilderness areas (over 5,000 acres), national memorial parks (over 5,000 acres), and international parks that were in existence as of August 1977. Appendix A lists the mandatory Federal areas.

Most impaired – Data representing a subset of the annual measurements that correspond to the dirtiest, or haziest, days of the year.

Nitrate – Solid or liquid particulate matter composed of nitric acid [HNO_3] or ammonium nitrate [NH_4NO_3]. Atmospheric nitrate aerosols are often formed from the atmospheric oxidation of oxides of nitrogen (NO_x) and are generally less than 2.5 microns in aerodynamic diameter.

Organic carbon – Aerosols composed of organic compounds, which may result from emissions from incomplete combustion processes, solvent evaporation followed by atmospheric condensation, or the oxidation of some vegetative emissions.

Particulate matter – Any substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and has an aerodynamic diameter less than 10 microns (in the discussions of this report).

Rayleigh scattering – Light scattering of the natural gases in the atmosphere. At an elevation of 1.8 kilometers, the light extinction from Rayleigh scattering is approximately 10 inverse megameters (Mm^{-1}).

Relative humidity – Partial pressure of water vapor at the atmospheric temperature divided by the vapor pressure of water at that temperature, expressed as a percentage.

Soil – Particulate matter composed of pollutants from the earth's soil, with an aerodynamic diameter less than 2.5 microns. The soil mass is calculated from chemical mass measurements of aluminum, silicon, calcium, iron, and titanium as well as their associated oxides.

Sulfate – Solid or liquid particulate matter composed of sulfuric acid [H_2SO_4], ammonium bisulfate [NH_4HSO_4], or ammonium sulfate [$(NH_4)_2SO_4$]. Atmospheric sulfate aerosols are often formed from the atmospheric oxidation of sulfur dioxide and are generally less than 2.5 microns in aerodynamic diameter.

Total carbon – Sum of the elemental carbon and organic carbon.

Visibility impairment – Any humanly perceptible change in visibility (light extinction, visual range, deciview, contrast, coloration) from a previous cleaner condition.

1. INTRODUCTION

1.1 What is regional haze?

Regional haze is visibility impairment caused by the cumulative air pollutant emissions from numerous sources over a wide geographic area. Visibility impairment is caused by particles and gases in the atmosphere. Some particles and gases scatter light while others absorb light. The net effect is called "light extinction." The result of these processes is a reduction of the amount of light from a scene that is returned to the observer, as well as an addition of scattered light to the sight path, creating a hazy condition. To a viewer, haze can be perceived as a reduction in the visual clarity of an object.

1.2 What is the purpose of this Tracking Progress guidance document for the regional haze program?

This Tracking Progress guidance document is intended to provide States, Tribes, and other interested parties with a consistent way to evaluate changes in visibility impairment in mandatory Federal Class I areas under the regional haze program. This guidance document provides background on the regional haze program, and addresses a number of important issues for tracking progress:

- methods for calculating light extinction from the data on particulate matter components measured in the IMPROVE (Interagency Monitoring for PROtected Visual Environments) ambient monitoring network;
- how to take into account the effect of relative humidity on light extinction

calculations;
- what to do when data for a particulate matter component is missing from a specific 24-hour sample;
- data completeness requirements for calculating annual averages or values for the 20% worst visibility (most visually impaired) or 20% best visibility (least visually impaired) days at a monitoring site;
- methods for selecting the 20% worst visibility and 20% best visibility days in a year;
- procedures for calculating baseline values for the 2000-2004 period;
- procedures for calculating current condition values for future five year periods; and
- procedures for comparing current conditions to mandatory Federal Class I area visibility goals and baseline conditions in order to evaluate progress.

Procedures for calculating visibility conditions are introduced in Chapter 2 with further explanation in Chapter 3, and the procedures for establishing trends in visibility conditions are presented in Chapter 4.

This document provides guidance to EPA, Regional, State and Tribal air quality management authorities and the general public on how EPA intends to exercise its discretion, in implementing Clean Air Act provisions and EPA regulations concerning the tracking of progress under the regional haze program. The guidance is designed to implement national policy on these issues. Sections 169A and 169B of the Clean Air Act (CAA) (42 U.S.C. §§ 7491, 7492) and implementing regulations at 40 CFR 51.308 and 51.309 contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose binding, enforceable requirements on any party, and may not apply to a particular situation based upon the circumstances. EPA, Regional, State and Tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions by EPA regarding a particular State Implementation Plan (SIP) demonstration will only be made based on the statute and regulations. Therefore, interested parties are free to raise questions and objections about the appropriateness of the application of this guidance to a particular situation; EPA will, and the regional organizations, States and Tribes should, consider whether or not the recommendations in the guidance are appropriate in that situation. This guidance is a living document and may be revised periodically without public notice. EPA welcomes public comments on this document at any time and will consider those comments in any future revision of this guidance document.

1.3 Does this guidance document apply to Tribal Class I areas as well as mandatory Federal Class I areas?

Not directly, although the procedures for calculating light extinction and tracking visibility changes over time that are described in this guidance can be used by Tribes that are conducting their own air quality monitoring using the IMPROVE protocol. The CAA and the regional haze rule call for the protection of visibility in 156 “mandatory Federal Class I areas.”[1] Tribes can establish Class I areas for the purposes of the prevention of significant deterioration program, but the CAA does not provide for the inclusion of Tribal areas as mandatory Federal Class I areas subject to section 169A and 169B of the CAA. For this reason, progress goals do not have to be established for Tribal Class I areas.

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[1] Areas designated as Class I areas are those national parks exceeding 6,000 acres, wilderness areas and national memorial parks exceeding 5,000 areas, and all international parks which were in existence on August 7, 1977. Visibility has been identified as an important value in 156 of these areas. See 40 CFR part 81, subpart D. The extent of a Class I area includes subsequent changes in boundaries, such as park expansions. (CAA section 162(a)). States and tribes may designate additional areas as Class I, but the requirements of the visibility program under section 169A of the CAA apply only to "Class I areas," and do not affect these additional areas. For the purpose of this guidance document, the term “Class I area” will be used to mean “mandatory Federal Class I area.”

However, Tribes may find it advantageous for a number of reasons to participate in regional planning organizations (RPO) for regional haze and to develop regional haze Tribal implementation plans (TIPs). Participation in an RPO may allow some Tribes to build capacity and enhance their air quality management capabilities. Under the Tribal Air Rule, Tribal governments may elect to implement air programs in much the same way as States, including development of Tribal implementation plans.[2] In this way, Tribes can work with other States and Tribes on the development and adoption of specific emissions reduction strategies designed to protect air quality across a broad region including Tribal and State lands.

1.4 What is the statutory and regulatory basis for the regional haze program?

Section 169A of the 1977 Clean Air Act amendments (CAAA) set forth legislative requirements for addressing visibility impairment due to air pollution. It established a national visibility goal to remedy existing impairment and prevent future impairment in 156 national parks and wilderness areas across the country designated as mandatory Federal Class I areas. It also called for EPA to develop regulations requiring state implementation plans to address visibility. These plans must include a long-term strategy and Best Available Retrofit Technology (BART) on certain existing sources for making "reasonable progress" toward this goal.

EPA issued initial visibility regulations in 1980[3] that addressed visibility impairment in a mandatory Federal Class I area that is "reasonably attributable" to a single source or small group of sources. EPA subsequently issued regulations to address regional haze (i.e. visibility impairment caused by emissions from numerous sources located over a broad geographic region) in 1999.[4] The regional haze rule requires States with mandatory Federal Class I areas to develop

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[2] See 63 Federal Register 7254 (February 12, 1998), and 40 CFR Part 49.

[3] See 45 Federal Register 80084 (December 2, 1980).

[4] See 64 Federal Register 35713 (July 1, 1999). See also 40 CFR 51.300-309.

SIPs that include reasonable progress goals for improving visibility in each mandatory Federal Class I area, and emission reduction measures to meet those goals.

1.5 What are the initial milestones of the regional haze program?

After publication of the regional haze rule in 1999, the first step in the implementation process was the upgrade and expansion of the IMPROVE visibility monitoring network to 110 sites nationally. The expanded IMPROVE monitoring network was deployed during the 1999-2001 time frame in accordance with Table 1-1.

Table 1-1. Deployment of IMPROVE Sites, 1999-2001.

Year	Number of IMPROVE Sites Deployed	Number of Years of Data for Calculating Baseline Conditions (2000-2004)
1999	60	5
2000	41	4
2001	9	3
TOTAL	110	

Representative monitoring data collected from this network will be used to establish baseline conditions (for the 2000-2004 period) for each Class I area and to track progress toward goals established in future SIPs. One can see from Table 1-1 that 101 (or 92%) of the 110 sites are expected to have at least 4 complete years of data for the purpose of determining baseline conditions. Only 9 sites are expected to use 3 years of data to establish baseline conditions.

Most States (and Tribes as appropriate[5]) – those participating in regional planning

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[5] Under the Tribal Air Rule (63 FR 7254; February 12, 1998; 40 CFR part 49), Tribal governments may elect to implement air programs in much the same way as states, including

organizations – are expected to submit regional haze "planning" SIPs in the 2004 time frame, and control strategy SIPs in the 2008 time frame.[6] Nine western States have the option under Section 51.309 of the regional haze rule to implement many of the recommendations of the Grand Canyon Visibility Transport Commission (GCVTC) within the framework of the regional haze rule, provided they submit initial regional haze SIPs in 2003. Progress reviews are to be conducted every 5 years after SIP submittal, and comprehensive SIP revisions are required in 2018 and every 10 years thereafter.

1.6 What visibility metric will be used for setting goals and tracking progress?

As stated at 40 CFR 51.308(d)(1), baseline visibility conditions, progress goals, and changes in visibility must be expressed in terms of deciviews. The 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 is expressed by the following formula:

$$dv = 10 \ln(b_{ext}/10)$$

where b_{ext} represents total light extinction expressed in inverse megameters (i.e., $Mm^{-1} = 10^{-6}\ m^{-1}$). See Section 3 of this document for further details on calculating deciviews from IMPROVE

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development of Tribal implementation plans (TIPs).

[6] For States that choose not to participate in regional planning organizations, the regional haze SIP deadlines are linked to the dates by which PM-2.5 areas are designated. For geographic areas designated as attainment or unclassifiable for PM-2.5, regional haze SIPs are due within 1 year. These SIPs could be due as early as 2003-5. For geographic areas designated as nonattainment, regional haze SIPs are due within 3 years, the same time that control strategies to attain the PM-2.5 standard would be due. These SIPs could be due in the 2006-8 time frame.

monitoring data.

1.7 What key requirements in the regional haze rule relate to progress goals for mandatory Federal Class I areas?

In their initial SIPs, States are required to adopt progress goals for improving visibility from baseline conditions (2000-2004) to 2018 for each Class I area in the State. A State that does not have any Class I areas will not establish any progress goals in its SIP, but it is required to consult with nearby states having Class I areas that may be impacted by emissions from the State. A State without any Class I areas will also need to adopt emission reduction strategies to address its contribution to visibility impairment problems in Class I areas located in other States. Specifically, a State is required to set progress goals for each Class I area in the State that:

- provide for an improvement in visibility for the most impaired (i.e., 20% worst) days over the period of the implementation plan, and
- ensure no degradation in visibility for the least impaired (i.e., 20% best) days over the same period.

In Class I areas with higher levels of visibility impairment, the conditions on the best days may still be several deciviews higher than estimated natural conditions. EPA expects that for most of these areas, emission reduction strategies to improve visibility conditions on the worst days should also lead to improvements on the best days. States should track progress on the best days as well as the worst days in order to determine if emission reduction strategies lead to an improvement in the overall distribution of visibility conditions. If an improvement in best day conditions is not observed over time, States may wish to consider adjusting their emission reduction strategies in order to improve best day conditions as well.

The reasonable progress goals must provide for a rate of improvement sufficient to attain natural conditions by 2064. States will determine whether they are meeting their goals by comparing visibility conditions from one five-year average to another (e.g. 2000-2004 to 2013-2017). In order to conduct the analysis for setting progress goals, the State will need to use this Tracking Progress guidance document for determining five-year baseline conditions. A separate guidance document will address methods for estimating Natural Visibility Conditions (i.e. the ultimate goal of the visibility improvement program).

1.8 How does a State determine the rate of progress it must analyze in the progress goal development process?

In developing any progress goal, the State will need to analyze and consider in its set of options the rate of improvement between 2004 (when 2000-2004 baseline conditions are set) and future periods (such as 2018) that, if maintained in subsequent implementation periods, would result in achieving estimated natural conditions by the year 2064. For example, an eastern Class I area for which the 20% worst deciview baseline condition is 29 deciviews and the estimated natural condition is 11 deciviews, the rate of improvement that the State must analyze for establishing the 2018 progress goal is equal to18 deciviews (i.e. the difference between current and estimated natural conditions) divided by 60 years (i.e. 2004 to 2064) which equals 0.3 deciviews per year. Carried out over 14 years (i.e., 2004 to 2018), this rate of improvement would lead to a reduction in the 20% worst average value of 4.2 deciviews.

The state must demonstrate in the SIP whether it finds that this rate of improvement is reasonable or not, taking into consideration the relevant statutory factors (*see next question*). If it finds that this rate is not reasonable, the State shall evaluate alternative rates of progress and include a demonstration supporting its finding that an alternate rate is reasonable. In order to determine the 2004-2018 progress rate for these analyses, the State will need to calculate 2000-2004 baseline conditions in accordance with this guidance document, and use separate EPA guidance for estimating Natural Visibility Conditions.

1.9 What other factors should be considered in developing Class I area progress goals?

Other important issues to be considered in developing Class I area progress goals include the reasonable progress factors in the CAA, consultation with other States and Tribes, and emission reductions due to other Clean Air Act programs. The reasonable progress factors[7] to consider in developing any progress goal are:

- 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 existing source subject to such requirements.

