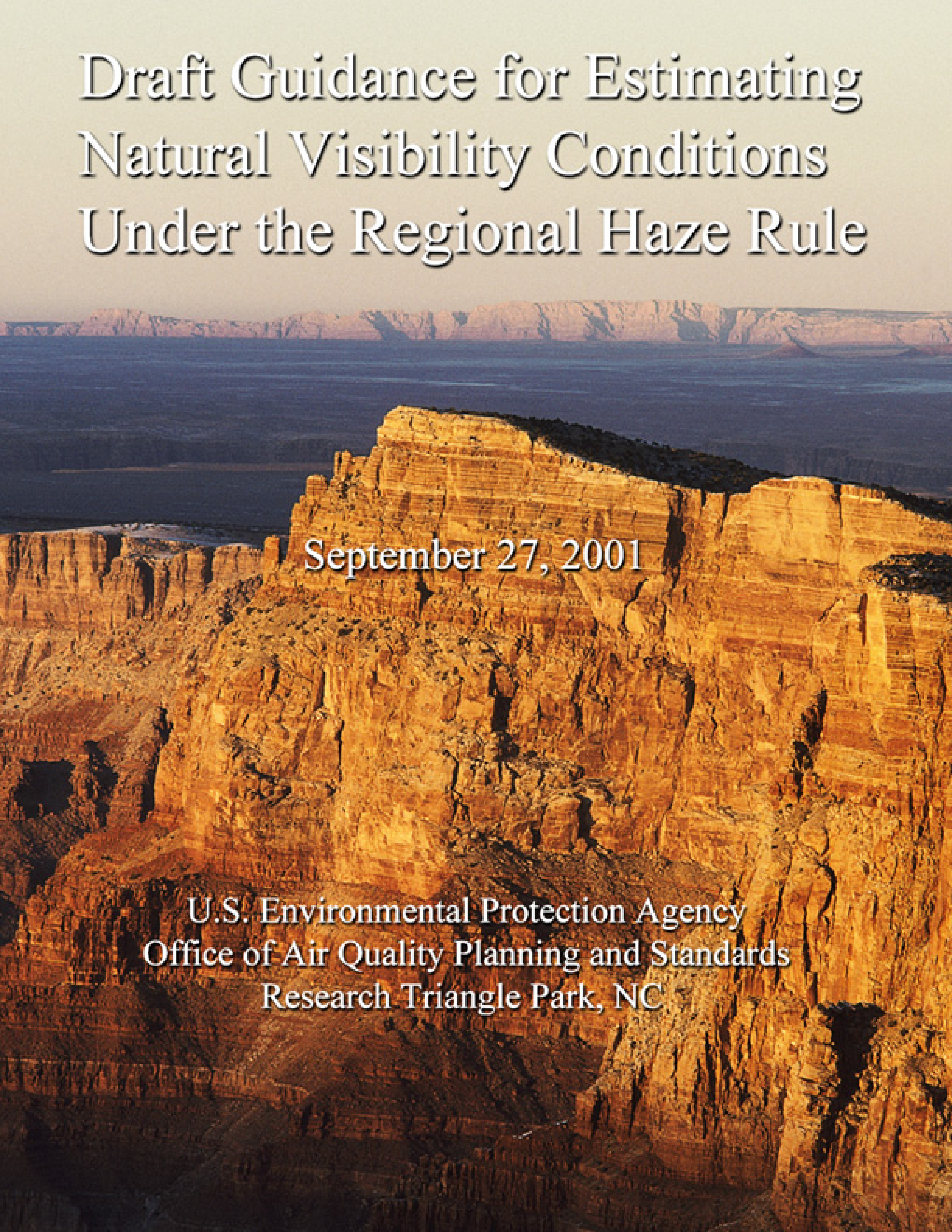

Draft Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule

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

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Abbreviations and Acronyms

b_{ext} - Total light extinction

CAA – Clean Air Act

CAAA – 1990 Clean Air Act Amendments

CASTNet - Clean Air Status and Trends Network

CM - Coarse mass

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

EPA – United States Environmental Protection Agency

f(RH) – Relative humidity adjustment factor

IMPROVE – Interagency Monitoring of PROtected Visual Environments

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

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

NAAQS – National Ambient Air Quality Standards

NWS - National Weather Service

OC - Organic carbon

OMC - Organic carbon mass

OP - Pyrolized organics

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

SIP – State Implementation Plan

TOR - Thermal optical reflectance

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*) – A measure of visibility derived from calculated light extinction measurements so that uniform changes in haziness correspond to uniform incremental changes in visual perception across the entire range of conditions, from pristine to highly impaired. The deciview haze index is calculated directly from the total light extinction (b_{ext} expressed in inverse megameters [Mm^{-1}]):

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

Default approach - The basic approach recommended by EPA to estimate the natural visibility conditions. States are welcome to adopt the default values for natural visibility conditions or, with sufficient technical justification, to propose alternatives to the basic approach or to generate refined estimates. In the absence of any refinement, EPA recommends that the default values that are provided in this document be adopted.

Default values - the values obtained from adopting the default approach to estimating natural visibility conditions.

Elemental carbon – Often referred to as soot or light-absorbing carbon. 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.

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 coefficient refers to the absorption and scattering by aerosols, and the total light extinction coefficient refers to the sum of the aerosol light extinction coefficient, the absorption coefficient of gases (such as NO_2), and the atmospheric light extinction coefficient due to molecular light scattering (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 Class I areas.

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

Nitrate – Solid or liquid particulate matter containing ammonium nitrate [NH_4NO_3] or other nitrate salts. 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 context of this report).

Rayleigh scattering – Light scattering by 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 – The partial pressure of water vapor at the existing atmospheric temperature divided by the vapor pressure of water at that temperature, expressed as a percentage.

Soil – Particulate matter composed of material from the earth's crust, 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 [$(NH_4)_2SO_4$], or other sulfate salts. 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 conditions (e.g., light extinction, visual range, deciview, contrast, coloration) from that which would have existed under natural conditions.

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 the scattering and absorption processes is a reduction of the amount of light from a scene that is returned to the observer, and scattering of other light into the sight path, creating a hazy condition.

The primary cause of regional haze in many parts of the country is light scattering resulting from fine particles (i.e., particulate matter less than 2.5 microns in diameter, referred to as $PM_{2.5}$) in the atmosphere. These fine particles can contain a variety of chemical species including carbonaceous species (i.e., organics, and elemental carbon), as well as ammonium nitrate, sulfates, and soil. Additionally, coarse particles between 2.5 and 10 microns in diameter can contribute to light extinction. Each of these components can be naturally occurring or the result of human activity. The natural levels of these species result in some level of visibility impairment, in the absence of any human influences, and will vary with season, daily meteorology, and geography.

1.2 What is meant by the term "natural visibility conditions?"

The term "natural visibility conditions" represents the ultimate goal of the regional haze program, consistent with the national visibility goal set forth in section 169A of the Clean Air Act. The national visibility goal is to remedy existing and prevent future human-caused impairment of visibility in mandatory Federal Class I areas. Regional haze strategies are to make reasonable progress towards this goal.

Natural visibility conditions represent the long-term degree of visibility that is estimated to exist in a given mandatory Federal Class I area in the absence of human-caused impairment. It is recognized that natural visibility conditions are not constant, but rather they vary with changing natural processes (e.g. windblown dust, fire, volcanic activity, biogenic emissions). Specific natural events can lead to high short-term concentrations of particulate matter and its precursors. However, for the purpose of this guidance and implementation of the regional haze program, natural visibility conditions represents a long-term average condition analogous to the five-year average best and worst day conditions that are tracked under the regional haze program.

1.3 What is the purpose of the Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule?

The purpose of this document is to provide guidance to the States in implementing the regional haze program under the Clean Air Act. The regional haze regulations were developed by EPA in 1999.[1] They are designed to protect visual air quality in 156 national parks and wilderness areas (known as "mandatory Federal Class I areas") across the country. As part of the program, States will develop goals and implement strategies for improving visibility in each mandatory Federal Class I area. Estimates of natural visibility conditions are needed by the States for the goal development process. This guidance document describes "default"[2] and

[1]64 Federal Register 35769, July 1, 1999.

[2] In the context of this guidance, the term "default" refers to the basic approach recommended by EPA to estimate the natural visibility conditions, and the values obtained from adopting this approach. States are welcome to adopt the default values for natural visibility conditions or, with sufficient technical justification, to propose alternatives to the basic approach or to generate refined estimates. In the absence of any refinement, EPA recommends that the default values that are provided in this document be adopted.

"refined" approaches for estimating natural conditions. EPA believes that natural conditions estimates developed using the default approach will be adequate to satisfy the requirements of the regional haze rule for the initial SIP submittals due no later than 2008.

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 estimation of natural visibility 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 (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 and State 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 States should, consider whether or not the recommendations in this 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.

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

Not directly, although the procedures for estimating natural conditions that are described in this guidance can be used by Tribes if desired. The CAA and the regional haze rule call for the protection of visibility in 156 “mandatory Federal Class I areas.”[3] 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 and natural conditions estimates do not have to be established for Tribal class I areas.

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.[4] 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.

1.5 What is the statutory and regulatory background for the regional haze program?

In section 169A of the 1977 Amendments of the Clean Air Act, Congress established a national visibility goal as the “prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Federal Class I areas which impairment results from

[3] 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.”

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

manmade air pollution." States are required to develop implementation plans that make "reasonable progress" toward this goal.

EPA issued initial visibility regulations in 1980[5] that addressed visibility impairment in a specific mandatory Federal Class I area that is determined to be "reasonably attributable" to a single source or small group of sources. Regulations to address regional haze were deferred until improved techniques could be developed in monitoring, modeling, and in understanding the effects of specific pollutants on visibility impairment. The 1990 Clean Air Amendments included 169B to focus attention on regional haze issues. It called for EPA to establish the Grand Canyon Visibility Transport Commission, and to issue regional haze rules within 18 months of receipt of a final report from the Commission. EPA issued regional haze regulations in 1999.[6]

As noted in question 1.2 above, we need to estimate the national visibility goal of the Clean Air Act, or "natural visibility conditions,"as part of the implementation process for the regional haze program.

1.6 What visibility metric will be used for estimating natural conditions, setting goals, and tracking progress?

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:

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

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

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

where b_{ext} represents total light extinction expressed in inverse megameters.

1.7 What are the key requirements and milestones for State implementation plans, pertaining to the estimation of natural visibility conditions under the regional haze rule?

The overall framework of the regional haze rule requires States to develop SIPs that include 1) reasonable progress goals for improving visibility in each mandatory Federal Class I area, and 2) set of emission reduction measures to meet these goals. 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 20% most impaired (i.e., worst visibility) days over the period of the implementation plan, and
- ensure no degradation in visibility for the 20% least impaired (i.e., best visibility) days over the same period.

