III.K.2 VISIBILITY AND REGIONAL HAZE

A. Overview

Visibility refers to the visual quality of a vista with respect to detail, color rendition and contrast. It can refer to the maximum distance at which an object can be seen under prevailing conditions, and is sometimes known as “visual range.” When molecules and small particles in the air reflect (scatter) and absorb light in the atmosphere, this extinguishes light and prevents it from reaching a viewer’s eye; this “light extinction” affects visibility. Haze is the reduction in visibility caused when sunlight encounters tiny particles in the air, with the term “regional haze” referring to the air pollution, whether local or from a long distance, that reduces visibility in specific national parks and wilderness areas identified as Class I areas. Regional haze is caused by particles released by human activities or natural sources, and is regulated under the Regional Haze Rule (40 CFR 51.300-309). The pollutants, also called haze species, that create regional haze and impair visibility are measurable, for instance as sulfates, nitrates, organic carbon, elemental carbon, fine soil, sea salt, and coarse mass. (In regional haze analyses, the terms aerosol, particulates, particles, and pollutants may be used interchangeably.)

The particles that cause haze may be naturally occurring (e.g., from windstorms, wildfire, or volcanic activity) or may be released directly or indirectly as the result by human activities (referred to as anthropogenic sources). Natural sources contribute to visibility impairment, but natural emissions cannot be realistically controlled or prevented by the states. Anthropogenic emissions can be generated or originate within the boundaries of the state (referred to as “state-origin”), or can be generated outside the boundaries of the United States and then transported into a state. Although they contribute to visibility impairment, international-origin emissions cannot be regulated, controlled, or prevented by the states. Nevertheless, their impact on visibility can be significant so it is important to assess their contribution to impairment.

Haze-causing particles are also be classified by whether they were released directly, or were formed in the atmosphere. Particulate matter emitted directly into the atmosphere is referred to as primary particulate, which includes crustal materials and elemental carbon; particulate matter produced in the atmosphere from photochemical reactions of gas-phase precursors and subsequent condensation to form secondary particulates is referred to as secondary particulate, which includes ammonium nitrate, ammonium sulfates, and secondary organic aerosols. Secondary $PM_{2.5}$ is generally smaller than primary $PM_{2.5}$, and because the ability of $PM_{2.5}$ to scatter light depends on particle size, with light scattering for fine particles being greater than for coarse particles, secondary $PM_{2.5}$ plays an especially important role in visibility impairment. Moreover, the smaller secondary $PM_{2.5}$ can remain suspended in the atmosphere for longer periods and is transported long distances, thereby contributing to regional-scale impacts of pollutant emissions on visibility.

B. Sources of Visibility Impairment

EPA has identified two general causes of visibility impairment in Class I areas:

- Impairment due to smoke, dust, colored gas plumes, or layered haze emitted from stacks which obscure the sky or horizon and are relatable to a single stationary source or a small group of stationary sources; and

- Impairment due to widespread, regionally homogeneous haze from a multitude for sources that impairs visibility in every direction over a large area

While this Plan may address visibility impacts associated with visible plumes, its primary focus is to reduce regional, homogeneous haze coming from a variety of sources. Alaska's Class I areas are more typically subject to the latter cause of visibility impairment, both as natural and anthropogenic. Emissions impacts from within Alaska are seasonally driven with wildfire smoke in the summer and windblown dust in the spring/summer. International emission impacts are also seasonally driven with impacts in the winter (Eurasian arctic haze), spring (Asian dust), and summer (fires).

1. Natural Sources

Natural sources of visibility impairment are those not directly attributed to human activities. Natural events (for example, biological activities, ocean spray, windstorms, wildfire, volcanic activity) create aerosols that contribute to haze in the atmosphere. Natural visibility conditions are not constant; they vary with changing natural processes throughout the year. Specific natural events can lead to high short-term concentrations of visibility-impairing particulate matter and its precursors. Therefore, natural visibility conditions, for the purpose of Alaska's regional haze program, are represented by a long-term average of conditions expected to occur in the absence of emissions normally attributed to human activities. Natural visibility conditions reflect the contemporary vegetated landscape, land-use patterns, and meteorological/climatic conditions. Current methods of analyzing monitoring data do not distinguish between natural and anthropogenic emissions, but seasonal patterns and event timelines can provide insight into the relative contributions of natural sources of visibility impairment.

2. Anthropogenic Sources

Anthropogenic or human-caused sources of visibility impairment include anything directly attributable to human activities that produce emissions of visibility-impairing pollutants. Some examples include transportation, power generation, agricultural activities, mining operations, fires for land management, industrial fuel combustion and dust from soils disturbed by human activities. Anthropogenic effects on visibility are not constant; they vary with changing human activities throughout the year. As noted previously, international-origin emissions cannot be regulated, controlled, or prevented by the states and therefore are beyond the scope of this planning document. Any reductions in international origin anthropogenic emissions would likely fall under the purview of the U.S. EPA through international diplomatic activities.