EPA plans to develop additional guidance on how to address these factors in the goal setting process.

States with mandatory Federal Class I areas are required to develop Class I area progress goals and consult with other States in developing Class I area progress goals and long-term strategies to meet these goals. If one State is reasonably anticipated to cause or contribute to visibility impairment in a Class I area located in another State, the two States are required to consult with one another on the development of progress goals for the affected Class I area. Furthermore, these States must include strategies in their SIPs that address their respective contributions to the haze in the affected Class I area. A State can take projected emissions reductions from other States into account in setting specific Class I area goals. This consultation process is essential because of the regional nature of the haze problem. EPA supports the

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[7] See CAA section 169A(g).

regional planning organization process currently under way to implement the regional haze program. We expect that much of the consultation, strategy development, apportionment demonstrations, and technical documentation needed for SIPs of participating States will be facilitated and developed through the RPO process.

In developing progress goals, the regional haze rule also requires States to take into account any emission reduction strategies in place or on the way in order to meet other Clean Air Act requirements. For example, emission reduction strategies (e.g. strategies to attain the $PM_{2.5}$ and ozone NAAQS, and national mobile source measures such as the Tier II or heavy duty diesel regulations) implemented in the State and/or in regions contributing to visibility impairment in the State's class I areas should be taken into account by the State as it develops Class I area progress goals for regional haze. Progress goals for regional haze certainly cannot be any less than the level of visibility improvement expected due to implementation of emission reduction measures for other programs.

1.10 Would EPA accept a progress goal providing for a reduced rate of visibility degradation?

Any progress goal calling for degradation of visibility, even at a modest rate, would not be considered to make "reasonable progress" toward natural conditions. Therefore, it is not expected that EPA would approve any demonstrations that show further visibility degradation as reasonable progress.

1.11 What are the regional haze rule requirements for progress reviews and future SIP revisions?

After the initial SIPs are approved, States will conduct formal progress reviews (in the form of a SIP revision) every 5 years (e.g. in 2013 if the initial SIP is submitted in 2008).

Progress will be reviewed for each Class I area by comparing "current" conditions to the 2000-2004 baseline value to determine whether air quality improvements are consistent with the progress goals established in the SIP. Progress reviews in 2018 and beyond shall also compare the current visibility conditions to visibility conditions five years prior and to the 2000-2004 baseline value. In each five-year review, the State will also check progress in terms of emissions reductions to determine whether emissions reductions measures contained in the plan have occurred in a timely and effective manner.

If progress is not consistent with the visibility and emission reduction goals established in the previous SIP, the State must evaluate the reason for lack of progress and take any appropriate. If the lack of progress is primarily due to emissions from within the State, then the State may need to revise its implementation plan within 1 year to include additional measures to make progress. If the lack of progress is primarily due to emissions from outside the State, then the State may need to reinitiate the regional planning process to address this problem in the next major SIP revision (e.g. in 2018).

States will be required to conduct a comprehensive SIP revision in 2018 and every 10 years thereafter. This process will involve re-evaluating rates of progress for each mandatory Federal Class I area within the State and establishing new visibility improvement goals for these areas. Using the previous example, suppose that the eastern Class I area made only 2 deciviews of improvement on the worst days (e.g. from 29 to 27 deciviews) by 2018. Assuming the same estimate of 11 deciviews for natural conditions, the rate of improvement that the State must analyze for establishing the 2028 progress goal is equal to:

$$\frac{\text{(Current worst day conditions - estimated natural conditions)}}{\text{(2064 - current year)}} = \text{yearly } dv \text{ improvement}$$

yearly dv improvement x 10 years = total *dv* improvement between 2018 and 2028

or,

$$\frac{(27dv - 11dv)}{(2064 - 2018)} = \frac{16dv}{46years} = 0.35dv/yr$$

$$0.35dv/yr \times 10yr = 3.5dv \quad \text{by } 2028$$

The revised SIP must also include revised emission reduction measures needed to meet the new Class I area progress goals.

1.12 What are the major analytical tasks involved in addressing specific requirements in the regional haze rule regarding tracking progress?

As noted above, the first step in tracking progress for the regional haze rule is collecting and analyzing filter samples from IMPROVE network sites. In order to identify the 20% most impaired and 20% least impaired days in a particular year, a deciview value needs to be determined for each 24-hour sample period, and then these values should be sorted from highest to lowest. Averages (in deciviews) for that year can be calculated for the days in the 20% most impaired and 20% least impaired “bins.”

The average deciview values for the 20% most impaired and 20% least impaired days in each year should then be averaged for the five consecutive years 2000-2004 to define baseline conditions. Similarly, when checking mid-course progress (e.g. in 2013), or for calculation of current conditions for future SIPs, the annual average values for the 20% most impaired and 20% least impaired days will be averaged for the 5 most recent years of data available, and then those values should be compared to the baseline values for that site. For mandatory Federal Class I areas with multiple representative monitors, separate visibility values and progress goals should be established for each site representing the area.

In order to facilitate this tracking process, States having one or more mandatory Federal

Class I areas are required by the rule to establish, and update as necessary, three important visibility parameters for the 20% best and 20% worst visibility days at each mandatory Federal Class I area within the State.

- **Baseline conditions** - Baseline conditions represent visibility for the 20% best and worst days for the initial 5-year period of the regional haze program. Baseline conditions are calculated based on monitored data collected during the 2000-2004 period.

- **Current conditions** - Current conditions for the best and worst days are calculated from a 5-year average (in deciviews), based on the most recent 5-year block of monitored data. Calculations of current conditions for each mandatory Federal Class I area are revised every 5 years at the time of each periodic SIP revision, and would be used to evaluate: (1) the amount of progress made in relation to the reasonable progress goals established for that mandatory Federal Class I area; (2) the amount of progress made since the last 5-year progress review, and (3) the amount of progress made from the baseline period of the program (2000-2004).

- **Estimate of natural visibility conditions** - The CAA sets a national visibility goal of "remedying existing impairment and preventing future impairment." Following from the national goal, the regional haze rule calls for improvements on the worst days to remedy existing impairment, and no degradation on the best days to prevent future impairment. Thus, the ultimate goal of the regional haze program is "natural conditions,"or the visibility conditions that would be experienced in the absence of human-caused impairment. Under the haze rule, natural conditions need to be estimated for the 20% best and 20% worst days. These estimates should represent long-term averages, analogous to the 5-year averages used to determine baseline conditions and current conditions. A separate guidance document provides a methodology for developing estimates of natural visibility conditions for each Class I area. Potential approaches for refining those estimates are also discussed in that document.

1.13 What air quality monitoring is under way to support tracking progress toward improving visibility conditions under the regional haze rule?

The IMPROVE visibility monitoring program was initiated in two mandatory Federal Class I areas in 1986 and grew to include 30 sites in 1988. The IMPROVE program has been coordinated and funded through a cooperative multi-organizational approach, with participation by EPA, the Federal land managers (Department of Agriculture, U.S. Forest Service; Department of Interior, National Park Service, Fish & Wildlife Service, Bureau of Land Management), National Oceanic and Atmospheric Administration (NOAA), the States, and multi-state organizations such as the Mid-Atlantic Regional Air Management Association (MARAMA), Northeast States for Coordinated Air Use Management (NESCAUM), Western States Air Resources Council (WESTAR) and The State and Territorial Air Pollution Program Administrators (STAPPA). The IMPROVE monitoring protocols include aerosol monitoring of particulate matter mass and its chemical components, optical monitoring of light scattering or overall light extinction, and photographic monitoring. Some but not all sites included on-site monitoring of relative humidity. Through calendar year 1999, the IMPROVE sampling schedule was one 24-hour aerosol sample twice a week, on Wednesdays and Saturdays.

In 1999, EPA provided funding for a significant expansion of the IMPROVE network. When fully deployed, the network will include aerosol monitoring at a total of 110 mandatory Federal Class I area sites. The new sites in the expanded network were selected in order to provide "representative" monitoring for all but one of 156 mandatory Federal Class I areas. New IMPROVE sites began coming on-line in 1999. Most sites were fully deployed by the end of 2000, although a few did not come online until 2001 (see Table 1-1). In the expanded IMPROVE network, one 24-hour sample is collected every 3 days, consistent with the sampling schedule for the Federal Reference Method for the PM-2.5 National Ambient Air Quality Standard (NAAQS). Under this schedule, a total of 121 aerosol samples can be collected for each IMPROVE site each year.

Most of the new IMPROVE sites include aerosol monitoring only. With limited network funds, priority was given to aerosol monitoring with chemical composition analysis of collected particulate matter samples. This allows the States, Tribes, and federal land managers to evaluate changes in visibility impairment, and to identify the principal types of emission sources contributing to the visibility impairment there. Figure 1-1 shows the locations of the monitoring sites in the expanded IMPROVE network. It should be noted that some States, Tribes, and Federal Land Managers have funded the operation of additional IMPROVE sites to represent mandatory Federal Class I areas or other areas of the county. At the time of publication of this guideline, there are a few dozen such additional sites known as IMPROVE protocol sites.

1.14 Why haven't particulate matter monitors been deployed at all mandatory Federal Class I areas?

Because of the broad spatial distributions of regional haze, and in order to use monitoring resources efficiently, EPA determined, in conjunction with State and Federal land managers, that some neighboring mandatory Federal Class I areas could be represented by a single monitoring site. In addition, one isolated mandatory Federal Class I area (Bering Sea, an uninhabited and infrequently visited island 200 miles from the coast of Alaska) was considered to be so remote from electrical power and people that it would be impractical to collect routine aerosol samples. EPA consulted with the States in order to design a network that was as representative of all mandatory Federal Class I areas as possible. All mandatory Federal Class I areas (except Bering Sea) are currently covered by at least one IMPROVE monitoring site, and some are covered by multiple sites. If changes are made in the sites which cover specific mandatory Federal Class I areas, all the calculations discussed in this document should be perfomed for the new sites.

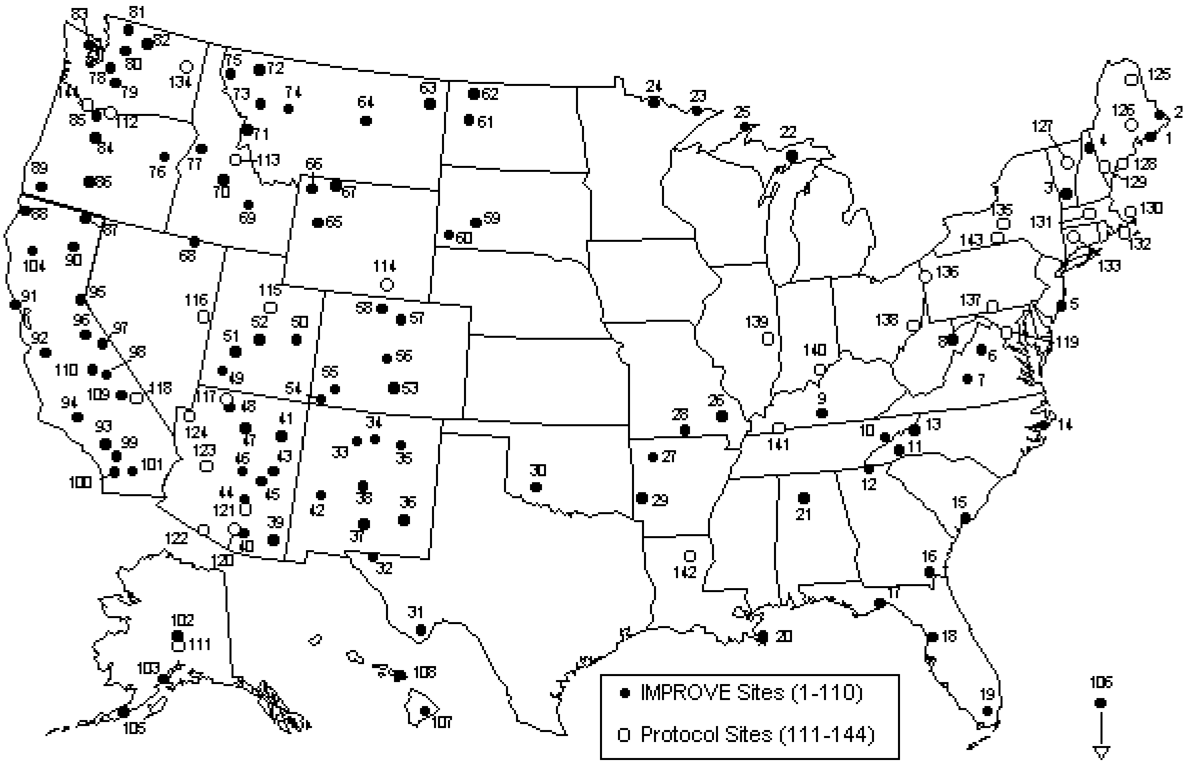

Figure 1-1. Expanded IMPROVE Visibility Monitoring Network. (Site 106 represents the US Virgin Islands).

1.15 Does this guidance pertain to tracking of Class I area changes in visibility by western States submitting regional haze plans under Section 51.309 of the regional haze rule?

Yes, any State with a mandatory Federal Class I area should track changes in visibility according to this guidance, regardless of whether the State has submitted a regional haze implementation plan under Section 51.308 or Section 51.309. Western States (and Tribes as appropriate) that are implementing Section 51.309 to improve air quality at the 16 mandatory Federal Class I areas on the Colorado Plateau will not be required to set progress goals for these areas for the 2003-2018 period, but they will be required to track progress in these 16 areas every five years according to Section 51.309(d)(10). Progress reviews and implementation plan revisions are required in 2008, 2013, and 2018. For each mandatory Federal Class I area in the State, the progress review should include an assessment of the following:

- Current visibility conditions (i.e. the most recent five year average) for the most impaired and least impaired days
- The difference between current conditions and baseline conditions (2000-2004) for most impaired and least impaired days
- The change in visibility conditions over the past five years for the most impaired and least impaired days.
- The change in visibility conditions as compared to the State's projection of visibility improvement required in Section 51.309(d)(2).