Baseline visibility conditions for the 20% worst and 20% best days are to be determined using monitoring data collected during calendar years 2000-2004. Baseline conditions for 2000-2004, progress goals, and tracking changes over time are to be expressed in terms of the deciview index.[7]

[7] The deciview is a haze index derived from calculated light extinction, such that uniform changes in haziness correspond to uniform incremental changes in visual perception across the entire range of conditions, from pristine to highly impaired. Deciview = 10 ln(b_{ext} / 10).

Most States (and Tribes as appropriate[8]) participating in regional planning organizations will submit regional haze implementation plans, including estimates of natural conditions and proposed progress goals, in the 2008 time frame. The regional haze SIP deadlines are linked to the dates when $PM_{2.5}$ designations are finalized. For states that choose to participate in a regional planning organization, the initial (committal) SIP is due within one year of the $PM_{2.5}$ designation and the full control strategy SIP is due within three years of the $PM_{2.5}$ designation, but not later than December 31, 2008. For states that choose not to participate in a regional planning organization, regional haze SIPs are due within one year of the $PM_{2.5}$ designation (for geographic areas designated as attainment or unclassifiable) and within three years of the $PM_{2.5}$ designation (for geographic areas designated as nonattainment), which is the same time that control strategies to attain the $PM_{2.5}$ standard are due. 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 2018 that, if maintained in subsequent implementation periods, would result in achieving estimated natural conditions in 2064. In the example in Figure 1-1, baseline conditions for the 20% worst days exceed estimated natural conditions by 18 deciviews. The rate the State must analyze and consider for the 2018 progress goal is equal to 18 divided by 60 years = 0.3 deciviews per year x 14 years (2004 to 2018) = 4.2 deciviews. The state must demonstrate in the SIP whether it finds that this rate is reasonable or not, taking into consideration the relevant statutory factors. If it finds that this first rate is not reasonable, the State shall include a demonstration supporting its finding that an alternate rate is reasonable.

In order to determine the 2004-2018 progress rate for this analysis, the State should calculate baseline conditions in accordance with EPA guidance on tracking progress, and use this guidance document for estimating natural conditions.

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[8] 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 development of Tribal implementation plans.

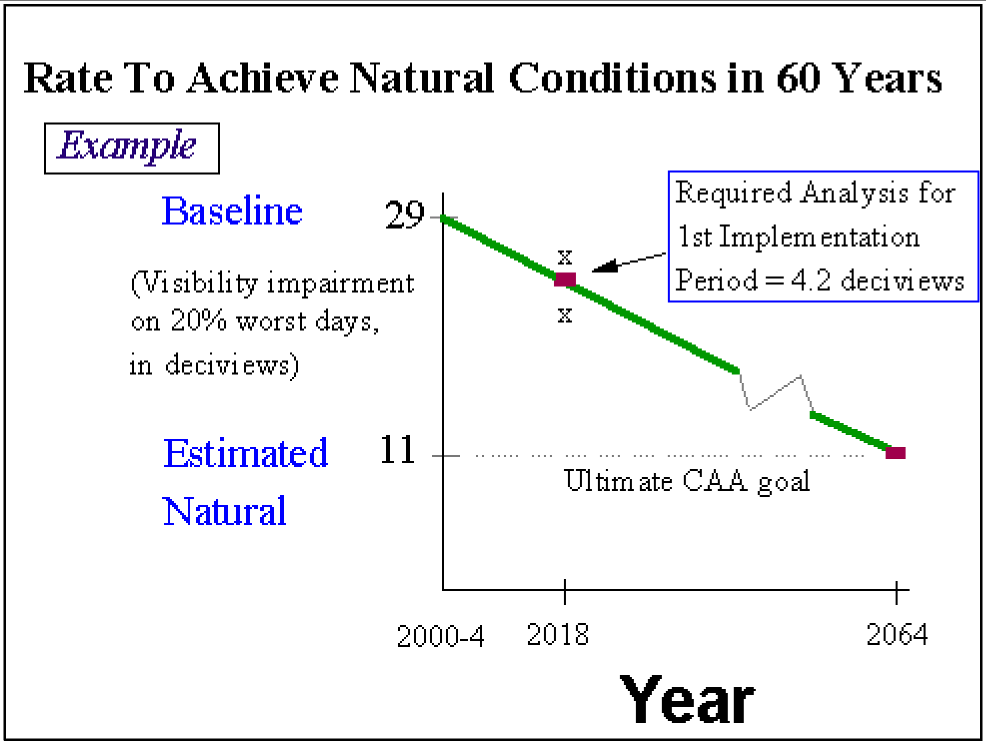

Figure 1-1. Method for determining Mandatory Federal Class I area rate of progress to be analyzed in SIP development process.

1.8 What other factors should be considered in developing progress goals?

Other important issues to be considered in developing mandatory Federal Class I area progress goals include the reasonable progress factors in the CAA, consultation with Tribes and other States, and emission reductions due to other Clean Air Act programs. The reasonable progress factors[9] to consider in developing any progress goal are:

- the costs of compliance;
- the time necessary for compliance;

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

- 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.

Because visibility impairment results from human activities and their emissions transported over long distances - hundreds of miles in many cases - addressing impairment can be effective only through efforts among multiple States. For this reason, States are required to consult with other States (and Tribes, as appropriate) in developing mandatory Federal Class I area progress goals and long-term strategies to meet these goals. If a State is reasonably anticipated to cause or contribute to impairment in a mandatory Federal Class I area in another State, it is required to consult with that State on the development of that State's progress goals, and it must include strategies in its SIP that address its contribution to the haze in that State's mandatory Federal Class I area. Emissions reductions from other States may likewise be taken into account in setting mandatory Federal Class I area goals. EPA supports the regional planning organization process currently under way as the most effective means to address the requirements of the regional haze program, and it is expected that much of the consultation, apportionment demonstrations, and technical documentation needed for SIPs will be facilitated and developed by the regional planning organizations.

Progress goals should also 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 implemented to attain the $PM_{2.5}$ and ozone NAAQS, and national mobile source measures such as the Tier II or heavy duty diesel regulations, should be taken into account in developing mandatory Federal Class I area progress goals for regional haze. Thus, EPA does not expect any progress goals for regional haze to be less ambitious than the level of visibility improvement expected from other programs.[10]

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[10] See regional haze rule, 40 CFR Section 51.308(d)(1)(vi).

1.9 What progress reviews and future SIP revisions are required under the regional haze rule?

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 in terms of changes in visibility based on monitoring data, and in terms of the implementation of emission reduction measures contained in the plan. If progress is not consistent with the visibility and emission reduction goals established in the original SIP, the State must evaluate the reason for lack of progress and take any appropriate further action. 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 as noted above and establishing new visibility improvement goals for these areas. The revised SIP should also include any revised emission reduction measures needed to meet the new mandatory Federal Class I area progress goals.

1.10 Should estimates of natural visibility conditions reflect contemporary conditions and land use patterns, or historic conditions?

For the purposes of this guidance, estimates of natural visibility conditions should reflect contemporary conditions and land use patterns. That is, estimates should attempt to calculate the degree of visibility impairment that exists today, given current vegetative landscapes, when human emissions contributions are removed. We believe that this is a more practical approach than attempting to speculate about what visibility conditions would have existed under the vegetative landscapes that existed 3 or 4 centuries ago, i.e., prior to the arrival of European settlers.

1.11 What estimates of natural conditions are referenced in the regional haze rule and preamble?

Section 308(d)(2)(iii) of the regional haze rule states that "[n]atural visibility conditions must be calculated by estimating the degree of visibility impairment existing under natural conditions for the most impaired and least impaired days, based on available monitoring information and appropriate data analysis techniques." In the preamble to the regional haze rule, EPA states that "it will be appropriate to derive regional estimates of natural visibility conditions by using estimates of natural levels of visibility-impairing pollutants in conjunction with the IMPROVE methodology for calculating light extinction from measurements of the five main components of fine particle mass (sulfate, nitrate, organic carbon, elemental carbon, and crustal material)."

The 1991 peer-reviewed report of the National Acid Precipitation Assessment Program (NAPAP) provides annual average estimates of natural concentrations for these six main components of PM for the eastern and western regions of the country.[11] By applying assumptions for average extinction efficiencies for each PM component and for the effect of humidity, the NAPAP report also included estimates of natural visibility conditions on an annual average basis. Those estimates are equivalent to about 9.6 deciviews in the eastern region and 5.3 deciviews in the western region of the U.S.

In the regional haze preamble, EPA used the NAPAP estimates for natural concentrations of PM mass components, but used assumptions for average extinction efficiencies and annual

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[11] National Acid Precipitation Assessment Program. 1991. Acid Deposition: State of Science and Technology. Report 24. Visibility: Existing and Historical Conditions – Causes and Effects. Table 24-6. Washington, DC.

average humidity, based on updated methodologies developed under the IMPROVE program. Using this approach, EPA found that an appropriate estimate for natural conditions for the 20% worst days would be approximately 11-12 deciviews in the east and 8 deciviews in the west.

The preamble further stated that "with each subsequent SIP revision, the estimates of natural conditions for each mandatory Federal Class I area may be reviewed and revised as appropriate as the technical basis for estimates of natural conditions improve." Possible approaches for refining natural conditions estimates are discussed later in this document.

1.12 How are the natural visibility conditions at a mandatory Federal Class I area determined?

The general approach to estimating natural visibility conditions is based on the IMPROVE methodology for calculating visibility extinction. Using estimates of the natural concentrations of the primary components of particulate matter, along with estimates of the extinction efficiencies of these species, and site-specific factors to account for the effects of relative humidity on light scattering by particles, values for the annual average light extinction at each mandatory Federal Class I area are calculated. Figure 1-2 summarizes the types of data used in the approach to estimating natural visibility conditions.