1.16 Does this guidance on Tracking Progress address all of the required elements of the five-year progress reviews required under the regional haze rule?

No, the primary focus of this document is to describe a recommended methodology for calculating total light extinction values for a mandatory Federal Class I area based on ambient monitoring data. The document also provides basic guidance on the types of visibility assessments needed as part of the five-year progress reviews. However, the State will need to evaluate both ambient monitoring information and the effectiveness of emission reduction measures in the five-year progress reviews. EPA will develop guidance for the full progress review process at a later date.

1.17 What information is provided in the rest of this guidance document?

The remainder of this document provides guidance on procedures to measure regional haze and to track progress towards meeting the national visibility goals. Section 2 of this document provides a summary step-by-step description of recommended calculations for tracking progress in regional haze improvement. Section 3 elaborates on that process, and presents equations and supporting information needed to perform the calculations. Section 4 discusses the final comparisons used for tracking progress in visibility.

An appendix is included in this document which lists the monthly relative humidity correction factors for each mandatory Federal Class I area. These factors are used for calculating light extinction at each mandatory Federal Class I area.

2. SUMMARY OF TRACKING PROGRESS CALCULATION PROCEDURES

2.1 What is the purpose of this section of the guidance document?

This section of the guidance document describes the process that should be carried out to track progress in improving visibility in mandatory Federal Class I areas, using data from the IMPROVE monitoring sites. The required calculation procedures should be carried out in a nationally consistent manner. The IMPROVE program will perform these calculations for all IMPROVE and IMPROVE protocol monitoring sites, and provide the results through the IMPROVE web site (http://vista.cira.colostate.edu/improve) as a service for those agencies who do not wish to implement the process themselves. To this end, the IMPROVE program will ensure that all data and calculations are available in a timely manner, consistent with SIP schedules. Data provided to the web site from the IMPROVE monitoring efforts will be used to calculate light extinction and deciview values, 5-year average results, and visibility trends at all IMPROVE sites. This centralized approach will assure consistent treatment of all composite components of $PM_{2.5}$, missing data, data substitution, and averaging, and will reduce the effort needed from Federal, State, Tribes, and other interested parties or agencies doing assessments. The calculations should be done according to the equations and procedures presented in Section 3 of this guidance document, which are also detailed on the IMPROVE web site. All monitoring data will be accessible for review by the responsible agencies, so that data flagging or adjustments for special occurrences or other factors can be implemented effectively. However, this service in no way usurps or relieves individual States from their regulatory responsibility to assess the change in visibility in each mandatory Federal Class I area. The aim of this approach is to achieve consistency in the calculation procedures while making the process easier for those states, Tribes, and other parties or agencies, who choose to do their own assessments.

2.2 What is the sequence of steps needed to calculate data for tracking progress?

Figure 2-1 summarizes the step-by step process for assessing visibility trends. The process begins with the transfer of quality-assured, state-reviewed, IMPROVE $PM_{2.5}$ monitoring data to the IMPROVE web site. Then the following sequence of steps will be carried out on data from each IMPROVE site, leading to the data needed for calculation of trends in visibility at each site.

Step 1. Assemble Composite Components of $PM_{2.5}$

Several of the particle components needed to assess $PM_{2.5}$ light extinction are termed composite components. Such variables may be a composite of multiple measured species, or may be derived from measured species by appropriate conversion factors. Composite components include Fine Soil, which is the sum of several crustal elements; Organic Carbon (OC), which is the sum of four measured OC fractions and the pyrolyzed organics (OP); Light Absorbing Carbon (LAC), which is the sum of three measured elemental carbon (EC) fractions less the OP fraction; Coarse Mass, which is the difference between measured PM_{10} and $PM_{2.5}$ mass; Sulfate, which may be determined based upon either measurements of particulate sulfur or of sulfate ion, with correction for associated ammonium ion; and Nitrate, which is calculated as the mass of ammonium nitrate. The first step in the data process should be to complete these component variables, using a procedure such as that summarized below:

Fine Soil is calculated by summing the five crustal elements (Al, Si, Ca, Fe, and Ti), accounting for their presence as oxides (e.g., Al_2O_3), and applying adjustment factors to correct for factors such as non-soil potassium, and the presence of other soil components. If any of the

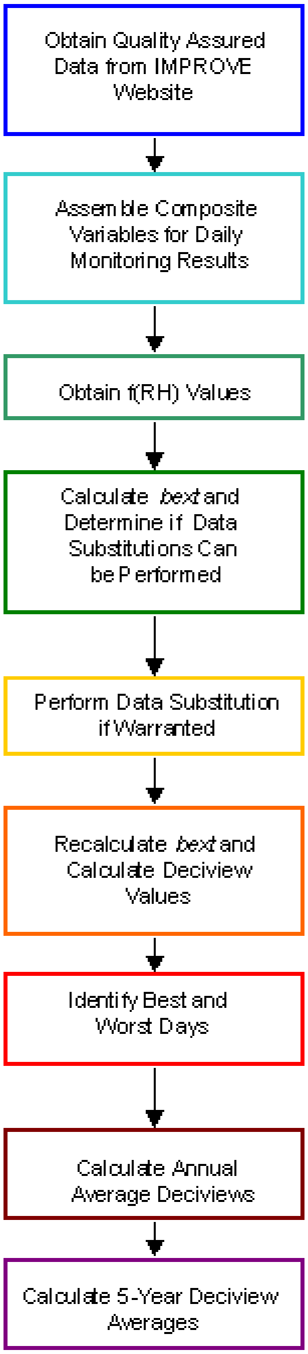

Figure 2-1. Summary of Step-by-Step Process for Tracking Progress Calculations.

five primary crustal elements is below the minimum detection limit, it is assigned a value of half the minimum detection limit. If any of the five crustal elements is missing from the data set, generally all five will be missing, because of the analytical method used for these elements. In that case the Fine Soil data are flagged as missing.

Organic Carbon is calculated by first summing the five fractions, and then subtracting the filter OC blank. If the result after blank subtraction is negative, a value of zero is assigned for Organic Carbon.

Light Absorbing Carbon is calculated in a similar way, by first summing the three elemental carbon fractions, subtracting the OP fraction, and then subtracting the filter blank. If the result after blank subtraction is negative, a value of zero is assigned for Light Absorbing Carbon.

Coarse Mass is calculated by subtracting the $PM_{2.5}$ value from the corresponding PM_{10} value. If the result after blank subtraction is negative, a value of zero is assigned for Coarse Mass.

Sulfate is preferably calculated from the particulate sulfur determination, but if that analysis is missing then the ionic $SO_4^=$ determined by ion chromatography is used. The total mass of sulfate present is then calculated assuming it exists in the aerosol as ammonium sulfate ($(NH_4)_2SO_4$). Nitrate is calculated directly from the measured nitrate ion values, with a factor of 1.29 applied to account for associated ammonium ion.

Step 2. Assess Missing Variables

Once the calculations outlined in the first step above have been completed, the entire data set should be reviewed to identify any missing data for the composite components. Those variables for which one or more results are missing should be addressed as in the following steps to fill in the missing data with long-term average values. Days for which no data at all are available are not included in any further calculations.

Step 3. Determine Quarterly Average Concentrations for Missing Variables

Using at least one complete quarter, and preferably all five of the same quarters from a five year period immediately prior to the year under consideration, the quarterly average concentrations are determined for each variable for which one or more data points were found to be missing in Step 2. All data for each variable in the data set are averaged, including data that have been set to zero (e.g., for Organic Carbon, Light Absorbing Carbon) and those that are based partly on assigned non-detect values (e.g., Fine Soil). The resulting quarterly average concentrations are then used in subsequent steps, to determine whether missing data can be replaced with the average values.

In this context, a complete quarter is defined as one in which data for a species are available for at least 50% of the sampling days, and which has no more than 10 consecutive sampling days with data missing for that species. With a sampling schedule of every third day, this requirement means that no more than one consecutive month of data can be missing. Quarters which do not meet these criteria should not be used to calculate the quarterly average values.

In carrying out this step, care must be taken that the sampling and analytical procedures are uniform throughout the data period being considered. For example, it must be determined that monitors have not been moved, that filter mask sizes have not been changed, etc. Such determinations require a careful review of the history of any siting changes as well as changes in the monitoring procedures for the site. If siting or procedural changes are made, it is important to establish that comparability in the monitoring data has been maintained throughout the changes.

Step 4. Obtain *f(RH)* Values

Calculations of light extinction and deciview values require *f(RH)* factors, which adjust the light scattering effect of hygroscopic aerosol species to account for particle growth caused by water vapor in the atmosphere. It is recommended that the *f(RH)* factors used be site-specific, and be associated with monthly, rather than (e.g.) seasonal or annual time frames. A table of recommended monthly *f(RH)* values for the Class I areas is included as Appendix A of this guidance document. The appropriate *f(RH)* values are used with monitoring data from each IMPROVE site in all visibility calculations.

Step 5. Evaluate Feasibility of Substituting Average Values

In this step, light extinction calculations are carried out for each IMPROVE site having any missing data in two ways: 1) using the original data from the past one to five "complete" years, (as defined below in Step 7) and 2) by substituting the appropriate quarterly concentrations determined in Step 3 for the individual species concentrations in the data set. Comparison of the two sets of results then determines whether the quarterly average concentrations can be used to fill in any missing data. This step in the overall process requires several steps in itself, as described below.

First, for a given IMPROVE site, the total light extinction values (b_{ext}, see Section 3) for all days with no missing data are calculated. This calculation is done as described in Section 3 of this guidance document, using the appropriate *f(RH)* factors, and the appropriate calculations of the individual composite components. This calculation produces a list of b_{ext} values for the original data set, with no missing values.

The second step is to recalculate the b_{ext} values for the same sampling days, but with the appropriate quarterly average values for a single species (from Step 3 above) substituted in place of all of the individual values of that species. For example, the quarterly average values of sulfate at a site would be substituted for the corresponding individual sulfate values, for all the days from that site with no missing data. The b_{ext} values are then calculated for the resulting data set. The product of this step is a second set of b_{ext} values, corresponding one-to-one with those calculated from the original values.

Next, these two sets of b_{ext} values are compared for each sample day in the set. If the relative difference between the two b_{ext} values is less than 10% for 90% of the sample days in the set, then it is acceptable to replace any missing values for that species with the appropriate quarterly averages for that species. If this criteria is not met, then any missing values for that species must remain missing.

The preceding process should be repeated as necessary, for each species with any missing data, one at a time, e.g., producing a set of b_{ext} values with quarterly average sulfate substituted for all individual sulfate values, then another set of b_{ext} values with quarterly average nitrate substituted for all individual nitrate values, etc. Each such set of b_{ext} values is compared to the original set, to make a judgment about substitution of averages for just one particle species. Note that this process is to be carried out for each composite species for each year, i.e., producing up to 35 tests for each five-year period, depending on the extent of missing data. It is expected that at any given IMPROVE site, it may be reasonable and appropriate to replace missing data with quarterly averages for some species, but not for others.

In calculating b_{ext} values in this step of the overall process, a value of 10 inverse megameters (i.e., $10/10^6$ m, or 10 Mm^{-1}) for Rayleigh scattering should be used for all sites. EPA believes that variations in this factor with elevation are too small to be of concern in trends assessment, so a single value should be used for all sites.

Instances in which data on more than one aerosol component are missing in the same sample are likely to be rare. As a result, the process for dual substitution is not presented at length here. However, substitution of two variables in the same sample could be done, subject to adequate justification and testing, such as in the substitution test described previously. The same acceptance criterion of less than 10% difference in b_{ext} values in 90% of the data should apply. For example, currently, elemental and organic carbon data are likely to either be present or missing in the same samples, because of the common analysis method for these species. As a result, this substitution test could also be carried out for those two species simultaneously. That is, the quarterly average values for both species could be substituted for their individual values at a site, the b_{ext} values could be calculated, and the comparison made to assess whether simultaneous replacement of missing EC and OC data with averages is appropriate.

Once the suitability of replacing missing data with averages has been assessed as described above, all missing data for those species meeting the acceptance criterion should be replaced with the appropriate quarterly average values, and the b_{ext} values for those samples are calculated. Missing data for species not meeting the criterion should be left missing, and no b_{ext} values should be calculated for those samples.

Step 6. Calculate Deciview Values

In this step the b_{ext} values calculated in Step 5 are converted to deciview values. Note that the appropriateness of substituting averages for missing data could just as easily be evaluated in terms of deciview values, instead of the b_{ext} values, since a difference of 10% in b_{ext} is equivalent to a difference of 1 deciview. That is, if the deciview values calculated with substituted averages differ from those of the original data by less than 1 deciview for 90% of the samples, then replacement of missing data with annual average values is appropriate. Otherwise, the missing data should remain missing.

Step 7. Data Completeness

In this step the data sets resulting from previous steps are reviewed for completeness.

In order for a year of data from a site to be used to track progress in improving visibility, all four quarters of that year should be at least 50% complete; and overall, the year should be 75% complete. That is, complete data (including that filled in by substitution of averages) should be available for at least 50% of the sampling days in each quarter of the year and for 75% of all scheduled sampling days for the year. In addition, there should be no more than 10 missing sampling days in a row at any time during the calendar year. With a sampling schedule of every third day, this requirement means that a site should not be out of operation for more than one consecutive month during the calendar year.

Annual data sets meeting these completeness criteria should be used in subsequent steps to calculate 5-year average visibility results for tracking progress. Every attempt should be made to get 5 years of complete data within each 5-year period, and EPA expects that failure to meet this goal will be rare. However, if maximum data recovery is not achieved, EPA believes that a minimum of 3 years of data meeting these completeness requirements is needed to calculate the 5-year averages within each 5-year period. This recommendation for at least 3 years out of 5 is consistent with the policy established in EPA's regulations governing monitoring and analysis of $PM_{2.5}$, which establishes minimum data requirements for $PM_{2.5}$ NAAQS comparisons. Because of the close relationships between visibility impairment and fine particle concentrations, as well as between the regional haze program and efforts to attain national ambient air quality standards, we believe that similar data completeness policies should apply. Due to delays in deployment, some of the 110 IMPROVE monitoring sites will have no more than 3 or 4 years of complete data at the time when baseline conditions are calculated (Table 1-1). The 3-year completeness criterion will allow calculation of baseline conditions at these sites. If three years with complete data are not available, estimates for baseline or current conditions should be prepared in consultation with the EPA/OAQPS.

Step 8. Identify Best and Worst Days

In this step, the 20% best and 20% worst visibility days within a year are identified, based on the deciview values. This step is conducted only for those years of data that meet the data completeness requirements stated in Step 7 above.

Step 9. Calculate Annual Average Deciviews

In this step, an annual average deciview value is calculated for the best 20% of the days in a year, and for the worst 20% of the days in the year. This process uses the best and worst days identified in the previous step, and thus also should be carried out only for years meeting the data completeness requirements.

Step 10. Calculate 5-Year Deciview Averages

Once the annual average deciview values are calculated for the 20% best and 20% worst days in each year, those values should be then averaged to produce best and worst average deciview values over the prescribed 5-year periods. As noted above, a minimum of 3 years of complete data should be available before a five-year average is calculated. If three years with complete data are not available, estimates for baseline or current conditions should be prepared in consultation with the EPA/OAQPS. The resulting estimates for the 5-year period then should be used as the basis for tracking progress (Section 4).

2.3 This 10-step process focuses on using complete years of data. What if an incomplete year would obviously have been a particularly bad or good visibility year?

This potential occurrence is an indication of one instance in which it would be appropriate to include data from incomplete years in calculations. For example, suppose that numerous high-deciview (i.e., poor visibility) sample results occurred, for days in a year in which data completeness overall fell below the recommendation stated above. Suppose further that if those high-deciview results were included in the calculation of the five-year averages (i.e., Step 10 above), they would increase the five-year average for the 20% worst days. That increase would bring the five-year average <u>closer to its true value</u>. That is, if the deciviews on the missing days in the incomplete year would have been even higher than on the days with data, then including the days with data at least moves the calculated average closer to what it would have been had measurements been available. Conversely, if the missing sampling days in the incomplete year would have been lower than those on the days with data, then they would not affect the top 20%, and would not affect the five-year average. Thus is it reasonable to include the highest 20% deciview readings from an incomplete year, <u>if</u> those values increase the five-year average of the highest 20% of deciviews, relative to that based on complete years only. For similar reasons, it is also appropriate to include the lowest 20% of deciview readings from an incomplete year, if those values decrease the five-year average for the lowest 20% of deciviews, relative to that based on complete years only. As a result, the highest and lowest deciview readings from incomplete years may be included in tracking progress calculations, provided they meet the criteria outlined above. This inclusion is analogous to the policy represented in provisions of Appendices K, M, and N to 40 CFR 50 regarding particulate matter, and makes use of incomplete years to provide more accurate estimates for tracking progress.

In any five-year period of baseline or current conditions, there should be at most two incomplete years of data. One process for using an incomplete year of data is as follows. First, calculate quarterly average deciview values from those years with complete data (i.e., the 3 or more years meeting the data completeness criteria). Second, substitute the appropriate quarterly average deciview values for all sampling days in an incomplete year that have some missing data, or even no data at all (the purpose of this substitution is to fill in the middle of the data set from the incomplete year, to define the 20% highest and lowest values. Consequently, substituting even for days with no data is appropriate). Third, sort all deciview values within each incomplete year, and calculate the averages of the 20% best and 20% worst visibility days. Finally, if the average deciview value of the 20% worst days in the incomplete year is higher than the corresponding average calculated from all the complete years, then include the average from the incomplete year along with those from the complete years, and calculate a new 5-year average. Similarly, if the average deciview value of the 20% best days in the incomplete year is lower than the corresponding average calculated from all the complete years, then include the average from the incomplete year along with those from the complete years, and calculate a new 5-year average.

3. METHOD TO CALCULATE THE HAZE INDEX

3.1 What causes haze?

Haze is caused by the presence of particles and gases in the air which either absorb or scatter light. Light reflected from landscape features is scattered and absorbed (attenuated) as it passes through the atmosphere toward the observer, and other light is scattered into the observer's sight path by the intervening atmosphere. The degree to which light is attenuated by these scattering and absorption processes can be expressed in terms of a coefficient of light extinction, b_{ext}. Absorption of light due to gases, b_{ag}, is caused primarily by the presence of nitrogen dioxide (NO_2) in the atmosphere, and absorption due to particles, b_{ap}, is caused primarily by elemental carbon (also called light absorbing carbon). Scattering by gases in the atmosphere, b_{sg}, is described by the Rayleigh scattering theory [vandeHulst, 1981] and is referred to as Rayleigh scattering. The magnitude of the Rayleigh scattering term depends on atmospheric pressure and varies from about 9 Mm^{-1} to 11 Mm^{-1} for most locations of interest depending primarily on site elevation. To simplify comparisons of values among sites at a variety of elevations, the IMPROVE program assumes a standard value of 10 Mm^{-1} for Rayleigh scattering in visibility calculations regardless of site elevation. Scattering by particles, b_{sp}, is caused by both fine and coarse aerosol species and is the largest contributor to total light extinction in most rural locations [Malm et al., 1994a]. The sum of these individual coefficients provides the overall light extinction coefficient, b_{ext}, which is used to calculate the haze level.

3.2 How are haze levels calculated?

Tracking of trends for the regional haze rule requires the calculation of haze levels, in deciview units, from measured particle species concentrations representative of each mandatory Federal Class I area. The species concentrations needed are not directly measured, but are determined from measured particle composition data which are routinely measured by the IMPROVE network at selected mandatory Federal Class I areas across the U.S. Under IMPROVE protocols, particle measurements are made every third day on a 24-hour integrated sampling interval, starting at midnight. $PM_{2.5}$ (particulate matter < 2.5 μm aerodynamic diameter) and PM_{10} (particulate matter < 10 μm aerodynamic diameter) mass are measured at all sites, with chemical speciation provided for the $PM_{2.5}$ fraction. The chemical speciation results provide concentration values for the major chemical constituents of $PM_{2.5}$ (i.e., sulfate, nitrate, organic carbon, elemental carbon, and soil). The species concentrations are used along with site-specific correction factors to correct for the effects of relative humidity, and species-specific extinction efficiencies to account for the different degree to which each species causes light extinction, to determine daily overall light extinction values. These total light extinction values (expressed as b_{ext}) are then used to calculate the haze index in terms of deciviews. Figure 3-1 summarizes this process.

3.3 How are the monitoring data used for the calculation of b_{ext} obtained?

The IMPROVE network has monitoring sites at 110 locations to monitor conditions representative of the 155 mandatory Federal Class I areas. At each of the sites, an IMPROVE sampler is operated. These samplers each have 4 modules (identified as A, B, C, and D) which are used to collect particulate matter samples for chemical or gravimetric analysis. Modules 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

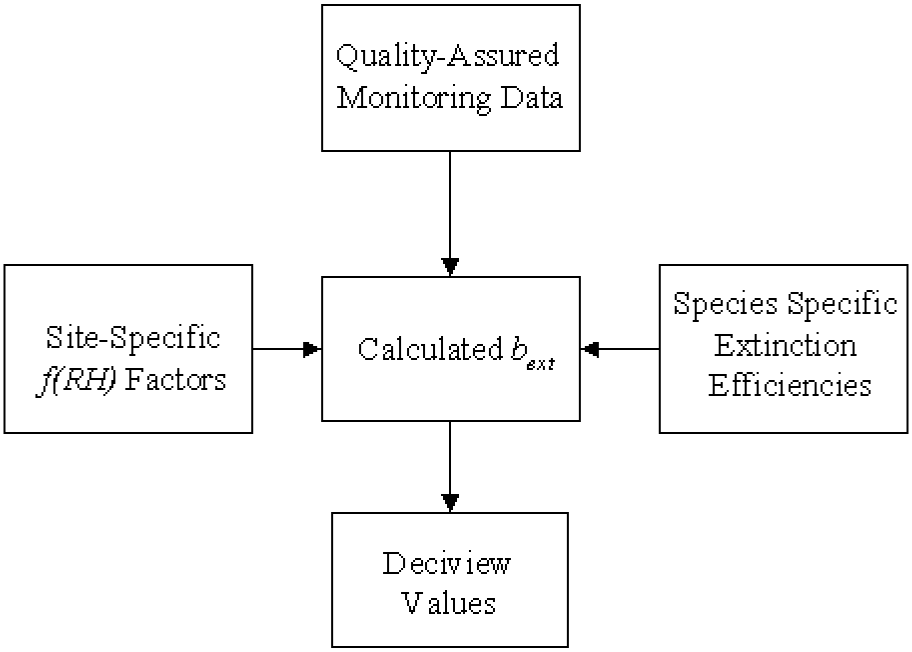

Figure 3-1. Summary of Process to Calculate Haze Index.

before the nylon filter to remove acidic gases, is used primarily for nitrate. Module C, with tandem quartz filters, collects samples which are analyzed for carbon in eight temperature fractions and used to determine both organic carbon and light absorbing carbon concentrations.

Sulfate ion concentration is determined by multiplying the concentration of elemental sulfur, as determined from proton induced x-ray emission (PIXE) analysis of the Module A sample, by 3 to account for the oxygen in the sulfate ion. When elemental sulfur data are not available, sulfate measured by ion chromatographic analysis of the Module B sample can be used to determine the dry sulfate concentration.

Fine particle sulfate content originates predominantly from atmospheric oxidation of sulfur dioxide to sulfuric acid, either by aqueous reactions in cloud droplets or through gas-phase photochemistry. If there is inadequate ammonia in the atmosphere to fully neutralize the sulfuric acid, then the resulting aerosols are acidic. Depending on the ammonia available, solutions of varying acidity may be formed, ranging from ammonium sulfate (fully neutralized) to sulfuric acid. The dry ammonium sulfate value is calculated from independent measurements of sulfate (SO_4^{2-}) and ammonium (NH_4^+) ion using:

$$[SULFATE] = (0.944)\left[NH_4^+\right] + (1.02)\left[SO_4^{2-}\right] \tag{1}$$

where [SULFATE] is the mass of the ammoniated sulfate ion, [SO_4^{2-}] is the concentration of sulfate ion, and [NH_4^+] is the concentration of ammonium ion after adjusting for the ammonium associated with ammonium nitrate. If only the sulfate ion is measured, as is the case at nearly every IMPROVE site, then one must assume a form of sulfate (i.e., a degree of neutralization by ammonia) and multiply by an appropriate multiplication factor, for instance, 1.37 * [SO_4^{2-}], if ammonium sulfate is assumed as is the case for the IMPROVE program.

The mass of organic material present can be calculated from the measured $PM_{2.5}$ OC mass, which is determined by thermal optical reflectance (TOR) analysis [Chow, et al., 1993]. An average ambient particulate organic compound is assumed to have a constant fraction of carbon by weight. Organic carbon mass concentration (OMC) is simply:

$$[OMC] = (1.4)[OC] \tag{2}$$

where the factor of 1.4 was selected to adjust the organic carbon mass for other elements assumed to be associated with the organic carbon molecule [White and Roberts, 1977; Japar et al., 1984].

Light absorbing carbon (LAC) is also determined by TOR analysis and is calculated from the sum of elemental carbon fractions minus the pyrolized fraction.

Nitrate ion concentration is determined by ion chromatographic analysis of the sample collected in Module B. Assuming that the nitrate ion is associated with fully neutralized nitrate aerosol, [NH_4NO_3], the ammonium nitrate mass, [NITRATE], can be estimated from the nitrate ion mass concentration by using a multiplication factor of 1.29, which accounts for the mass ratio of NH_4NO_3 to NO_3^-.

Soil mass concentration, [SOIL], is estimated by summing the mass of those elements predominantly associated with soil, with allowance for oxygen present in the common compounds (e.g., Al_2O_3, SiO_2, CaO, K_2O, FeO, Fe_2O_3, TiO_2) as shown in Equation :

$$\begin{aligned}[SOIL] = 2.2[Al] + 2.49[Si] + 1.63[Ca] \\ +2.42[Fe] + 1.94[Ti]\end{aligned} \tag{3}$$

Since potassium can originate from wood smoke as well as from soil, iron is used as a surrogate for determining [SOIL]. The concentrations of these elements are determined by analysis of the Module A sample by PIXE. In addition, a correction is applied for other compounds such as MgO, Na_2O, water, and carbonate [Malm, et. al., 1994a].

Coarse particle mass (CM) is estimated gravimetrically by subtracting the gravimetric fine mass ($PM_{2.5}$ from Module A) from total gravimetric mass (PM_{10} from Module D), i.e.,:

$$[CM] = [PM_{10}] - [PM_{2.5}] \tag{4}$$

In the IMPROVE program, no additional chemical analyses are carried out on the coarse fraction. It is assumed that in rural areas of the country the primary constituent of coarse mass is naturally occurring wind-blown dust, along with some vegetative material.

3.4 What are the species specific scattering efficiencies for aerosol components?

The calculation of light extinction from aerosol species concentrations treats each species contribution separately and merely sums them. This formulation implies no interaction between the various aerosol species with respect to their contributions to extinction. This would be the case if each of the particles were composed of only one species (e.g. sulfate particles separate from nitrate particles which are separate from organic carbon particles, etc.). This is referred to as an externally mixed aerosol because the mix of species is not internal to the particles. Calculations of extinction from internally mixed aerosols are much more difficult and require information that has never been routinely collected.