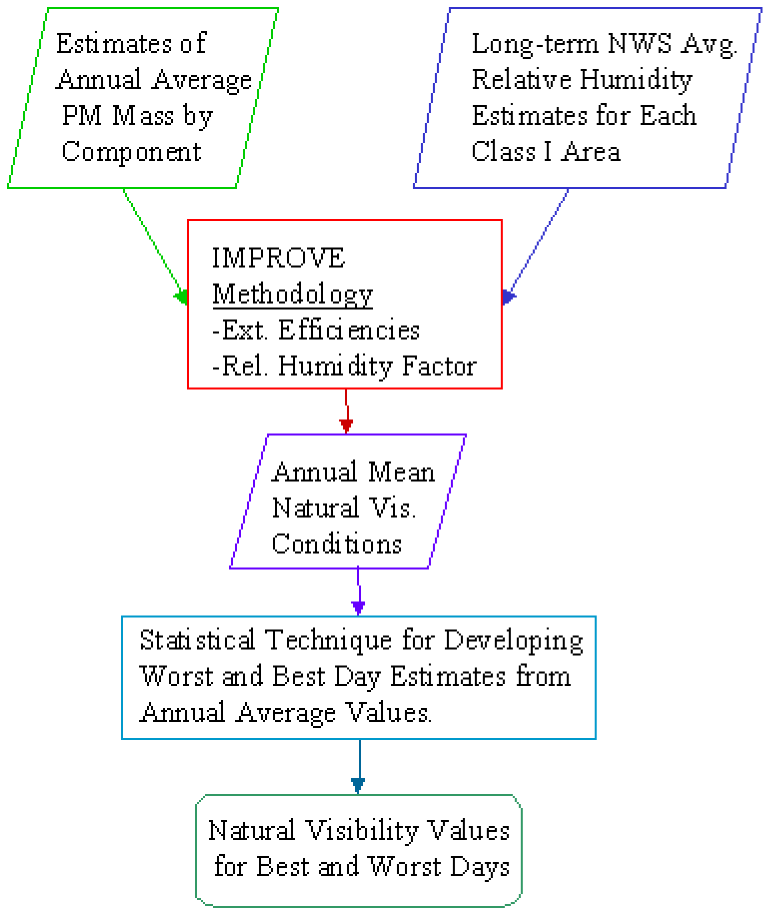

Figure 1-2. Types of Data Used in Approach for Estimating Natural Visibility Conditions.

1.13 What approaches for estimating natural conditions are discussed in this guidance document?

Chapter 2 of this guidance document describes the default approach for estimating natural visibility conditions for each mandatory Federal Class I area. This approach (see Figure 1-2) relies on the NAPAP estimates for PM mass components and the IMPROVE methodology for calculating light extinction. Important enhancements incorporated in this approach include the use of 10-year average relative humidity data from more than 300 weather stations, for development of appropriate relative humidity adjustment factors (*f(RH)*), and statistical techniques for estimating values for the 20% most impaired and 20% least impaired days. EPA believes that this approach provides an adequate estimate of natural conditions for the purpose of developing initial visibility improvement goals, and expects to be able to propose to approve goals in SIP submissions relying on this approach..

Chapter 3 of this guidance describes some alternative approaches by which States may refine their natural conditions estimates based on additional data and analyses. For example, one possible refined approach would involve updating the estimates of natural PM mass concentrations for each PM component, based on recent peer-reviewed literature, rather than using the NAPAP default values. These methods do not represent an exhaustive list and States are free to develop alternative approaches that will provide natural visibility conditions estimates that are technically and scientifically supportable. Any refined approach should be based on accurate, complete, and unbiased information and should be developed using a high degree of scientific rigor.

1.14 How are natural emissions from fire taken into account in estimates of natural PM and visibility levels?

In the preamble to the haze rule, EPA recognized that the Departments of Agriculture and Interior are expected to increase prescribed fire emissions in coming years in order to restore ecosystem health and reduce hazardous excess fuel accumulation caused by many years of fire suppression. Increases in prescribed fire are expected to result in a reduction in wildfire emissions over time. In light of this, EPA stated in the preamble that it would be appropriate to consider some portion of prescribed fire as "natural" in determining natural conditions.

Appendix A of NAPAP Report 24 discusses the approach used to estimate natural mass levels for each PM component. The estimates are based on compilations of natural versus manmade emission levels, ambient measurements in remote areas, and regression studies using manmade and/or natural tracers. Uncertainties are recognized in the estimates of each PM component. The report recognizes that estimated natural levels of both organic carbon and elemental carbon include contributions from fire emissions. The NAPAP report includes organic carbon as the most significant natural PM component by mass in both the eastern and western regions. Because most of the studies cited in the NAPAP Appendix were conducted in relatively remote areas, it is reasonable to assume that the contribution of fire to PM mass in the NAPAP estimates represents the natural regional contribution by fire (both prescribed and wildfire). Since the estimate of natural visibility conditions is a long-term (five-year) average, and because we expect to be able to further refine estimates over time based on improved information and methods, a regional contribution by fire emissions to overall natural visibility conditions should be adequate for the purpose of developing initial progress goals.

EPA encourages the development of a fire emissions tracking database for a number of air quality management purposes. The categorization of fires as natural or human-caused in such a tracking system can be useful for assessing regional policy goals, such as annual fire emission goals recommended by the Grand Canyon Visibility Transport Commission (GCVTC) and the Western Regional Air Partnership (WRAP), but we do not believe that all states will find it necessary to develop or implement this type of approach.

EPA and States should be able to develop enhanced estimates of the contribution of fire emissions to natural visibility conditions in mandatory Federal Class I areas using information from a number of additional activities and technical tools over the coming years, including:

- implementation of a coordinated fire tracking system;
- the collection of multiple years of speciated PM data in mandatory Federal Class I areas, and the assessment of potential contributions by natural fire events using data from the fire tracking system;
- development of chemical analysis techniques to identify carbon attributed to fire

versus other sources;

- development of improved emissions factors and tracking of fire activity levels; and
- improved regional scale fire modeling, or remote sensing tools to retrospectively determine whether smoke from a fire impacted a Class I airshed.

1.15 Can a State delay submittal of its control strategy SIP and associated mandatory Federal Class I area progress goals until it has developed a "refined" estimate of natural conditions?

No, States cannot use the development of a refined estimate of natural visibility conditions as a reason for delaying the submittal of regional haze control strategy SIPs required by statute and regulation. EPA believes that the default approach to estimating natural visibility conditions presented in this document is adequate for the development of progress goals for the first implementation period under the regional haze rule. In addition, the timeline for implementing the regional haze program already includes a significant amount of lead time for developing these SIPs, and EPA does not believe that SIP due dates may be extended beyond the existing regulatory requirements. EPA expectes that States will need to begin assessing progress goals and emission reduction strategies beginning in the 2004-2005 time frame in order to leave adequate time for air quality modeling, analysis of the statutory factors, consultation with other States or Tribes, development of regional recommendations, and adoption of individual State regulations by 2008. Because the process of planning and implementing strategies and evaluating progress is an iterative one, there will be future opportunities to refine progress goals based on new information about natural visibility conditions, rates of growth and development, and the effectiveness of controls.

2. DEFAULT APPROACH TO ESTIMATING NATURAL VISIBILITY CONDITIONS

This section of the guidance document presents the default approach to be used in estimating the natural visibility conditions for both the 20% most and 20% least impaired days.

2.1 What are the default estimates of the natural concentrations for the $PM_{2.5}$ components?

The estimates of the annual averages for the natural levels of fine particle constituents and of coarse particles are drawn from the 1991 report of NAPAP[12]. That report draws published data from a variety of sources, and presents estimates for the natural levels of sulfates, organics, light absorbing carbon (also referred to as elemental carbon), ammonium nitrate, soil dust, and coarse particles for the eastern and western regions of the US. With minor adjustments, these estimates provide the starting point for calculating natural visibility conditions in the mandatory Federal Class I areas.

The approach to estimating natural conditions presented in the NAPAP report defines two separate regions of the US: (1) the East, which consists of all the states east of the Mississippi River, and up to one tier of states west of the Mississippi; and (2) the West, including the desert/mountain regions of the Mountain and Pacific time zones. Geographically, these two subregions show strong differences in haze sources, vegetation, relative humidity, and regional haze levels. Furthermore, within these two subregions, spatial variations in the natural aerosol levels would be expected.

[12]Trijonis, J.C., NAPAP State of Science & Technology, Vol. III, 1990.

Table 2-1 presents the default estimated natural concentrations of the particulate species for the East and the West along with estimates of the dry extinction efficiencies for each species. These concentration estimates are used with the respective estimates of the dry extinction efficiencies to establish the light extinction attributed to natural sources in the East and West. As Table 2-1 shows, the natural concentration estimates differ between the East and West only in the concentrations of sulfate and organic species.

Table 2-1. Average Natural Levels of Aerosol Components[a]

	Average Natural Concentration		Dry Extinction Efficiency
	East (μg/m^3)	West (μg/m^3)	(m^2/g)
Ammonium sulfate [b]	0.23	0.11	3
Ammonium nitrate	0.10	0.10	3
Organic carbon [c]	1.40	0.47	4
Elemental carbon	0.02	0.02	10
Soil	0.50	0.50	1
Coarse Mass	3.0	3.0	0.6

a: After Trijonis, ref. 8
b: Values adjusted to represent chemical species in current IMPROVE light extinction algorithm; Trijonis estimates were 0.2 μg/m^3 and 0.1 μg/m^3 of ammonium bisulfate.
c: Values adjusted to represent chemical species in current IMPROVE light extinction algorithm; Trijonis estimates were 0.2 μg/m^3 and 0.1 μg/m^3 of organic carbon.

2.2 What should be done if the default estimate for any naturally contributed species exceeds the corresponding measured concentrations?

Contributions by natural sources to haze are defined as those not from man-made sources, so neither natural nor man-made contributions to haze can exceed the total haze levels over any period of time. The default natural concentration estimates are for long-term average conditions, and so may be larger than the measured current concentrations for short periods, but should not exceed the average concentration over several annual cycles. If the average measured level of any of the six particle species (for the baseline period, or for any other five-year period) is smaller than the corresponding default natural values, then the default values should be replaced by values that are equal to or less than the measured values. This would constitute a refinement of the default as discussed in section 3.

2.3 How are the long-term relative humidity data used to determine f(RH) values?

The U.S. EPA recently sponsored a project to examine measured hourly relative humidity data (below 95% RH) 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.[13] These relative humidity factors were calculated from available hourly relative humidity data from 292 National Weather Service (NWS) stations across the 50 states and District of Columbia as well as from 25 IMPROVE and IMPROVE protocol monitoring sites, 46 Clean Air Status and Trends Network (CASTNet) sites, and 12 additional sites administered by the National Park Service.

The hourly RH measurements from each site were converted to hourly *f(RH)* values using a non-linear weighting factor curve, based on a modified ammonium sulfate growth curve, applied to the ten years of surface relative humidity data. 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):

---

[13] 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.

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

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. Annual averages for *f(RH)* at each mandatory Federal Class I area were then calculated from the monthly averages.

The annual average *f(RH)* values for all mandatory Federal Class I areas are tabulated in Appendix A of this document. Those values are used in the default approach to establishing natural visibility conditions. The 12 monthly-averaged *f(RH)* values for each of these Class I areas are also tabulated in Appendix A. In most regions there is a seasonal cycle of relative humidity, which is evident in the appropriate monthly *f(RH)* values. The monthly *f(RH)* values may be used in refined estimates of the natural visibility conditions (Chapter 3). Note that Appendix A includes *f(RH)* values only for the designated mandatory Federal Class I areas. However, the software program needed to calculate *f(RH)* values for other sites is available for use by States, Tribes, and other agencies, upon request to EPA.