Most routine aerosol monitoring programs and many special study visibility characterization programs were designed to measure bulk aerosol species mass concentrations such as sulfates, nitrates, carbonaceous material, and selected elements [Heisler et al., 1980; Malm et al. 1994b; Tombach and Thurston, 1994; Watson et al., 1990; Macias et al. 1981]. They were not designed to determine the microphysical and chemical characteristics of these species. However, the inherent limitations of estimating aerosol optical properties from bulk aerosol measurements have been addressed, at least in part, by a number of authors. For instance, Ouimette and Flagan [1982] have shown from basic theoretical considerations that if an aerosol is mixed externally, or if in an internally mixed aerosol the index of refraction is not a function of composition or size, and the aerosol density is independent of volume, then:

$$b_{sp} = \sum_i \alpha_i m_i \tag{5}$$

where α_i is the specific mass scattering efficiency and m_i is the mass of the individual species.

Sloane [1983, 1984, 1986], Sloane and Wolff [1985], and more recently Lowenthal et al. [1995], Malm [1998], and Malm and Kreidenweiss [1997] have shown that differences in estimated specific scattering between external and internal model assumptions are usually less than about 10%. In the absence of detailed microphysical and chemical information of ambient particles, the above studies demonstrate that a reasonable estimate of aerosol extinction can be achieved by assuming each species is externally mixed.

In general the extinction contribution for each species is the product of three factors: the dry extinction efficiency for that species (α_i), the relative humidity adjustment term that varies as a function of relative humidity for that species ($f_i(RH)$), and the dry concentration of that species (m_i). The relative humidity adjustment factor, $f_i(RH)$, is defined to be the ratio of scattering by a species at some relative humidity to scattering by that species under dry conditions, i.e. $f_i(RH) = b_{spi}(RH)/b_{spi}(RH=0)$ where i refers to the i^{th} species.

The extinction efficiencies for soil and coarse mass are taken from a literature review by Trijonis and Pitchford [1987]. For soil, the dry extinction efficiency of 1 m^2/g is used, and for coarse mass, a value of 0.6 m^2/g is used. For both nitrate and sulfate, a dry extinction efficiency of 3 m^2/g is based on literature reviews by Trijonis et al. [1990] and by White [1990]. Trijonis' best estimate for sulfates and nitrates is 2.5 m^2/g with an error factor of 2, while White's average low and high estimates for the rural West are 3.0 and 3.7 m^2/g, respectively. For organics Trijonis estimates a dry extinction efficiency of 3.75 m^2/g, again with an error factor of 2, and White's low and high average estimates for the rural West are 1.8 and 4.1 m^2/g, respectively. Bases on these estimates, a dry extinction efficiency of 4 m^2/g is used. More recently, Malm et al. [1996] demonstrated that the assumption of the dry specific scattering values yielded good agreement between measured and reconstructed extinction across the entire IMPROVE monitoring network.

3.5 What effect does relative humidity have on the haze levels?

Some aerosol components are hygroscopic (principally sulfates and nitrates), meaning that particles composed of those materials grow in size by accumulating water from the atmosphere under moist conditions. This causes an enhanced amount of light scattering that is directly related to the atmospheric relative humidity. Implicit to the use of Equation (5) is an assumed linear relationship between aerosol species mass and extinction. However, the relationship between measured light scattering and hygroscopic species mass can be quite nonlinear, because of water uptake as a function of relative humidity. A number of authors have attempted to linearize the model, in an empirical way, by multiplying the hygroscopic species by such a factor as 1/(1-RH) to account for the presence of water mass [White and Roberts, 1977; Malm et al., 1989]. However, Malm et al. [1989] and Gebhart and Malm [1989] proposed a different approach. They multiplied the hygroscopic species by a relative humidity scattering enhancement factor, $f(RH)$, that is calculated on a sampling-period-by-sampling-period basis using Mie theory, an assumed size distribution, and laboratory measured aerosol growth curves which illustrate the size of aerosol particles as a function of relative humidity.

Tang (1996) published growth curves showing the ratio of particle diameter to particle diameter at zero relative humidity, D/D_o, as a function of increasing and decreasing relative humidity for a number of inorganic salts. For increasing or decreasing RH, many salts exhibit a hysteresis in the D/D_o vs RH relationship, with sharp discontinuities at the deliquescence (relative humidity at which the crystal abruptly absorbs water) and crystallization (relative humidity at which particles abruptly lose water and recrystalize) humidities. Because mixtures of ammoniated sulfate compounds with other species have been shown to be hygroscopic below the deliquescent values [Sloane, 1984; Sloane, 1986; Stelson and Seinfeld, 1982] and because the growth factor and light-scattering efficiency for ambient aerosols has previously been observed to be rather smooth [Sloane, 1984; Sloane, 1986; Sloane, 1983; Wexler and Seinfeld, 1991; Waggoner et al., 1981; Day et al., 2000; Malm et al., 2000a; Malm et al., 2000b; Malm and Day, 2001], it is not known whether the upper or lower limb of the hysteresis curve applies for a particular aerosol sample. Therefore, as a “best estimate” for the sulfate species growth, the curves are smoothed between the deliquescence and crystallization points.

Malm et al. [2000a, b] and Malm and Day [2001] have demonstrated that in both the East and West, the best estimate growth curves yield good agreement between measured and theoretically predicted $f(RH)$ functions and between measured and predicted ambient fine particle scattering. However, the sulfate $f(RH)$ function is quite different for the East than West because of sulfate ammoniation. In the East where sulfates can be quite acidic, average growth of the sulfate aerosol begins at much lower relative humidities (<30%) than in the West. In the Colorado Plateau region of the West, growth does not typically initiate until about 40-50% relative humidity. Because ammonium mass concentration is not routinely measured in the IMPROVE program, the "smoothed" ammonium sulfate growth curve is used for estimating sulfate *f(RH*) curves. This smooth curve is illustrated in Figure 3-2, which shows the *f(RH)* for ammonium sulfate as a function of relative humidity.

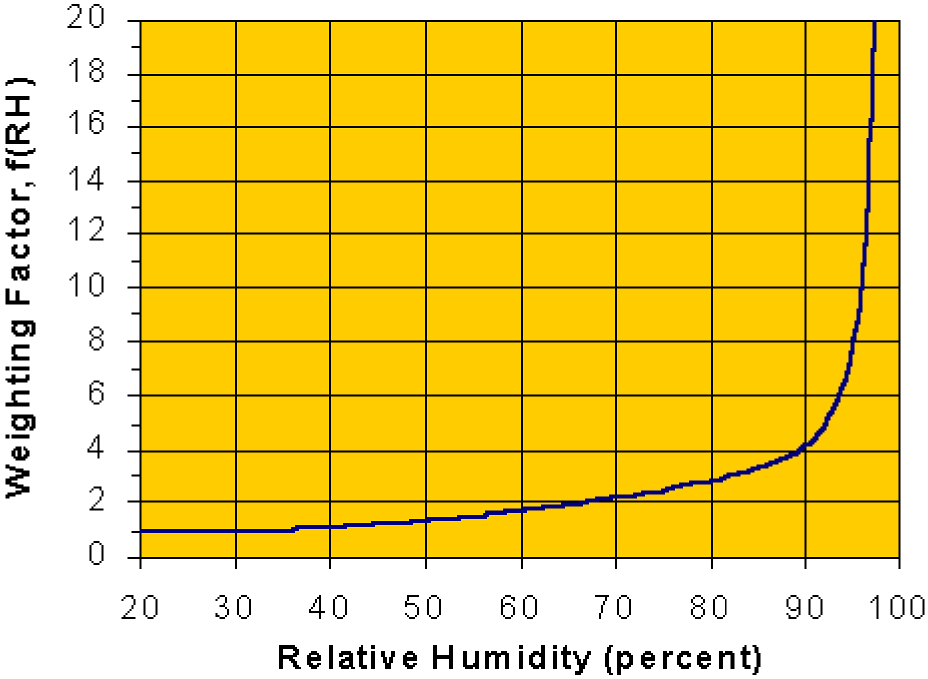

Figure 3-2. Smoothed Ammonium Sulfate Growth Curve.

The value of *f(RH)* rises very slowly from 1 as the relative humidity increases, only reaching 2 at about 70% relative humidity. However, *f(RH)* is non-linear and increases rapidly as it approaches 100% relative humidity (at which point it is undefined). For example *f(RH)* is 4 at about 90% relative humidity and increases to 10 at about 95% relative humidity. The importance of this effect is illustrated by considering that the same concentration of sulfate aerosol is responsible for 5 times the haze at 95% relative humidity as at 70% relative humidity.

Various functions for the hygroscopicity of particulate organic compounds have also been proposed. Assumptions must be made about the fraction of organics that are soluble. Models that treat water uptake for non-ideal multicomponent solutions using theoretical and semi-theoretical thermodynamic relationships have been developed, and have been applied to both visibility and climate forcing problems [Saxena and Peterson, 1981; Pilinis et al., 1995; Saxena et al., 1986, 1993]. The correct treatment of the hygroscopicity of species in multicomponent mixtures - especially organic species - remains problematic, not only because of the lack of suitable mixture thermodynamic data but also because of the lack of information about other critical mixture properties.

Scientists have experimentally measured growth of ambient particles as a function of relative humidity using tandem differential mobility analyzers (TDMA) in non-urban settings [Zhang et al., 1993; 1994; Swietlicki et al., 1999]. One study was carried out in Meadview, Arizona (west end of Grand Canyon) over a 31-day period during the summer of 1991, a second at Hopi Point, Arizona (midpoint of Grand Canyon), over a 13-day period during the winter of 1990, and a third at Claremont, California over an 11-day period during the summer of 1987 [Cai et al., 1993; Zhang et al., 1993; 1994; McMurry and Zhang, 1991]. A TDMA consists of two DMAs operated in series. The first DMA is used to select a size, while the second is used to measure the change in particle size as relative humidity is varied. Usually, a MOUDI size sampler [Marple et al., 1991] is run concurrent with the TDMA to derive estimates of particle composition.

Saxena et al. [1995], based on their modeling assumptions, concluded that at Grand Canyon aerosol organic species increased water absorption by inorganic species, while at Claremont the net effect of organics was to diminish water absorption by inorganics. On the other hand, Pitchford and McMurry [1994] showed that on 6 of the 8 sampling days at the Grand Canyon study cited above, if it is assumed that nitrates and sulfates uptake water at the same rate as measured in the laboratory, they alone could account for all of the measured water absorption.

Swietlicki et al.[1999] made TDMA measurements in Northern England and found growth to take place in two modes, one mode being less hygroscopic than the other. They concluded that growth could be attributed to the inorganic content of the aerosol. Cocker et al. [2001] measured hygroscopic properties of Pasadena, California aerosol and concluded that growth factors increased when forest fires were present. However, they were unable to attribute the growth to any single species because concurrent aerosol speciation was not carried out simultaneously.

McDow et al. [1994] measured water uptake by diesel soot, automobile exhaust, and wood smoke particles. They found all three emission types absorbed water, with the wood smoke sample weight increasing by about 10% as sample relative humidities increased, whereas diesel soot sample weight increased by only 2%-3%.

Chughtai et al. [1999] examined the hydration characteristics of BP2000 (commercially available carbon black), and of carbon produced from n-hexane, diesel fuel, JP8 (aviation fuel), pine needles, Utah coal, and acetylene. They examined water adsorption isotherms between 20% and 85% relative humidity and concluded that the ability of black carbons, produced from a variety of fuel types, to adsorb water generally increased with age and surface oxidation. At high relative humidity (83%), large surface areas determine the adsorption capacity. At lower relative humidity, however, the surface functional groups determine the extent of hydration. Even at 83% relative humidity, the water uptake was less than 10% of total mass for all carbon species other than BP2000. Because of its large surface area, BP2000 absorbed about 40% of its mass in water. Consequently, they concluded that commercial carbon blacks are not acceptable models for fuel-produced carbons.

Field experiments and subsequent data analysis at Great Smoky Mountains and Grand Canyon National Parks [Malm et al., 1997; Malm and Kreidenweis, 1996; Malm et al., 2000] and, more generally, data collected in the IMPROVE network [Malm et al., 1996] show that to within the uncertainty of the measurements and modeling assumptions, ambient organics in rural areas of the United States are at most only weakly hygroscopic. Therefore, based on the available data, the *f(RH)* for aerosol organics can be reasonably set equal to one.

The additive extinction by chemical species embodied in Equation 5 can be combined with the effect of RH discussed above, to estimate the scattering of light by fine particles. The following equation is used to estimate reconstructed particle light scattering:

$$\begin{aligned} b_{sp} = {} & (3) f_{SO4}(RH)[SULFATE] \\ & +(3) f_{NO3}(RH)[NITRATE] \\ & +(4) f_{org}(RH)[OMC] \\ & +(1)[SOIL] \\ & +(0.6)[CM] \end{aligned} \tag{6}$$

The brackets in Equation 6 indicate the species concentration, 3 m^2/g is the dry specific scattering efficiency for sulfates and nitrates, 4 m^2/g is the dry specific scattering efficiency for organic mass, and 1 m^2/g and 0.6 m^2/g are the respective scattering efficiencies for soil and coarse mass.

3.6 How are the f(RH) values determined?

Average $f_{SO4}(RH)$ values for each sampling period are calculated based on the ambient humidity, using Tang's [1996] ammonium sulfate growth curves. Assuming a lognormal sulfate mass size distribution, with a geometric mass mean diameter of 0.3 µm and a geometric standard deviation, σ_g, of 2.0, the $f_{SO4}(RH)$ values are calculated using D/D_o curves that are smoothed between the crystallization and deliquescent points. The $f_{NO3}(RH)$ associated with nitrates is assumed to be the same as for sulfates, while $f_{org}(RH)$ for organics is set equal to one.

To assess the changes in manmade pollution contributions to visibility impairment, it is appropriate to use relative humidity that is the same for the baseline period and future periods with changed emissions. In other words, it is more appropriate to eliminate the confounding effects of interannual variations in relative humidity, while maintaining typical regional and seasonal humidity patterns.

To that end, the U.S. EPA recently sponsored a project to examine measured hourly relative humidity data over a 10-year period (1988-1997) within the United States to derive month-specific climatological mean humidity correction factors for each mandatory Federal Class I area.[8] The hourly RH measurements (below 95% RH) from each site were converted to *f(RH)* values using a non-linear weighting factor curve. For days in which at least 16 hours of valid RH data were available, daily averages were determined from these hourly *f(RH)* values at each site. Monthly averages were then calculated from the daily *f(RH)* averages at each site. The monthly average *f(RH)* values were interpolated at 1/4-degree increments using the inverse distance weighting technique (with a distance interpolation exponent of 1):

$$f(RH)_g = \frac{\sum f(RH)_w / x_{wg}}{\sum 1/x_{wg}} \tag{7}$$

where the monthly $f(RH)_g$ of the grid cell is calculated from $f(RH)_w$ at the weather station, and the horizontal distance between the grid cell center and the weather station, x_{wg}, summed over all the weather stations within a 250-mile radius with valid *f(RH)* values for that month.

The results of that work are the values presented in Appendix A. These relative humidity factors have been calculated from available hourly relative humidity data from 292 National Weather Service stations across the 50 states and District of Columbia as well as from 25 IMPROVE and IMPROVE protocol monitor sites, 46 Clean Air Status and Trends Network (CASTNet) sites, and 12 additional sites administered by the National Park Service. Using a software tool available from EPA, monthly *f(RH)* values can be calculated for any location in the

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[8] U.S. EPA, *Interpolating Relative Humidity Weighting Factors to Calculate Visibility Impairment and the Effects of IMPROVE Monitor Outliers*, prepared by Systems Application International Corporation, Raleigh, NC, EPA Contract No. 68-D-98-113, August 30, 2001.

US. In most regions there is a seasonal cycle of relative humidity, which is accounted for by generating the appropriate monthly *f(RH)* values, as in Appendix A. The 12 monthly-averaged *f(RH)* values listed for each mandatory Federal Class I area in this way are to be used for all visibility and tracking progress calculations for that location.

3.7 How does light absorption contribute to light extinction?

Light absorption by gaseous species, primarily NO_2, is generally negligible in mandatory Federal Class I areas and not included in calculations of light extinction. However, estimating the total light extinction also requires a knowledge of light absorption by particles. Light absorption by particles is primarily due to elemental carbon (also called light-absorbing carbon). Horvath [1993] has reviewed the measurement of light absorption by elemental carbon, while Fuller et al. [1999] has explored theoretically the variability of absorption efficiency as a function of carbon morphology. Estimated mass absorption efficiencies of elemental carbon vary by more than a factor of two, as do direct measurements. Although particle light absorption can be estimated in a variety of ways, there is no one method that is generally accepted by the scientific community. For purposes of this guidance, elemental carbon light absorption is estimated using:

$$b_{ap} = 10\left[LAC\right] \tag{8}$$

were LAC is the concentration of light-absorbing carbon as measured using the Thermal Optical Reflectance (TOR) analysis method [Chow et al., 1993], and 10 is the specific absorption efficiency for LAC, which has been used by a number of scientists [Horvath, 1993].

3.8 How is the total light extinction calculated?

In addition to particle scattering and particle absorption, total light extinction needs to include a term b_{sg}, i.e. for Rayleigh scattering, which is scattering by the gas molecules in the atmosphere. Thus, $b_{ext} = b_{sp} + b_{ap} + b_{sg}$. As indicated in Section 3.7, carbon light absorption is estimated as ten times the concentration of light-absorbing carbon for the purposes of the guidance. A standard value of 10 Mm^{-1} for Rayleigh scattering is used in visibility calculations regardless of site elevation to simplify comparisons of values among sites at a variety of elevations.

Combining all of the factors discussed above, the following equation converts particle species concentration data in units of $\mu g/m^3$ for each sample period at a monitoring location to total light extinction in units of Mm^{-1}.

$$\begin{aligned} b_{ext} = {} & (3)f(RH)[SULFATE] + \\ & (3)f(RH)[NITRATE] \\ & +(4)[OMC] \\ & +(10)[LAC] \\ & +(1)[SOIL] \\ & +(0.6)[CM] \\ & +10 \end{aligned} \qquad \textbf{(9)}$$

Malm et. al. [1996] used this IMPROVE algorithm to successfully reconstruct scattering at nine sites, namely Grand Canyon, Petrified Forest, Guadalupe Mountains, Yellowstone, Rocky Mountain, Glacier, Pinnacles, and Bandelier national Parks, and the Bridger Wilderness area. Additionally comparisons were made between reconstructed and measured extinction at Acadia and Shenandoah National Parks for the time period 1988-1991. Those results were reported in the February 1993 IMPROVE report "Spatial and Temporal Patterns and the Chemical Composition of the Haze in the United States." ISSN No. 0737-5352-26. Finally, William Malm (personal communication) has compared measured and reconstructed scattering at Great Smoky Mountains National Park for the time period 1994-2000 and found that on average there was only a 1.2% difference between the two values.

3.9 How are deciview values calculated?

Once the reconstructed light extinction has been calculated for a monitoring period, as in Equation 8, visibility expressed as reconstructed deciview (*dv*) can be calculated. The deciview is a visibility metric based on the light-extinction coefficient that expresses incremental changes in perceived visibility [Pitchford and Malm, 1994]. Because the deciview expresses a relationship between changes in light extinction and perceived visibility, it can be useful in describing visibility trends. A one *dv* change is equivalent to about a 10% change in extinction coefficient, which is a small but perceptible scenic change under a wide range of visibility conditions. The deciview scale is defined by the following equation:

$$dv = 10 \ln(b_{ext} / 10) \quad \textbf{(10)}$$

The deciview scale is near zero for a pristine atmosphere (*dv* = 0 for a pure Rayleigh scattering condition) and increases as visibility is degraded.

3.10 Should outliers in the data be excluded?

Each annual estimate of best and worst days should be based on all valid measured aerosol concentrations during the calendar year. This includes high concentrations associated with regional forest fires or other unusual events. An analysis of IMPROVE data collected during 1994-1998 revealed that the difference in calculated 5-year mean visibility impairment (in deciviews) caused by excluding outliers (measurements greater than 2 standard deviations from the mean) ranged from 0.4% (Great Smoky Mountains) to 3.4% (Point Reyes). Thus the impact from a small number of days tends to average out when the visibility is examined on a deciview scale over a 5-year period. It is important to include these extreme concentrations in the estimates for 5-year baseline and current visibility conditions, because the impact from these events may be part of natural background and is thus reflected in the estimate for the target visibility levels. When an outlier in the data is clearly not representative of the regional haze levels, the result should be flagged and an explanation provided of the cause of the outlier. If a very localized fire (for example, a nearby structural fire) severely impacts the loading of a specific sampler but does not degrade the visibility outside of the immediate vicinity (e.g., within 1 mile), the data should be flagged in all data files and calculations. Such occurrences may not be appropriate for inclusion in visibility trends analysis. On the other hand, events which result in apparent outliers in the data and do have an impact on the regional visibility (e.g., forest fires) should be included in subsequent trends analysis. The data should be flagged and explained if possible, but should remain in the data set. Any supporting evidence which may be used to help quantify the impact of the episode causing the outlier should be collected, if possible.

4. PROCEDURES FOR COMPARING FIVE-YEAR PERIODS

4.1 How are the daily deciview values, calculated as described in Section 3, used to track progress in improving visibility?

The daily deciview values from the best and worst days in each year are first selected, then averaged over annual and five-year periods, and finally those five-year averages are compared to assess progress. This section of the guidance document describes the procedures for carrying out this process.

4.2 How are the selection and averaging of the best and worst days in each year done?

Once the daily deciview values have been calculated for each sampling day at a site, including those days for which missing data were replaced by appropriate averages, the deciview values for each year are ranked from lowest to highest. Then the lowest 20% of the deciview values for the year (i.e., the best 20% of the days in terms of visibility) are averaged, to produce an annual average deciview value for the best 20% of the days. Similarly, the highest 20% of the deciview values for the year (i.e., the worst 20% of the days in terms of visibility) are averaged, giving the annual average deciview value for the worst 20% of the days. A description of the methods used to calculate percentiles can be found in 40 CFR 50, Appendix N.

This process should be repeated for each year of data available. Note that the data completeness recommendations stated earlier in this document may eliminate some years from being included in this calculation. For each complete year of data for a site, the results of this calculation are two values, i.e., the average deciview values for the best and worst days, respectively.

4.3 How are the five-year deciview averages determined?

The annual average deciview values for the 20% best and 20% worst visibility days in each year are further averaged over the five-year periods specified in the regional haze rule. For example, the baseline five-year period is 2000-2004. The annual average deciview values for the 20% best days in each year in that period are averaged together, producing a single average deciview value for the best days. Similarly, the annual average deciview values for the 20% worst days in each year in that period are averaged together, producing a single average deciview value for the worst days. Thus each five-year period is characterized by two values, i.e., the average deciview values for the best and worst days, respectively. These averages over the 2000-2004 time period are the basis against which improvements in visibility are judged. Corresponding averages are to be calculated over successive five-year periods, i.e., 2005-2009, 2010-2014, etc.

Within any specified five-year period, there should be at least three complete years of data from which annual averages are drawn for this calculation of five-year averages. If a five-year period has less than three complete years of data, then estimates should be prepared through consultation with EPA/OAQPS..

4.4 What is the nature of the comparison between five-year average deciview values?

The comparison should be a simple arithmetic comparison of the current five-year average deciview values to those from the baseline (i.e., 2000-2004) period. The five-year average deciview values for the 20% worst days are compared to judge progress in improving visibility, and the five-year average deciview values for the 20% best days are compared to check whether any degradation of visibility on the best days has occurred. The first such SIP comparison will take place in 2018, with an interim progress check in 2013.

4.5 What if siting or procedural changes are implemented at an IMPROVE site?

If siting or procedural changes that may affect the monitoring data at a site occur, care must be taken to ensure the comparability of the monitoring data before and after the change is implemented. When possible, the monitoring agency should conduct comparative sampling adequate to demonstrate data comparability.

4.6 What if changes are made in the sites selected to cover a mandatory Federal Class I area?

Currently, all mandatory Federal Class I areas are covered by at least one IMPROVE monitoring site. The sites chosen to represent the different mandatory Federal Class I areas were chosen in consultation between EPA and the States. If a different site or additional sites are selected to represent a given mandatory Federal Class I area, the calculations presented in this document for trends assessment must be performed using the data from the newly selected monitoring site(s).

4.7 Are trends in the individual species important, as well as the overall trend in visibility?

Trends in individual particle species that are important contributors to haze should be tracked. Progress in improving visibility may be stated in a SIP in terms of reductions in species concentrations, as well as in terms of visibility. For example, if sulfate is the dominant cause of light extinction in a mandatory Federal Class I area, the SIP may focus on planned reductions in sources of sulfate, and trends in sulfate concentrations should be tracked as an indication of the effectiveness of emissions reductions.

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6. APPENDIX A

Monthly Site-Specific *f(RH)* Values for Each Mandatory Federal Class I Area

Origin of Relative Humidity and f(RH) Values

In terms of visibility reduction caused by fine particles, it is appropriate to treat relative humidity differently for different objectives. If the objective is the most reliable short-term estimate of visibility, then the measured or estimated relative humidity for the specific time and location of the aerosol speciation data is most appropriate. On the other hand, if the objective is to assess the long-term changes in manmade visibility impairment, it is appropriate to use relative humidity that is the same for the baseline period and future periods. In other words, it is more appropriate to eliminate the confounding effects of varying relative humidity, if the purpose is to track the visibility effects of air pollution emissions over extended time periods.

A number of approaches were considered to prevent variations in the relative humidity adjustment factor from confounding efforts to track progress related to emission controls. The simplest approach would use the same typical or overall average adjustment factor for all class I areas at all times. However, this would enhance the contributions of hygroscopic particle species in dry locations and during typically dry seasons above what they truly should be, while reducing their contributions in moist locations and seasons. Such distortions of the contributions to haze by hygroscopic particle species are unnecessary if a set of Class I area-specific adjustment factors are used that reflect seasonal changes in relative humidity.

A second approach would be to review relative humidity data over a long period of time to derive climatological estimates for relative humidity adjustment factors. These climatological estimates would then be used to estimate visibility extinction coefficients. These estimates are more likely to reflect “typical” relative humidity at the different mandatory Federal Class I areas during different times of year and, thus, are more likely to be more appropriate for establishing trends in visibility at the mandatory Federal Class I areas.

Recently, the U.S. EPA sponsored a project to examine measured hourly relative humidity data over a 10-year period within the United States, to derive month-specific climatological mean humidity correction factors for each mandatory Federal Class I area.[1] The results of that work are presented in the table below. These relative humidity factors have been calculated from available hourly relative humidity data from 292 National Weather Service stations across the 50 states and District of Columbia as well as from 25 IMPROVE and IMPROVE protocol monitor sites, 46 CASTNet sites, and 12 additional sites administered by the National Park Service.

The hourly RH measurements from each site were converted to *f(RH)* values using a non-linear weighting factor curve, based on a modified ammonium sulfate growth curve. For days in which at least 16 hours of valid RH data were available, daily averages were determined from these hourly *f(RH)* values at each site. Monthly averages were then calculated from the daily *f(RH)* averages at each site.

The monthly average *f(RH)* values were interpolated at 1/4-degree increments using the inverse distance weighting technique (with a distance interpolation exponent of 1):

$$f(RH)_g = \frac{\sum f(RH)_w / x_{wg}}{\sum 1 / x_{wg}}$$

where the monthly $f(RH)_g$ of the grid cell is calculated from $f(RH)_w$ at the weather station, and the horizontal distance between the grid cell center and the weather station, x_{wg}, summed over all the weather stations within a 250-mile radius with valid *f(RH)* values for that month.