2.4 How is the default natural light extinction at a mandatory Federal Class I area calculated?

The calculation of natural light extinction is based on the IMPROVE methodology. Using the values in Table 2-1, the natural light extinction can be calculated from Equation 1:

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

where b_{ext} is the reconstructed total light extinction in inverse megameters (i.e., $Mm^{-1} = 10^{-6}\ m^{-1}$). (Note: A value of 10 Mm^{-1} is used for all mandatory Federal Class I areas as an estimate of the light extinction caused by the light scattering from gas molecules, i.e., Rayleigh scattering). Relative humidity correction factors, *f(RH)*, are included for the sulfate and nitrate species as these are hygroscopic (i.e., absorb water) and their extinction efficiencies change with relative humidity. Annual average site-specific *f(RH)* values for all 156 mandatory Federal Class I areas (Appendix A) have been determined from historical data, and are used in the default approach to establish site-specific natural visibility conditions.

Example calculations with Equation 1 will illustrate the use of the default approach. Looking at two examples in the East, and referring to Table 2-1 for default concentrations and Appendix A for annual *f(RH)* values, we see that the natural total light extinction for Acadia National Park (Maine), is:

$$
\begin{aligned}
b_{ext} &= 3(3.39)[0.23] + 3(3.39)[0.1] + 4[1.4] + 10[0.02] + 1[0.5] + 0.6[3.0] + 10 \\
&= 21.46\,Mm^{-1}
\end{aligned}
$$

Similarly, for the Everglades National Park (Florida), b_{ext} is:

$$
\begin{aligned}
b_{ext} &= 3(2.66)[0.23] + 3(2.66)[0.1] + 4[1.4] + 10[0.02] + 1[0.5] + 0.6[3.0] + 10 \\
&= 20.73\,Mm^{-1}
\end{aligned}
$$

In the West, we see that Bandelier National Monument (New Mexico) has a default natural light extinction of:

$$\begin{aligned} b_{ext} &= 3(1.85)[0.12] + 3(1.85)[0.1] + 4[0.47] + 10[0.02] + 1[0.5] + 0.6[3.0] + 10 \\ &= 15.60 Mm^{-1} \end{aligned}$$

and, Yellowstone National Park (Wyoming), has a default b_{ext} of:

$$\begin{aligned} b_{ext} &= 3(2.13)[0.12] + 3(2.13)[0.1] + 4[0.47] + 10[0.02] + 1[0.5] + 0.6[3.0] + 10 \\ &= 15.78 Mm^{-1} \end{aligned}$$

The default natural light extinction values have been calculated by this approach for all 156 mandatory Federal Class I areas, and are listed in Appendix B.

2.5 How are the default b_{ext} values used to estimate natural visibility in deciview units?

The default light extinction values are used to calculate estimates for the annual average deciview values (*dv*) at each mandatory Federal Class I area. These default *dv* values are determined from Equation 2:

$$dv = 10 \ln(b_{ext} / 10) \qquad \textbf{(2)}$$

where b_{ext} is the default total light extinction in Mm^{-1} as calculated by Equation 1. From the examples above, the default annual average *dv* for Acadia National Park, is:

$$\begin{aligned} dv &= 10 \ln(21.46 / 10) \\ &= 7.64 \end{aligned}$$

For the Everglades National Park, the default *dv* value is:

$$dv = 10\ln(20.73/10)$$
$$= 7.29$$

The default *dv* value for Bandelier National Monument is:

$$dv = 10\ln(15.60/10)$$
$$= 4.45$$

and, for Yellowstone National Park, the default *dv* is:

$$dv = 10\ln(15.78/10)$$
$$= 4.56$$

The calculated annual average *dv* value for each mandatory Federal Class I area is presented in Appendix B along with the default total light extinction values.

2.6 How are the 20% best visibility days and the 20% worst visibility days determined in the default approach?

The calculated *dv* value represents an estimate of the annual average of daily natural visibility *dv* values. If daily values for the natural background visibility *dv* were available, those values could be arranged in order and the averages of the best 20% and the worst 20% of the values could be calculated to establish the regional haze rule goals for each mandatory Federal Class I area. However, since daily natural visibility *dv* values are not available, the default approach provides only an estimate of the annual average natural background *dv*, and the averages for the best and worst 20% must be estimated.

Ames and Malm[14] have shown that the frequency distributions of daily reconstructed *dv*

[14]Rodger Ames and William Malm, *Recommendations for Natural Condition Deciview Variability: An Examination of IMPROVE Data Frequency Distributions*, 2000.

values for sites in the East and in the West can each be well represented by normal distributions. Consequently, the average *dv* values for the 20% best visibility days and the 20% worst visibility days can be estimated from 10^{th} and 90^{th} percentile dv values, respectively. That is, since the frequency distributions appear to behave normally, the 10^{th} and 90^{th} percentiles for a mandatory Federal Class I area can be estimated from the following equations:

$$p10 = dv - 128sd \tag{3}$$

and,

$$p90 = dv + 128sd \tag{4}$$

where *sd* represents the standard deviation of the daily *dv* values for that area, and *dv* is the annual average of the *dv* values. Estimates of *sd* for current visibility conditions were derived from a database of current visibility conditions from numerous sites in both the East and the West. At each site, daily *dv* values were calculated from the reconstructed light extinction values, and the mean and standard deviation of the daily *dv* values were determined. Comparison of sites within the same region showed that, in the East, the current visibility conditions have on average a *dv* value of approximately 18 with an average *sd* of approximately 5. In the West, the current visibility conditions showed an average *dv* of approximately 8 and an average *sd* of approximately 2.4. More important in the present context, by inspection of the relationships between *sd* and average *dv*, Ames and Malm[10] inferred best estimates of the *sd* values for natural visibility in both the West and East. In the West this best estimate of the natural visibility *sd* is 2, whereas in the East the best estimate of the natural visibility *sd* is 3.

These estimates of the standard deviation of natural contributions to visibility impairment can be used in Equations 3 and 4 above, along with the default natural *dv* values, to estimate the averages of the 20% best and 20% worst natural visibility contributions. For example, the calculated 10^{th} and 90^{th} percentile *dv* for Acadia National Park are:

$$p10 = 7.64 - 1.28(3) = 3.80$$
$$p90 = 7.64 + 1.28(3) = 11.48$$

Appendix B provides the default 10th and 90th percentile natural visibility deciview values for each of the 156 mandatory Federal Class I areas. Figure 2-1 is a map of the 10th percentile default *dv* at mandatory Federal Class I areas across the U.S., indicating a range from approximately 2 *dv* in the West to 3 *dv* in the East. Figure 2-2 is a map of the 90th percentile *dv*, which ranges from approximately 7 *dv* in the west to 11 dv in the East. (Note that different color scales apply to the East and West portions of Figures 2-1 and 2-2, as indicated in the figures). Higher *dv* values in the northwest than southwest U.S. are due to higher RH in the northwest. Higher natural condition organic carbon mass concentrations in the East are primarily responsible for higher default 10th and 90th percentile *dv* in the East relative to the western U.S.