In most regions there is a seasonal cycle of relative humidity which is accounted for by this process of appropriate *f(RH)* values for each month of the year from the daily-averaged values. Thus, the 12 monthly-averaged *f(RH)* values determined in this way for each Class I area

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[1] U.S. EPA, *Interpolating Relative Humidity Weighting Factors to Calculate Visibility Impairment and the Effects of IMPROVE Monitor Outliers*, prepared by Systems Application International Corporation, Raleigh, NC, EPA Contract No. 68-D-98-113, August 30, 2001.

should be used for all aerosol speciation data or model predictions for that location. However, a more complicated approach has also been investigated, as described below..

The regional haze regulation requires separate tracking of visibility changes for the worst 20% and best 20% of visibility days. If there is a significant correlation in any month at any site between daily relative humidity and the sulfate or nitrate concentrations, then use of the monthly-averaged *f(RH)* will systematically over- or under-predict the contribution to visibility impairment of the aerosol species. Fortunately, this concern can be tested at a number of locations in all regions of the country using the IMPROVE database. If the use of monthly-averaged values were found to cause large systematic biases in any region of the country, the Class I areas in those regions would require two *f(RH)* values for each month. One value would be the average *f(RH)* associated with relative humidity conditions that correspond to the worst 20% and the other value associated with relative humidity conditions that correspond to the best 20% of the light extinction values. Therefore there is the potential that some Class I area locations could require up to 24 *f(RH)* values for use in calculating extinction for aerosol data.

The U.S. National Park Service has tested this possibility, by examining data for each of the 12 months from 20 mandatory Federal Class I areas where relative humidity measurements are made. In nearly all cases, no statistically significant correlations were found between measured concentrations of SO_4^{2-}, NO_3^- and $[SO_4^{2-} + NO_3^-]$ vs. daily values of relative humidity in a large majority of months. Furthermore, deciview calculations were made using day-specific vs. climatological values for the relative humidity adjustment factor for each of 10 years in 15 mandatory Federal Class I areas. In 14 of the 15 areas, little if any difference was observed in the year to year calculations for the mean deciview values for the 20% worst and 20% best days, nor was there any difference in the trends. Some difference in the mean deciview value for the worst 20% days was observed in one mandatory Federal Class I area. However, the overall trend in the mean worst and best deciview values for this site was similar using the two types of *f(rh)* values. These results suggest there is a relatively weak correlation between hygroscopic components of PM and relative humidity and that the choice of a “climatological” vs. “day-specific” method for computing *f(RH)* has little apparent effect on observed trends in visibility. Consequently, the simpler climatological approach is used in regional haze calculations.

Appendix A. Monthly Site-Specific *f(RH)* Values for Each Mandatory Federal Class I Area

Class 1 Area	ST	Jan. f(RH)	Feb. f(RH)	Mar. f(RH)	Apr. f(RH)	May f(RH)	June f(RH)	July f(RH)	Aug. f(RH)	Sep. f(RH)	Oct. f(RH)	Nov. f(RH)	Dec. f(RH)
Acadia NP	ME	3.26	2.94	2.84	3.37	3.11	2.98	3.41	3.83	4.04	3.82	3.56	3.53
Agua Tibia Wilderness	CA	2.39	2.38	2.40	2.22	2.22	2.18	2.28	2.29	2.32	2.29	2.10	2.16
Alpine Lakes Wilderness	WA	4.25	3.79	3.47	3.90	2.93	3.22	2.92	3.12	3.25	3.91	4.47	4.51
Anaconda-Pintler Wilderness	MT	3.32	2.88	2.54	2.35	2.36	2.31	1.96	1.88	2.10	2.52	3.15	3.29
Arches NP	UT	2.62	2.34	1.80	1.64	1.55	1.31	1.36	1.53	1.60	1.64	2.04	2.34
Badlands NM	SD	2.64	2.66	2.57	2.42	2.80	2.69	2.49	2.42	2.24	2.26	2.72	2.72
Bandelier NM	NM	2.23	2.10	1.78	1.60	1.59	1.44	1.73	2.08	1.90	1.65	1.96	2.16
Bering Sea Wilderness	AK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Big Bend NP	TX	2.00	1.86	1.61	1.52	1.63	1.58	1.69	1.96	2.13	1.86	1.84	1.91
Black Canyon of Gunnison NP	CO	2.38	2.22	1.93	1.89	1.87	1.61	1.68	1.94	1.97	1.77	2.13	2.25
Bob Marshall Wilderness	MT	3.57	3.10	2.77	2.59	2.66	2.70	2.34	2.23	2.58	2.92	3.47	3.54
Bosque del Apache Wilderness	NM	2.11	1.93	1.57	1.38	1.39	1.28	1.75	1.96	1.86	1.60	1.80	2.15
Boundary Waters Canoe Area	MN	2.98	2.59	2.68	2.35	2.31	2.87	3.11	3.36	3.51	2.78	3.20	3.19
Breton Wilderness	LA	3.74	3.54	3.65	3.62	3.83	4.03	4.30	4.33	4.15	3.71	3.67	3.71
Bridger Wilderness in Bridger-Teton Forest	WY	2.52	2.35	2.34	2.19	2.10	1.80	1.50	1.49	1.74	2.00	2.44	2.42
Brigantine Div. Of Forsythe NWR	NJ	2.83	2.64	2.73	2.60	3.03	3.16	3.44	3.72	3.64	3.34	2.85	2.83
Bryce Canyon NP	UT	2.62	2.38	1.93	1.62	1.50	1.30	1.31	1.51	1.51	1.61	2.00	2.39
Cabinet Mountains Wilderness	MT	3.81	3.27	2.85	2.61	2.66	2.68	2.30	2.18	2.56	2.98	3.70	3.86
Caney Creek Wilderness	AR	3.42	3.09	2.85	3.01	3.56	3.57	3.44	3.43	3.63	3.49	3.38	3.51
Canyonlands NP	UT	2.60	2.32	1.72	1.57	1.47	1.22	1.30	1.45	1.55	1.61	1.98	2.28
Cape Romain NWR	SC	3.25	2.95	2.87	2.84	3.16	3.67	3.64	4.06	4.02	3.68	3.35	3.19
Capitol Reef NP	UT	2.70	2.44	1.95	1.71	1.60	1.36	1.37	1.56	1.62	1.68	2.12	2.46
Caribou Wilderness	CA	3.69	3.13	2.83	2.45	2.37	2.17	2.07	2.13	2.20	2.38	3.01	3.41
Carlsbad Caverns NP	NM	2.05	1.96	1.59	1.54	1.64	1.56	1.83	2.07	2.20	1.83	1.90	2.14
Chassahowitzka NWR	FL	3.82	3.47	3.39	3.22	3.29	3.87	3.89	4.18	4.12	3.88	3.68	3.88
Chiricahua NM	AZ	2.02	1.95	1.59	1.25	1.26	1.14	1.82	2.09	1.79	1.47	1.63	2.17

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Class 1 Area	**ST**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**	**f(RH)**
Chiricahua Wilderness	AZ	1.99	1.91	1.57	1.23	1.25	1.14	1.81	2.07	1.78	1.46	1.62	2.15
Cohutta Wilderness	GA	3.34	3.09	2.95	2.77	3.35	3.80	3.99	4.19	4.22	3.79	3.36	3.46
Crater Lake NP	OR	4.57	3.92	3.68	3.36	3.22	2.99	2.84	2.87	3.05	3.59	4.57	4.56
Craters of the Moon Wilderness	ID	3.13	2.74	2.28	2.02	2.01	1.81	1.43	1.42	1.57	1.97	2.77	3.04
Cucamonga Wilderness	CA	2.51	2.44	2.39	2.16	2.12	2.07	2.14	2.15	2.16	2.19	2.08	2.20
Denali NP	AK	2.52	2.33	2.09	1.90	1.87	2.15	2.53	2.99	2.82	2.93	3.02	3.10
Desolation Wilderness	CA	3.22	2.77	2.39	2.01	1.84	1.63	1.52	1.57	1.65	1.86	2.40	2.95
Diamond Peak Wilderness	OR	4.52	3.96	3.64	3.66	3.16	3.12	2.90	2.93	3.05	3.67	4.55	4.57
Dolly Sods Wilderness	WV	2.98	2.79	2.81	2.56	3.12	3.39	3.54	3.87	3.85	3.27	2.97	3.10
Dome Land Wilderness	CA	2.47	2.29	2.18	1.93	1.84	1.77	1.79	1.82	1.81	1.89	1.96	2.16
Eagle Cap Wilderness	OR	3.77	3.16	2.47	2.10	2.04	1.87	1.61	1.56	1.61	2.25	3.44	3.97
Eagles Nest Wilderness	CO	2.17	2.17	1.99	2.04	2.13	1.89	1.83	2.04	2.03	1.85	2.14	2.12
Emigrant Wilderness	CA	3.20	2.82	2.52	2.11	1.92	1.68	1.54	1.57	1.59	1.85	2.37	2.85
Everglades NP	FL	2.74	2.57	2.55	2.40	2.36	2.74	2.61	2.89	2.98	2.78	2.60	2.68
Fitzpatrick Wilderness	WY	2.51	2.33	2.24	2.13	2.09	1.80	1.51	1.46	1.73	1.98	2.39	2.44
Flat Tops Wilderness	CO	2.31	2.19	1.99	2.00	2.02	1.76	1.68	1.85	1.94	1.83	2.15	2.20
Galiuro Wilderness	AZ	1.95	1.80	1.54	1.22	1.20	1.10	1.54	1.84	1.63	1.46	1.64	2.10
Gates of the Mountain Wilderness	MT	2.89	2.57	2.42	2.30	2.30	2.27	2.03	1.94	2.12	2.41	2.75	2.81
Gearhart Mountain Wilderness	OR	3.96	3.38	3.06	2.75	2.65	2.48	2.28	2.30	2.38	2.84	3.65	3.84
Gila Wilderness	NM	2.07	1.93	1.59	1.32	1.35	1.22	2.08	1.96	1.80	1.56	1.76	2.17
Glacier NP	MT	4.01	3.47	3.18	3.06	3.24	3.39	2.76	2.60	3.19	3.45	3.82	3.89
Glacier Peak Wilderness	WA	4.16	3.72	3.42	3.75	2.91	3.16	2.88	3.14	3.33	3.90	4.42	4.43
Goat Rocks Wilderness	WA	4.25	3.75	3.36	4.24	2.83	3.38	3.03	3.19	3.07	3.77	4.42	4.55
Grand Canyon NP	AZ	2.37	2.33	1.91	1.49	1.40	1.18	1.42	1.71	1.62	1.59	1.85	2.25
Grand Teton NP	WY	2.62	2.39	2.24	2.10	2.06	1.79	1.52	1.47	1.72	2.00	2.43	2.55
Great Gulf Wilderness	NH	2.78	2.56	2.58	2.77	2.93	3.22	3.49	3.81	3.98	3.42	3.06	2.92
Great Sand Dunes NM	CO	2.42	2.29	2.01	1.89	1.89	1.75	1.88	2.33	2.19	1.86	2.38	2.38
Great Smoky Mtns. NP	TN	3.31	3.04	2.91	2.70	3.17	3.86	3.82	3.96	4.24	3.77	3.29	3.44
Guadalupe Mountains NP	TX	1.96	1.95	1.58	1.48	1.55	1.52	1.87	2.15	2.17	1.78	1.91	2.21
Haleakala NP	HI	2.74	2.60	2.60	2.54	2.39	2.34	2.48	2.43	2.39	2.53	2.76	2.70