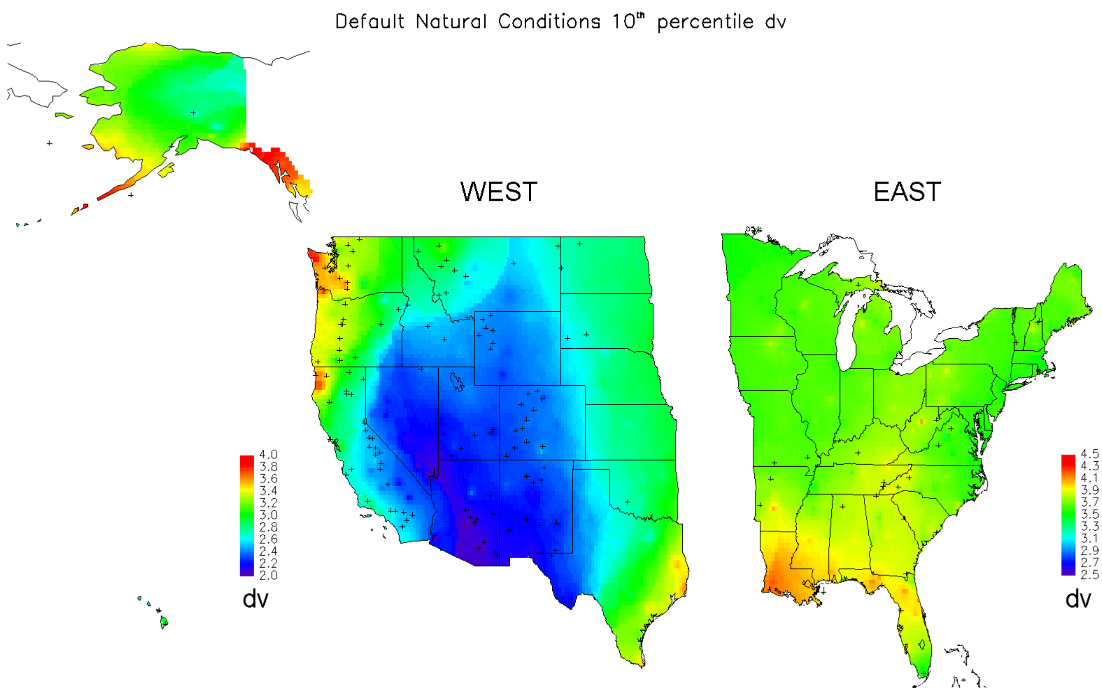

Figure 2-1. Estimates of the Default 10% Natural *dv* Values

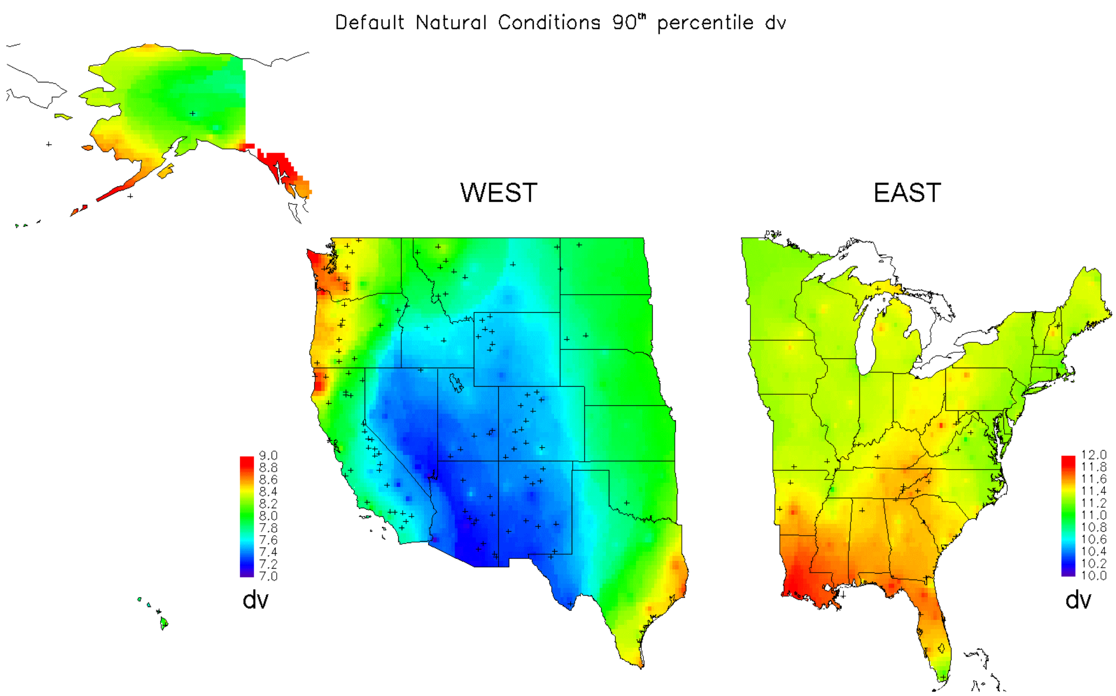

Figure 2-2. Estimates of the Default 90% Natural *dv* Values

3. REFINED ESTIMATION APPROACHES
REGIONAL & SITE-SPECIFIC APPLICATION

3.1 Why might States want to use a refined approach to estimate natural visibility conditions?

There are a variety of circumstances under which States might wish to adopt a refined approach to estimating natural visibility conditions. For example, if the default estimates of the natural background conditions are close to the current visibility conditions, small uncertainties can have significant impacts on States' ability to meet SIP goals. In some regions, natural sources are known to exhibit predictable seasonal influences on visibility. Therefore, States might wish to use refined estimates of natural visibility conditions to account for these influences. Also, States which receive significant visibility impacts from biomass smoke might wish to distinguish more explicitly between man-made and natural sources. These examples are non-exhaustive and there may be many other circumstances under which States find it desirable to develop more refined estimates. In all such cases, they should be prepared to support alternative approaches with sufficient information so that EPA and the reviewing public can verify their accuracy and validity.

3.2 What are some of the approaches that could be used by States to refine the default natural visibility estimates?

A refined approach is essentially one that uses species concentration estimates that differ from the NAPAP default values given in Table 2-1. Several possible refined approaches which can be adopted are described in this document, and States may identify others that are more appropriate for their own situations.

One possible refined approach is to revise the NAPAP default estimates of the natural concentrations of one or more of the composite components, and repeat the calculations with the refined concentrations. This approach might be adopted where there is an offset between the regional natural concentrations and the NAPAP default estimates. In this approach, the visibility calculations (i.e., Equations 1-4) would be carried out using refined annual average concentration estimates and the default annual average *f(RH)* values. Note that any refined natural concentration estimates must retain the distinction between natural and anthropogenic components. For example, the natural concentration estimate for a species can never exceed the actual measured concentration of that species over any time period.

In cases where constant values for natural species concentrations may not be appropriate, a second possible approach could estimate natural visibility using species concentrations that vary (e.g., seasonally, monthly, or climatologically). This approach might adopt the NAPAP default estimates for some species, and temporally varying estimates for others. Alternatively, the NAPAP estimates might be used for some seasons or time periods, and other technically justified estimates or measurements for the remaining time periods. This approach would use the refined concentration estimates, and if the time-varying species is hygroscopic (i.e., sulfate or nitrate), it would also use the appropriate monthly average *f(RH)* values (Appendix A).

Finally, a refined approach might account for infrequent natural events, such as forest fires or wind-blown dust, as major influences on visibility. Such an approach would require estimating the frequency and magnitude of the natural contribution to particle concentrations during the events.

3.3 Which refined approach is most appropriate for States to use?

To determine which approach is most appropriate, States should first identify whether any of the particle species concentrations are thought to deviate significantly from the NAPAP default values. Once identified, States should classify the deviations as either a constant offset (e.g. NAPAP sulfate values are too low near the sea coast), a systematic temporal variation (e.g. natural organics are seasonally higher in the summer), or an infrequent natural variation (e.g. dust produced by a natural sand dune area during wind events). The refinement of particle species concentrations could follow a range of different approaches, from using different annual average species concentrations, to using seasonal or monthly concentrations, to using different natural concentrations for individual sample events. EPA encourages flexibility in the approaches used, so that default and refined annual average, seasonal, monthly, and event-specific species concentrations may be intermingled to provide the best estimates of natural visibility for each of the mandatory Federal Class I areas.

3.4 What should States do if they want to use a refined approach, rather than the default approach to estimate natural visibility conditions?

States wishing to employ a refined approach should supply technical demonstrations that the refined approach provides improved site-specific or regional natural visibility estimates, relative to the default approach. The proposed refined approach must be based upon particle species classification into natural and manmade components (i.e. natural cannot exceed measured particle species concentration for any time period), and should be submitted to EPA for approval prior to implementation.

States wishing to adopt a refined approach based on a constant offset of the natural concentrations of the particle species should provide technical justification for revising the NAPAP default concentrations. Using the refined concentrations, the natural visibility condition should then be calculated based on an approach that is consistent with the methodology that is used to track trends, such as the default approach.

States wishing to adopt a refined approach based on estimates of annually varying (seasonally, monthly, climatologically, etc.) natural particle concentrations should also provide technical justification for the estimates of the natural particle species concentrations. For example, if seasonal variations in particle species are the basis for the refined approach, then estimates should be provided of natural concentrations in every season for every pertinent species. Those particle species components that do not vary significantly should be treated using a constant estimate of the natural concentrations (e.g., use NAPAP value for each season).

In any case, the appropriate mechanism for putting a refined estimation approach in place is to incorporate the approach in a new or revised SIP. The justification for the proposed refined approach will thereby be considered as part of the normal SIP review process.

3.5 How might an infrequent natural impact be quantified?

Infrequent events could be addressed by using a constant or temporally varying value for all non-event periods, for species affected by the event, and a different value for those species during the event. For example, consider a forest fire, which affects particulate organic and elemental carbon. The contribution of the fire event to the natural levels of those species might be estimated by assuming that the fire contributed all of the increment above the mean of the sample periods immediately pre- and post-fire event. Multiple pre- and post-event sample periods could be used to strengthen the comparison. Alternatively, an air quality model might be used to estimate the impact of the smoke plume on particle carbon levels, or other air quality measurements might be used to estimate the impact of the event.

3.6 Can natural visibility estimates be made on a sample-period-by-sample-period basis?

Yes, such calculations can be done, but refined concentration estimates should be justified to support such an approach. In that case, the calculation of the current b_{ext} would first be done for each sample day, using Equation 1, the appropriate monthly *f(RH)* values, and the daily monitoring data for each species. The resulting daily b_{ext} values would then be converted to deciviews by Equation 2. Those deciview values would then be sorted, and the highest 20% and lowest 20% identified, indicating the days with the most and the least visibility impairment, respectively. (This procedure is described in detail in a separate guidance document for tracking progress). For each of the days in these two groups, the natural contribution to light extinction would then be estimated. The average of each of these two groups of natural contributions would then be calculated.

As noted above, the natural concentration of each species assumed in this calculation must never exceed the actual measured concentration in any sample period. Furthermore, if this approach is taken, natural visibility conditions (i.e, the averages of the 20% worst and 20% best natural deciview values) should be recalculated each year.

Appendix A

Annual Average *f(RH)* and Monthly Average *f(RH)* Values at All Mandatory Federal Class I Areas

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 (below 95% RH) 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 and the draft report is available at

http://www.epa.gov/ttn/oarpg/gener.html.

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

[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.

Class 1 Area	ST	Ann. Ave. f(RH)	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	3.39	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	2.27	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	3.64	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	2.55	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	1.81	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	2.55	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	1.85	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	0.00
Big Bend NP	TX	1.80	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	1.97	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	2.87	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	1.73	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	2.91	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	3.86	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	2.07	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	3.07	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	1.81	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	2.95	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	3.37	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	1.75	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	3.39	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	1.88	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	2.63	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	1.86	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	3.73	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	1.68	2.02	1.95	1.59	1.25	1.26	1.14	1.82	2.09	1.79	1.47	1.63	2.17

Class 1 Area	ST	Ann. Ave. f(RH)	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)
Chiricahua Wilderness	AZ	1.67	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	3.53	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	3.60	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	2.18	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	2.26	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	2.52	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	2.15	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	3.64	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	3.19	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	1.99	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	2.49	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	2.03	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	2.17	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	2.66	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	2.05	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	1.99	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	1.59	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	2.40	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	2.96	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	1.74	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	3.34	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	3.60	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	3.65	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	1.76	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	2.07	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	3.13	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	2.11	2.42	2.29	2.01	1.89	1.89	1.75	1.88	2.33	2.19	1.86	2.38	2.38

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Great Smoky Mtns. NP	TN	3.46	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	1.84	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	2.54	2.74	2.60	2.60	2.54	2.39	2.34	2.48	2.43	2.39	2.53	2.76	2.70
Hawaii Volcanoes NP	HI	3.13	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	2.53	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	3.13	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	2.12	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	2.89	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	3.04	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	2.11	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	2.12	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	2.06	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	3.51	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	2.14	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	3.71	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	2.11	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	1.97	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	2.72	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	2.94	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	3.54	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	2.68	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	2.99	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	3.36	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	3.60	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	2.02	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	1.61	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	2.62	3.02	2.90	2.87	2.26	2.23	2.48	2.50	2.22	2.23	2.35	3.16	3.17

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Mesa Verde NP	CO	1.87	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	2.11	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	3.14	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	2.84	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	2.16	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	3.21	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	3.73	4.29	3.80	3.44	4.40	2.92	3.49	3.12	3.27	3.13	3.86	4.49	4.56
Mount Baldy Wilderness	AZ	1.71	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	3.62	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	3.62	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	3.92	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	3.64	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	2.02	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	3.23	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	2.08	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	3.62	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	3.56	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	3.95	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	3.25	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	3.60	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	1.90	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	1.75	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	1.66	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	2.43	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	2.83	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	3.24	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	2.03	2.05	2.12	2.01	2.14	2.26	2.03	1.84	1.97	1.99	1.88	2.09	2.02

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Red Rock Lakes Wilderness	MT	2.16	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	4.23	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	1.91	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	3.22	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	1.49	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	1.82	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	2.26	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	2.16	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	2.22	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	1.87	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	2.49	2.83	2.67	2.65	2.36	2.33	2.32	2.45	2.52	2.43	2.50	2.32	2.50
Sawtooth Wilderness	ID	2.24	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	2.60	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	2.61	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	3.31	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	2.10	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	3.19	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	3.55	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	1.65	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	4.25	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	3.43	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	2.56	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	3.79	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	2.81	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	1.61	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	2.99	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	2.06	2.35	2.30	2.24	2.02	1.99	1.91	1.97	2.00	2.03	2.02	1.91	2.04

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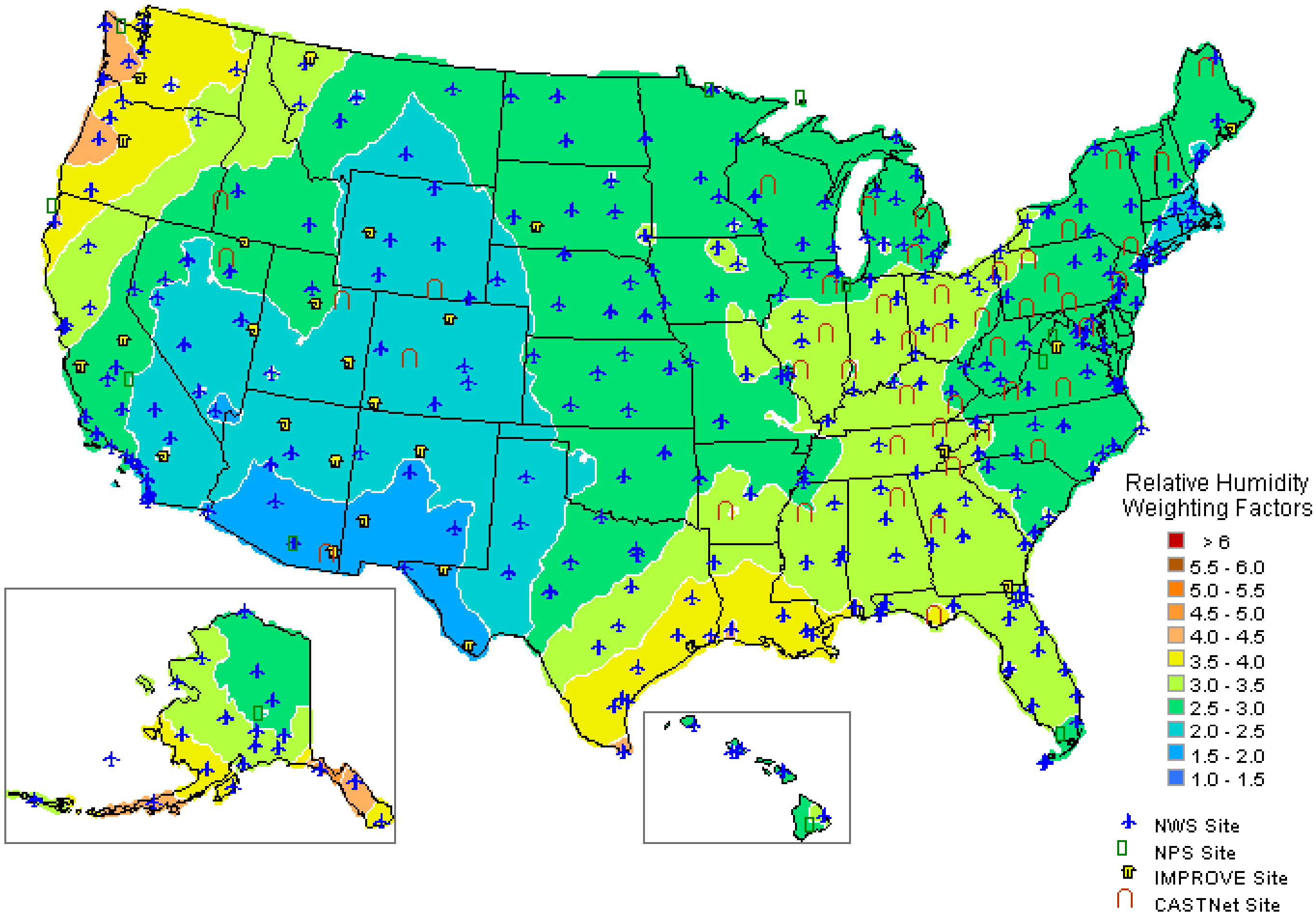
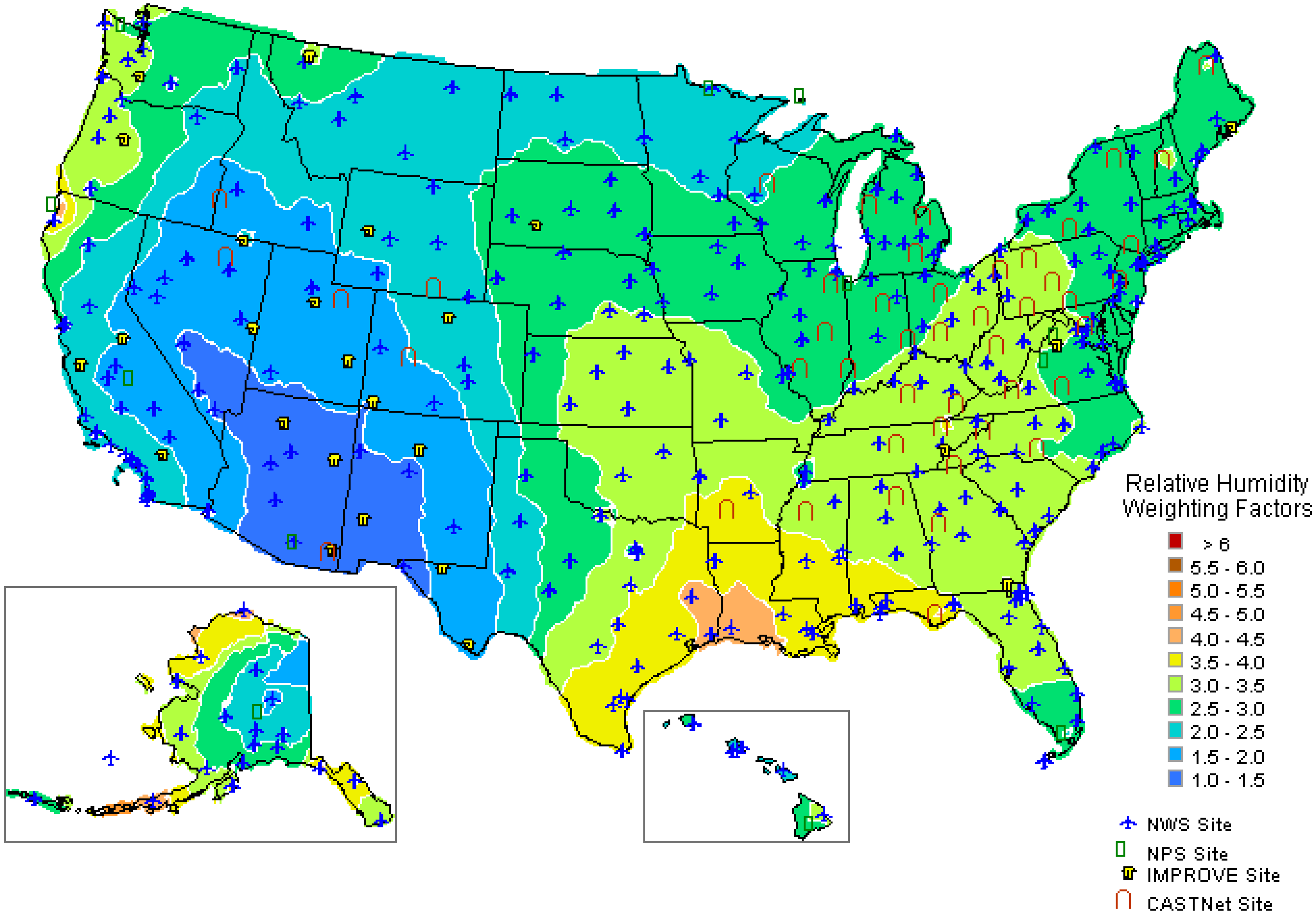
Teton Wilderness	WY	2.08	2.53	2.35	2.24	2.12	2.10	1.85	1.59	1.51	1.74	2.02	2.40	2.48
Theodore Roosevelt NP	ND	2.53	2.86	2.75	2.76	2.33	2.30	2.48	2.42	2.15	2.16	2.32	3.01	2.99
Thousand Lakes Wilderness	CA	2.72	3.81	3.19	2.91	2.53	2.42	2.19	2.09	2.14	2.23	2.43	3.13	3.53
Three Sisters Wilderness	OR	3.65	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	3.34	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	2.30	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	3.24	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	2.51	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	0.00
Voyageurs NP	MN	2.69	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	2.06	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	1.90	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	1.98	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	1.99	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	1.78	2.09	1.93	1.57	1.45	1.50	1.40	1.79	2.01	2.02	1.69	1.81	2.12
Wichita Mountains Wilderness	OK	2.63	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	2.44	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	3.51	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	2.13	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	2.96	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	2.22	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	1.74	2.65	2.42	1.97	1.62	1.50	1.29	1.24	1.41	1.43	1.57	1.98	2.41