Class 1 Area	**ST**	**Jan. f(RH)**	**Feb. f(RH)**	**Mar. f(RH)**	**Apr. f(RH)**	**May f(RH)**	**June f(RH)**	**July f(RH)**	**Aug. f(RH)**	**Sep. f(RH)**	**Oct. f(RH)**	**Nov. f(RH)**	**Dec. f(RH)**
Hawaii Volcanoes NP	HI	3.22	2.93	2.97	2.96	2.95	2.92	3.09	3.24	3.18	3.24	3.66	3.18
Hells Canyon Wilderness	ID	3.70	3.12	2.51	2.17	2.12	2.00	1.63	1.58	1.79	2.41	3.45	3.87
Hercules-Glades Wilderness	MO	3.22	2.92	2.67	2.71	3.25	3.28	3.28	3.33	3.44	3.08	3.11	3.25
Hoover Wilderness	CA	3.13	2.76	2.46	2.06	1.87	1.64	1.50	1.53	1.55	1.80	2.32	2.80
Isle Royale NP	MI	3.05	2.54	2.67	2.37	2.21	2.58	3.00	3.16	3.78	2.71	3.34	3.30
James River Face Wilderness	VA	2.83	2.64	2.66	2.43	2.98	3.28	3.39	3.67	3.64	3.15	2.81	2.96
Jarbridge Wilderness	NV	2.95	2.60	2.08	2.12	2.21	2.17	1.58	1.40	1.35	1.63	2.44	2.80
John Muir Wilderness	CA	2.93	2.64	2.42	2.06	1.89	1.72	1.65	1.69	1.71	1.89	2.23	2.60
Joshua Tree NP	CA	2.35	2.30	2.24	2.02	1.99	1.91	1.97	2.00	2.03	2.02	1.91	2.04
Joyce Kilmer-Slickrock Wilderness	NC	3.34	3.07	2.94	2.73	3.30	3.79	3.96	4.18	4.23	3.78	3.32	3.46
Kaiser Wilderness	CA	3.00	2.68	2.45	2.08	1.89	1.72	1.64	1.67	1.69	1.89	2.27	2.67
Kalmiopsis Wilderness	OR	4.54	3.90	3.83	3.45	3.46	3.32	3.20	3.20	3.29	3.56	4.39	4.32
Kings Canyon NP	CA	2.79	2.55	2.42	2.11	1.89	1.76	1.69	1.70	1.75	1.91	2.27	2.51
La Garita Wilderness	CO	2.34	2.20	1.91	1.80	1.79	1.60	1.73	2.08	2.01	1.76	2.17	2.26
Lassen Volcanic NP	CA	3.81	3.19	2.91	2.53	2.42	2.19	2.09	2.14	2.23	2.43	3.13	3.53
Lava Beds Wilderness	CA	3.98	3.36	3.07	2.70	2.62	2.43	2.31	2.34	2.42	2.72	3.52	3.81
Linville Gorge Wilderness	NC	3.26	3.01	2.95	2.68	3.33	3.93	4.07	4.52	4.38	3.69	3.23	3.36
Lostwood Wilderness	ND	2.99	2.89	2.90	2.32	2.27	2.64	2.68	2.36	2.28	2.36	3.24	3.21
Lye Brook Wilderness	VT	2.74	2.56	2.61	2.59	2.82	3.03	3.27	3.56	3.66	3.25	2.93	2.83
Mammoth Cave NP	KY	3.36	3.10	2.94	2.64	3.23	3.52	3.66	3.88	3.90	3.44	3.17	3.47
Marble Mountain Wilderness	CA	4.44	3.79	3.74	3.33	3.37	3.24	3.18	3.19	3.24	3.37	4.12	4.15
Maroon Bells-Snowmass Wilderness	CO	2.17	2.14	1.95	2.03	2.05	1.72	1.86	2.16	2.12	1.82	2.09	2.08
Mazatzal Wilderness	AZ	2.07	1.94	1.65	1.31	1.26	1.12	1.46	1.73	1.58	1.48	1.68	2.09
Medicine Lake Wilderness	MT	3.02	2.90	2.87	2.26	2.23	2.48	2.50	2.22	2.23	2.35	3.16	3.17
Mesa Verde NP	CO	2.45	2.28	1.87	1.52	1.47	1.33	1.60	1.98	1.89	1.66	2.11	2.34
Minarets (in Ansel Adams Wilderness)	CA	3.01	2.69	2.44	2.06	1.88	1.69	1.58	1.61	1.62	1.84	2.25	2.68
Mingo Wilderness	MO	3.29	3.04	2.77	2.64	3.04	3.18	3.29	3.46	3.48	3.12	3.09	3.28
Mission Mountain Wilderness	MT	3.60	3.13	2.73	2.52	2.60	2.62	2.27	2.19	2.50	2.87	3.51	3.59
Mokelumne Wilderness	CA	3.21	2.78	2.42	2.04	1.86	1.64	1.53	1.58	1.66	1.86	2.39	2.93
Moosehorn NWR	ME	2.97	2.69	2.66	3.01	2.96	3.10	3.41	3.80	3.91	3.54	3.24	3.20
Mount Adams Wilderness	WA	4.29	3.80	3.44	4.40	2.92	3.49	3.12	3.27	3.13	3.86	4.49	4.56

Class 1 Area	ST	Jan. f(RH)	Feb. f(RH)	Mar. f(RH)	Apr. f(RH)	May f(RH)	June f(RH)	July f(RH)	Aug. f(RH)	Sep. f(RH)	Oct. f(RH)	Nov. f(RH)	Dec. f(RH)
Mount Baldy Wilderness	AZ	2.18	2.04	1.69	1.36	1.32	1.18	1.60	1.89	1.71	1.56	1.81	2.21
Mount Hood Wilderness	OR	4.29	3.81	3.46	3.87	2.95	3.15	2.85	3.00	3.10	3.86	4.53	4.55
Mount Jefferson Wilderness	OR	4.41	3.90	3.56	3.74	3.07	3.11	2.89	2.91	3.03	3.78	4.55	4.54
Mount Rainier NP	WA	4.42	3.96	3.64	4.65	3.06	3.69	3.30	3.50	3.40	4.11	4.66	4.66
Mount Washington Wilderness	OR	4.44	3.93	3.58	3.73	3.09	3.11	2.98	2.91	3.02	3.76	4.56	4.56
Mount Zirkel Wilderness	CO	2.18	2.17	2.02	2.09	2.17	1.92	1.74	1.86	1.95	1.87	2.14	2.11
Mountain Lakes Wilderness	OR	4.29	3.62	3.32	2.98	2.86	2.64	2.49	2.50	2.64	3.10	4.12	4.26
North Absaroka Wilderness	WY	2.43	2.27	2.24	2.17	2.14	1.93	1.69	1.56	1.76	2.04	2.35	2.40
North Cascades NP	WA	4.10	3.69	3.43	3.74	2.93	3.20	2.93	3.23	3.45	3.93	4.39	4.38
Okefenokee NWR	GA	3.48	3.19	3.11	3.03	3.55	3.73	3.73	4.05	4.01	3.75	3.52	3.58
Olympic NP	WA	4.51	4.08	3.82	4.08	3.17	3.46	3.12	3.48	3.71	4.38	4.83	4.75
Otter Creek Wilderness	WV	2.97	2.79	2.82	2.57	3.18	3.50	3.69	4.06	3.96	3.32	2.99	3.14
Pasayten Wilderness	WA	4.17	3.72	3.41	3.72	2.89	3.16	2.88	3.15	3.32	3.86	4.42	4.46
Pecos Wilderness	NM	2.25	2.10	1.79	1.66	1.67	1.52	1.77	2.12	2.00	1.71	2.04	2.21
Petrified Forest NP	AZ	2.38	2.20	1.72	1.40	1.33	1.20	1.52	1.82	1.66	1.58	1.94	2.30
Pine Mountain Wilderness	AZ	2.15	2.03	1.73	1.36	1.30	1.14	1.44	1.75	1.60	1.52	1.73	2.12
Pinnacles NM	CA	3.16	2.84	2.64	2.44	2.27	2.03	2.03	2.11	2.09	2.26	2.48	2.87
Point Reyes NS	CA	3.63	3.25	3.05	2.66	2.53	2.33	2.48	2.57	2.62	2.65	2.94	3.27
Pres. Range-Dry River Wilderness	NH	2.83	2.59	2.60	2.83	3.04	3.38	3.67	4.00	4.26	3.54	3.14	2.96
Rawah Wilderness	CO	2.05	2.12	2.01	2.14	2.26	2.03	1.84	1.97	1.99	1.88	2.09	2.02
Red Rock Lakes Wilderness	MT	2.73	2.46	2.28	2.12	2.10	1.91	1.67	1.58	1.77	2.07	2.56	2.68
Redwood NP	CA	4.42	3.91	4.56	3.91	4.50	4.70	4.86	4.72	4.31	3.66	3.81	3.40
Rocky Mountain NP	CO	1.70	1.90	1.90	2.13	2.26	2.04	1.82	1.96	1.87	1.80	1.84	1.70
Roosevelt Campobello IP	NB	2.99	2.70	2.65	3.03	2.96	3.09	3.40	3.80	3.91	3.54	3.26	3.22
Saguaro Wilderness	AZ	1.80	1.63	1.43	1.13	1.12	1.05	1.41	1.77	1.55	1.41	1.56	2.05
Salt Creek Wilderness	NM	2.12	1.92	1.53	1.53	1.67	1.56	1.76	1.97	2.12	1.75	1.81	2.06
San Gabriel Wilderness	CA	2.53	2.46	2.42	2.19	2.16	2.12	2.20	2.21	2.23	2.26	2.12	2.23
San Gorgonio Wilderness	CA	2.73	2.77	2.56	2.26	2.19	1.86	1.80	1.85	1.88	1.92	1.93	2.15
San Jacinto Wilderness	CA	2.45	2.42	2.37	2.15	2.12	2.02	2.08	2.11	2.12	2.12	2.00	2.11
San Pedro Parks Wilderness	NM	2.32	2.14	1.79	1.62	1.59	1.43	1.69	2.02	1.91	1.68	2.05	2.24
San Rafael Wilderness	CA	2.83	2.67	2.65	2.36	2.33	2.32	2.45	2.52	2.43	2.50	2.32	2.50

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Sawtooth Wilderness	ID	3.34	2.87	2.32	2.01	2.00	1.84	1.43	1.40	1.50	1.96	2.94	3.31
Scapegoat Wilderness	MT	3.19	2.81	2.57	2.43	2.45	2.44	2.14	2.04	2.28	2.61	3.08	3.14
Selway-Bitterroot Wilderness	ID	3.50	3.02	2.59	2.34	2.36	2.31	1.93	1.86	2.09	2.55	3.30	3.50
Seney Wilderness	MI	3.34	2.84	2.92	2.67	2.64	3.08	3.56	4.03	4.06	3.43	3.59	3.51
Sequoia NP	CA	2.53	2.41	2.43	2.23	1.92	1.79	1.66	1.63	1.75	1.89	2.33	2.29
Shenandoah NP	VA	3.07	2.83	2.79	2.53	3.05	3.41	3.54	3.93	3.85	3.21	2.95	3.07
Shining Rock Wilderness	NC	3.28	3.02	2.94	2.71	3.37	3.87	4.09	4.46	4.37	3.76	3.30	3.39
Sierra Ancha Wilderness	AZ	2.10	1.97	1.67	1.32	1.27	1.14	1.51	1.79	1.62	1.51	1.72	2.13
Simeonof Wilderness	AK	4.26	4.08	3.64	3.88	3.91	4.33	5.01	5.18	4.54	3.80	4.02	4.33
Sipsey Wilderness	AL	3.36	3.09	2.88	2.80	3.28	3.66	3.88	3.90	3.92	3.59	3.27	3.44
South Warner Wilderness	CA	3.62	3.08	2.72	2.35	2.29	2.12	1.90	1.92	1.97	2.30	3.05	3.44
St Marks Wilderness	FL	3.73	3.42	3.42	3.37	3.51	4.00	4.13	4.38	4.17	3.81	3.71	3.80
Strawberry Mountain Wilderness	OR	3.89	3.33	2.75	2.93	2.27	2.39	1.98	1.97	1.87	2.63	3.69	4.07
Superstition Wilderness	AZ	2.05	1.92	1.63	1.29	1.25	1.12	1.48	1.74	1.58	1.47	1.68	2.09
Swanquarter Wilderness	NC	2.90	2.70	2.64	2.50	2.87	3.20	3.35	3.51	3.35	3.14	2.82	2.86
Sycamore Canyon Wilderness	AZ	2.35	2.30	2.24	2.02	1.99	1.91	1.97	2.00	2.03	2.02	1.91	2.04
Teton Wilderness	WY	2.53	2.35	2.24	2.12	2.10	1.85	1.59	1.51	1.74	2.02	2.40	2.48
Theodore Roosevelt NP	ND	2.86	2.75	2.76	2.33	2.30	2.48	2.42	2.15	2.16	2.32	3.01	2.99
Thousand Lakes Wilderness	CA	3.81	3.19	2.91	2.53	2.42	2.19	2.09	2.14	2.23	2.43	3.13	3.53
Three Sisters Wilderness	OR	4.47	3.95	3.61	3.72	3.11	3.11	3.00	2.91	3.03	3.79	4.60	4.57
Tuxedni Wilderness	AK	3.53	3.31	2.85	2.74	2.68	2.85	3.55	4.00	3.91	3.50	3.53	3.66
UL Bend Wilderness	MT	2.71	2.52	2.50	2.28	2.19	2.18	2.01	1.79	1.90	2.20	2.66	2.68
Upper Buffalo Wilderness	AR	3.30	2.97	2.72	2.83	3.39	3.43	3.39	3.39	3.58	3.30	3.22	3.34
Ventana Wilderness	CA	3.21	2.91	2.76	2.44	2.28	2.10	2.16	2.25	2.24	2.39	2.54	2.90
Virgin Islands NP (a)	VI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Voyageurs NP	MN	2.79	2.40	2.37	2.27	2.26	3.07	2.66	2.96	3.17	2.60	2.92	2.80
Washakie Wilderness	WY	2.50	2.34	2.23	2.12	2.11	1.84	1.56	1.49	1.75	2.00	2.38	2.46
Weminuche Wilderness	CO	2.38	2.21	1.85	1.68	1.65	1.46	1.63	1.97	1.92	1.71	2.12	2.28
West Elk Wilderness	CO	2.25	2.17	1.93	1.92	1.93	1.65	1.77	2.07	2.04	1.79	2.11	2.16
Wheeler Peak Wilderness	NM	2.34	2.17	1.87	1.75	1.78	1.62	1.79	2.19	2.09	1.77	2.18	2.30
White Mountain Wilderness	NM	2.09	1.93	1.57	1.45	1.50	1.40	1.79	2.01	2.02	1.69	1.81	2.12

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Wichita Mountains Wilderness	OK	2.72	2.56	2.40	2.44	2.98	2.70	2.32	2.53	2.90	2.62	2.66	2.78
Wind Cave NP	SD	2.52	2.50	2.45	2.45	2.70	2.54	2.28	2.25	2.17	2.22	2.60	2.55
Wolf Island Wilderness	GA	3.40	3.13	3.05	2.99	3.25	3.69	3.71	4.09	4.04	3.74	3.51	3.48
Yellowstone NP	WY	2.54	2.36	2.27	2.16	2.15	1.94	1.69	1.59	1.79	2.08	2.45	2.51
Yolla Bolly Middle Eel Wilderness	CA	3.95	3.35	3.14	2.76	2.68	2.47	2.44	2.50	2.56	2.70	3.31	3.62
Yosemite NP	CA	3.28	3.02	2.78	2.30	2.09	1.75	1.48	1.47	1.52	1.84	2.36	2.80
Zion NP	UT	2.65	2.42	1.97	1.62	1.50	1.29	1.24	1.41	1.43	1.57	1.98	2.41

a: *f(RH)* values for Virgin Islands National Park were not calculated because of the limited RH data available.