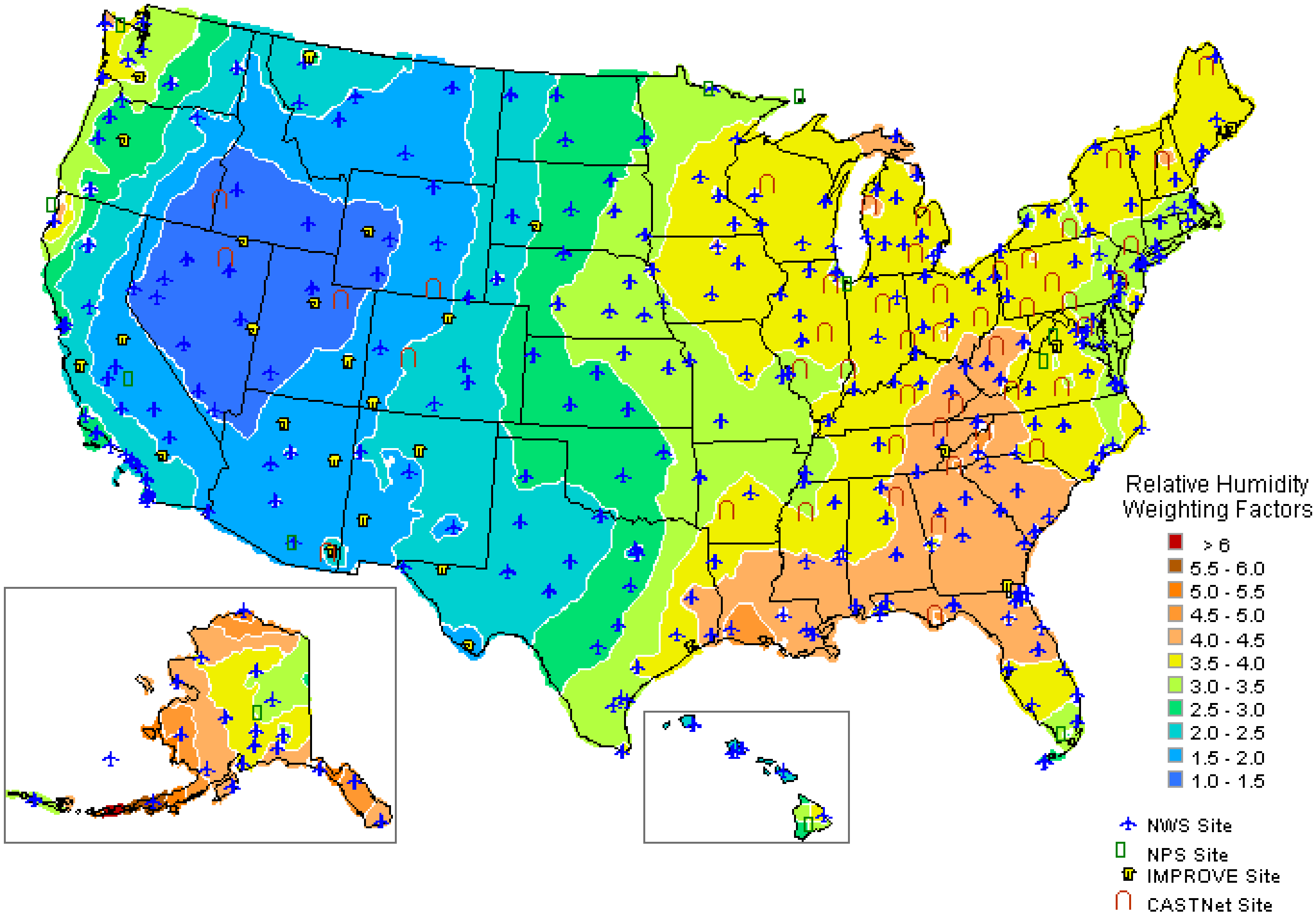
a: *f(RH)* values for Virgin Islands National Park were not calculated because of the limited RH data available.



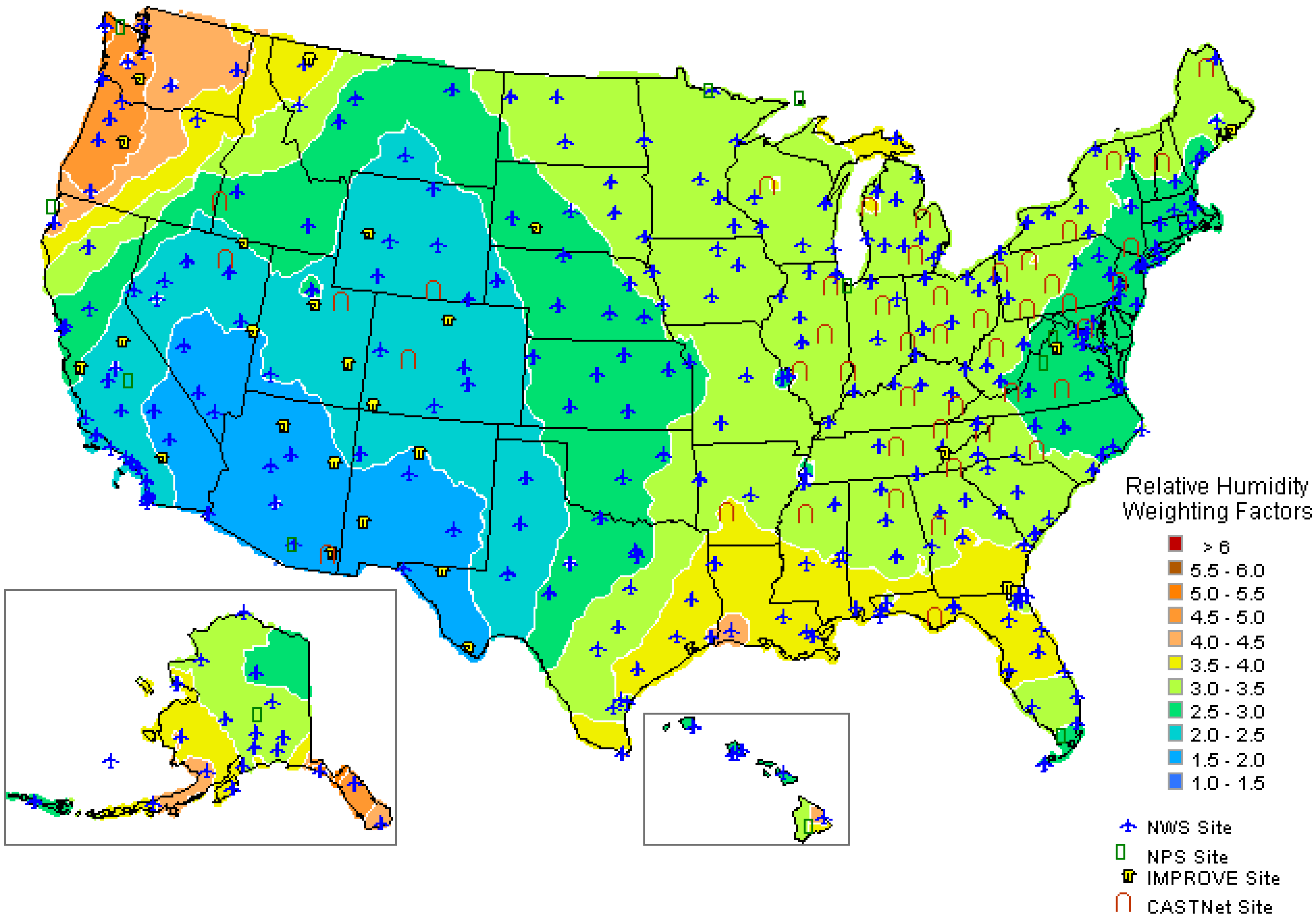
Monthly Average f(RH) Values for February (all weather stations shown)



Monthly Average f(RH) Values for May (all weather stations shown).



Monthly Average f(RH) Values for August (all weather stations shown).



Monthly Average f(RH) Values for November (all weather stations shown).

Appendix B

Default Natural b_{ext}, *dv*, and 10th and 90th Percentile *dv* Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	Lat.	Lon.	bext (Mm^{-1})	Ann. Avg. (dv)	Best Days (dv)	Worst Days (dv)
Acadia NP	44.37	-68.26	21.46	7.64	3.80	11.48
Agua Tibia Wilderness	33.41	-116.98	15.88	4.62	2.06	7.18
Alpine Lakes Wilderness	47.42	-121.42	16.79	5.18	2.62	7.74
Anaconda-Pintler Wilderness	45.98	-113.42	16.07	4.74	2.18	7.30
Arches NP	38.64	-109.58	15.58	4.43	1.87	6.99
Badlands NM	43.74	-101.94	16.06	4.74	2.18	7.30
Bandelier NM	35.78	-106.27	15.60	4.45	1.89	7.01
Bering Sea Wilderness	60.45	-172.79	0.00	0.00	0.00	0.00
Big Bend NP	29.31	-103.19	15.57	4.43	1.87	6.99
Black Canyon of Gunnison NP	38.58	-107.70	15.68	4.50	1.94	7.06
Bob Marshall Wilderness	47.75	-113.38	16.28	4.87	2.31	7.43
Bosque del Apache Wilderness	33.79	-106.83	15.52	4.40	1.84	6.96
Boundary Waters Canoe Area	47.95	-91.50	20.98	7.41	3.57	11.25
Breton Wilderness	29.73	-88.88	21.92	7.85	4.01	11.69
Bridger Wilderness in Bridger-Teton Forest	42.98	-109.76	15.75	4.54	1.98	7.10
Brigantine Div. Of Forsythe NWR	39.46	-74.45	21.14	7.49	3.65	11.33
Bryce Canyon NP	37.62	-112.17	15.57	4.43	1.87	6.99
Cabinet Mountains Wilderness	48.21	-115.71	16.33	4.90	2.34	7.46
Caney Creek Wilderness	34.41	-94.08	21.43	7.62	3.78	11.46
Canyonlands NP	38.46	-109.82	15.54	4.41	1.85	6.97
Cape Romain NWR	32.94	-79.66	21.46	7.64	3.80	11.48
Capitol Reef NP	38.36	-111.05	15.62	4.46	1.90	7.02
Caribou Wilderness	40.50	-121.18	16.11	4.77	2.21	7.33
Carlsbad Caverns NP	32.14	-104.48	15.61	4.45	1.89	7.01
Chassahowitzka NWR	28.75	-82.55	21.79	7.79	3.95	11.63
Chiricahua NM	32.01	-109.39	15.49	4.38	1.82	6.94
Chiricahua Wilderness	31.84	-109.27	15.48	4.37	1.81	6.93
Cohutta Wilderness	34.92	-84.58	21.59	7.70	3.86	11.54
Crater Lake NP	42.90	-122.13	16.76	5.16	2.60	7.72
Craters of the Moon Wilderness	43.47	-113.55	15.82	4.59	2.03	7.15
Cucamonga Wilderness	34.25	-117.57	15.87	4.62	2.06	7.18
Denali NP	63.72	-148.97	16.05	4.73	2.17	7.29
Desolation Wilderness	38.98	-120.12	15.80	4.57	2.01	7.13
Diamond Peak Wilderness	43.53	-122.10	16.78	5.18	2.62	7.74
Dolly Sods Wilderness	39.11	-79.43	21.26	7.54	3.70	11.38
Dome Land Wilderness	35.70	-118.19	15.69	4.51	1.95	7.07
Eagle Cap Wilderness	45.10	-117.29	16.02	4.71	2.15	7.27
Eagles Nest Wilderness	39.69	-106.25	15.72	4.52	1.96	7.08

Mandatory Federal Class I Area	Lat.	Lon.	bext (Mm^{-1})	Ann. Avg. (dv)	Best Days (dv)	Worst Days (dv)
Emigrant Wilderness	38.20	-119.75	15.81	4.58	2.02	7.14
Everglades NP	25.39	-80.68	20.73	7.29	3.45	11.13
Fitzpatrick Wilderness	43.27	-109.57	15.73	4.53	1.97	7.09
Flat Tops Wilderness	39.97	-107.25	15.70	4.51	1.95	7.07
Galiuro Wilderness	32.56	-110.32	15.43	4.34	1.78	6.90
Gates of the Mountain Wilderness	46.87	-111.81	15.96	4.68	2.12	7.24
Gearhart Mountain Wilderness	42.49	-120.85	16.34	4.91	2.35	7.47
Gila Wilderness	33.22	-108.25	15.53	4.40	1.84	6.96
Glacier NP	48.51	-114.00	16.58	5.06	2.50	7.62
Glacier Peak Wilderness	48.21	-121.04	16.76	5.16	2.60	7.72
Goat Rocks Wilderness	46.54	-121.48	16.79	5.18	2.62	7.74
Grand Canyon NP	35.97	-111.98	15.54	4.41	1.85	6.97
Grand Teton NP	43.68	-110.73	15.75	4.54	1.98	7.10
Great Gulf Wilderness	44.31	-71.22	21.20	7.51	3.67	11.35
Great Sand Dunes NM	37.73	-105.52	15.77	4.56	2.00	7.12
Great Smoky Mtns. NP	35.63	-83.94	21.53	7.67	3.83	11.51
Guadalupe Mountains NP	31.83	-104.80	15.60	4.45	1.89	7.01
Haleakala NP	20.81	-156.28	16.06	4.74	2.18	7.30
Hawaii Volcanoes NP	19.43	-155.27	16.45	4.98	2.42	7.54
Hells Canyon Wilderness	45.34	-116.57	16.05	4.73	2.17	7.29
Hercules-Glades Wilderness	36.69	-92.90	21.20	7.51	3.67	11.35
Hoover Wilderness	38.14	-119.45	15.78	4.56	2.00	7.12
Isle Royale NP	47.99	-88.83	20.97	7.40	3.56	11.24
James River Face Wilderness	37.62	-79.48	21.11	7.47	3.63	11.31
Jarbridge Wilderness	41.89	-115.43	15.77	4.56	2.00	7.12
John Muir Wilderness	37.39	-118.84	15.78	4.56	2.00	7.12
Joshua Tree NP	34.03	-116.18	15.74	4.54	1.98	7.10
Joyce Kilmer-Slickrock Wilderness	35.43	-84.00	21.58	7.69	3.85	11.53
Kaiser Wilderness	37.28	-119.18	15.79	4.57	2.01	7.13
Kalmiopsis Wilderness	42.27	-123.93	16.83	5.20	2.64	7.76
Kings Canyon NP	36.82	-118.76	15.77	4.56	2.00	7.12
La Garita Wilderness	37.96	-106.81	15.68	4.50	1.94	7.06
Lassen Volcanic NP	40.54	-121.57	16.17	4.81	2.25	7.37
Lava Beds Wilderness	41.71	-121.34	16.32	4.90	2.34	7.46
Linville Gorge Wilderness	35.89	-81.89	21.60	7.70	3.86	11.54
Lostwood Wilderness	48.60	-102.48	16.15	4.79	2.23	7.35
Lye Brook Wilderness	43.15	-73.12	21.06	7.45	3.61	11.29
Mammoth Cave NP	37.22	-86.07	21.43	7.62	3.78	11.46

Mandatory Federal Class I Area	Lat.	Lon.	bext (Mm^{-1})	Ann. Avg. (dv)	Best Days (dv)	Worst Days (dv)
Marble Mountain Wilderness	41.52	-123.21	16.75	5.16	2.60	7.72
Maroon Bells-Snowmass Wilderness	39.15	-106.82	15.71	4.52	1.96	7.08
Mazatzal Wilderness	33.92	-111.43	15.45	4.35	1.79	6.91
Medicine Lake Wilderness	48.50	-104.29	16.11	4.77	2.21	7.33
Mesa Verde NP	37.20	-108.49	15.62	4.46	1.90	7.02
Minarets (in Ansel Adams Wilderness)	37.65	-119.20	15.77	4.56	2.00	7.12
Mingo Wilderness	36.98	-90.20	21.21	7.52	3.68	11.36
Mission Mountain Wilderness	47.40	-113.85	16.26	4.86	2.30	7.42
Mokelumne Wilderness	38.58	-120.03	15.80	4.58	2.02	7.14
Moosehorn NWR	45.12	-67.26	21.28	7.55	3.71	11.39
Mount Adams Wilderness	46.19	-121.50	16.84	5.21	2.65	7.77
Mount Baldy Wilderness	34.12	-109.57	15.51	4.39	1.83	6.95
Mount Hood Wilderness	45.38	-121.69	16.77	5.17	2.61	7.73
Mount Jefferson Wilderness	44.55	-121.83	16.77	5.17	2.61	7.73
Mount Rainier NP	46.76	-122.12	16.97	5.29	2.73	7.85
Mount Washington Wilderness	44.30	-121.87	16.78	5.18	2.62	7.74
Mount Zirkel Wilderness	40.55	-106.70	15.71	4.52	1.96	7.08
Mountain Lakes Wilderness	42.34	-122.11	16.51	5.02	2.46	7.58
North Absaroka Wilderness	44.77	-109.78	15.75	4.55	1.99	7.11
North Cascades NP	48.54	-121.44	16.77	5.17	2.61	7.73
Okefenokee NWR	30.74	-82.13	21.63	7.71	3.87	11.55
Olympic NP	47.32	-123.35	16.99	5.30	2.74	7.86
Otter Creek Wilderness	39.00	-79.65	21.32	7.57	3.73	11.41
Pasayten Wilderness	48.85	-120.52	16.75	5.16	2.60	7.72
Pecos Wilderness	35.93	-105.64	15.64	4.47	1.91	7.03
Petrified Forest NP	35.08	-109.77	15.54	4.41	1.85	6.97
Pine Mountain Wilderness	34.31	-111.80	15.47	4.37	1.81	6.93
Pinnacles NM	36.49	-121.16	15.99	4.69	2.13	7.25
Point Reyes NS	38.12	-122.90	16.25	4.85	2.29	7.41
Pres. Range-Dry River Wilderness	44.21	-71.35	21.31	7.57	3.73	11.41
Rawah Wilderness	40.70	-105.94	15.72	4.52	1.96	7.08
Red Rock Lakes Wilderness	44.67	-111.70	15.81	4.58	2.02	7.14
Redwood NP	41.56	-124.08	17.17	5.41	2.85	7.97
Rocky Mountain NP	40.28	-105.55	15.64	4.47	1.91	7.03
Roosevelt Campobello IP	44.88	-66.95	21.28	7.55	3.71	11.39
Saguaro Wilderness	32.25	-110.73	15.37	4.30	1.74	6.86
Salt Creek Wilderness	33.61	-104.37	15.58	4.43	1.87	6.99
San Gabriel Wilderness	34.27	-117.94	15.87	4.62	2.06	7.18

Mandatory Federal Class I Area	Lat.	Lon.	bext (Mm^{-1})	Ann. Avg. (dv)	Best Days (dv)	Worst Days (dv)
San Gorgonio Wilderness	34.18	-116.90	15.80	4.58	2.02	7.14
San Jacinto Wilderness	33.75	-116.65	15.84	4.60	2.04	7.16
San Pedro Parks Wilderness	36.11	-106.81	15.62	4.46	1.90	7.02
San Rafael Wilderness	34.78	-119.83	16.02	4.72	2.16	7.28
Sawtooth Wilderness	44.18	-114.93	15.86	4.61	2.05	7.17
Scapegoat Wilderness	47.17	-112.73	16.09	4.76	2.20	7.32
Selway-Bitterroot Wilderness	45.86	-114.00	16.10	4.76	2.20	7.32
Seney Wilderness	46.26	-86.03	21.38	7.60	3.76	11.44
Sequoia NP	36.50	-118.82	15.76	4.55	1.99	7.11
Shenandoah NP	38.52	-78.44	21.26	7.54	3.70	11.38
Shining Rock Wilderness	35.39	-82.78	21.62	7.71	3.87	11.55
Sierra Ancha Wilderness	33.82	-110.88	15.47	4.36	1.80	6.92
Simeonof Wilderness	54.92	-159.28	17.19	5.42	2.86	7.98
Sipsey Wilderness	34.34	-87.34	21.49	7.65	3.81	11.49
South Warner Wilderness	41.33	-120.20	16.07	4.74	2.18	7.30
St Marks Wilderness	30.12	-84.08	21.85	7.82	3.98	11.66
Strawberry Mountain Wilderness	44.30	-118.73	16.24	4.85	2.29	7.41
Superstition Wilderness	33.63	-111.10	15.44	4.35	1.79	6.91
Swanquarter Wilderness	35.31	-76.28	21.06	7.45	3.61	11.29
Sycamore Canyon Wilderness	34.03	-116.18	15.74	4.54	1.98	7.10
Teton Wilderness	44.09	-110.18	15.75	4.54	1.98	7.10
Theodore Roosevelt NP	47.30	-104.00	16.05	4.73	2.17	7.29
Thousand Lakes Wilderness	40.70	-121.58	16.17	4.81	2.25	7.37
Three Sisters Wilderness	44.29	-122.04	16.79	5.18	2.62	7.74
Tuxedni Wilderness	60.15	-152.60	16.59	5.06	2.50	7.62
UL Bend Wilderness	47.55	-107.87	15.90	4.64	2.08	7.20
Upper Buffalo Wilderness	35.83	-93.21	21.31	7.57	3.73	11.41
Ventana Wilderness	36.22	-121.59	16.04	4.73	2.17	7.29
Virgin Islands NP (a)	18.33	-64.79	0.00	0.00	0.00	0.00
Voyageurs NP	48.59	-93.17	20.76	7.31	3.47	11.15
Washakie Wilderness	43.95	-109.59	15.74	4.54	1.98	7.10
Weminuche Wilderness	37.65	-107.80	15.64	4.47	1.91	7.03
West Elk Wilderness	38.69	-107.19	15.69	4.50	1.94	7.06
Wheeler Peak Wilderness	36.57	-105.42	15.69	4.51	1.95	7.07
White Mountain Wilderness	33.49	-105.83	15.56	4.42	1.86	6.98
Wichita Mountains Wilderness	34.74	-98.59	16.12	4.77	2.21	7.33
Wind Cave NP	43.55	-103.48	15.99	4.69	2.13	7.25
Wolf Island Wilderness	31.31	-81.30	21.57	7.69	3.85	11.53

Mandatory Federal Class I Area	Lat.	Lon.	bext (Mm^{-1})	Ann. Avg. (dv)	Best Days (dv)	Worst Days (dv)
Yellowstone NP	44.55	-110.40	15.78	4.56	2.00	7.12
Yolla Bolly Middle Eel Wilderness	40.11	-122.96	16.33	4.91	2.35	7.47
Yosemite NP	37.71	-119.70	15.85	4.60	2.04	7.16
Zion NP	37.25	-113.01	15.53	4.40	1.84	6.96

(a) *f(RH)* values for Virgin Islands National Park were not calculated because of the limited RH data available. As such no estimates for Natural Visibility Conditions are presented at this time.