C. Measuring or Quantifying Visibility Impairment

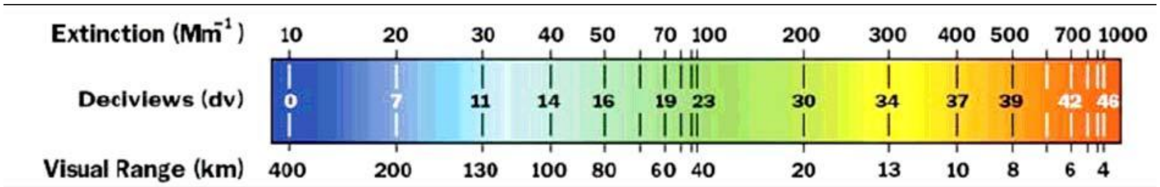
Visibility-impairing pollutants reflect, scatter, and absorb light in the atmosphere. "Light extinction" is the term used to describe light that is prevented from reaching a viewer's eyes by pollutants in the atmosphere. Light extinction can be measured by passing a light beam of known strength through a chamber of air and measuring the light attenuation by the gases and particles. Light that is scattered or absorbed by pollutants does not reach the other side of the chamber. Each haze species, or atmospheric pollutant, has a different light extinction capability, characterized by the extinction coefficient. Extinction coefficients are typically measured in the laboratory for each known species.

Molecules naturally found in the atmosphere also reflect, scatter, and absorb light. The interaction of light with very small molecules in the atmosphere causes "Rayleigh scattering," which also affects visibility.

Establishing the link between individual haze species and visibility impairment is the key to understanding regional haze. Light extinction caused by haze species can be calculated using the extinction coefficient and the measured concentration of the pollutant in the air. Light extinction is measured in inverse Megameters (Mm^{-1}). The specific visibility measurement unit used in the Regional Haze Rule to track visibility levels is the deciview (dv). The deciview is the natural logarithm of light extinction and is unitless. While the deciview value describes overall visibility levels, light extinction calculations can describe the contribution of each component haze species to measured visibility.

The relationship between units of light extinction (Mm^{-1}), haze index (dv), and visual range (km) is indicated by the scale below (Figure III.K.2-3). Visual range is the distance at which a given object can be seen with the unaided eye. The deciview scale is zero for pristine conditions and increases as visibility degrades. Each deciview change represents a perceptible change in visual air quality to the average person. Generally, a one deciview change in the haze index is likely perceptible by a person regardless of background visibility conditions.

Figure III.K.2-3
Visibility Measurement Scale



As the scale indicates, the deciview value gets higher as the amount of light extinction increases. The ultimate goal of the regional haze program is to reduce the amount of light extinction caused by haze species from anthropogenic emissions, until the deciview level for natural conditions is reached. That level is the deciview level corresponding to emission levels from natural sources only. The haze species concentrations are measured as part of the IMPROVE monitoring network deployed throughout the United States. Four sites are operated in Alaska: Denali Headquarters, Trapper Creek, Tuxedni and Simeonof.

D. Monitoring Visibility

1. Overview of the IMPROVE Program

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program was established in the mid-1980s to measure visibility impairment in Class I areas throughout the United States. The monitoring sites are operated and maintained through a formal cooperative relationship between the EPA, National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, and U.S. Forest Service. In 1991, several additional organizations joined the effort: State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials, Western States Air Resources Council, Mid-Atlantic Regional Air Management Association, and Northeast States for Coordinated Air Use Management. The primary monitoring data available within Alaska's Class I areas are from the IMPROVE program.

The objectives of IMPROVE are to establish current visibility and aerosol conditions in mandatory Class I areas, to identify chemical species and emission sources responsible for existing man-made visibility impairment, to document long-term trends for assessing progress towards the national visibility goal, and to provide regional haze monitoring representing all visibility-protected federal Class I areas where practical. The data collected at the IMPROVE monitoring sites are used by land managers, industry planners, scientists, public interest groups, and air quality regulators to better understand and protect the visual air quality resource in Class I areas. Most importantly, the IMPROVE Program scientifically documents for American citizens the visual air quality of their wilderness areas and national parks.

The IMPROVE program has used three monitoring approaches: scene monitoring with automated cameras (discontinued, but still a reference to range of conditions), measurement of optical extinction with transmissometers, and the measurement of the composition and concentration of the particles that produce the extinction with aerosol monitors. The IMPROVE monitoring network consists of aerosol, light scatter, light extinction and scene samplers in a large number of national parks and wilderness areas. The IMPROVE monitor sample filters are analyzed for 47 different compounds including fine mass ($PM_{2.5}$), total mass (PM_{10}), optical absorption, elements, ions (chloride, nitrate, nitrite, sulfate), and organics. The parameters used in regional haze analysis are described in Table III.K.2-1, in terms of both mass and extinction. Table III.K.2-2 is a color key, or legend, to the different haze pollutant species and their abbreviations, as they appear in figures throughout this document. References to sulfate and nitrate in this document are intended to reflect ammonium sulfate and ammonium nitrate, respectively.

Table III.K.2-1
IMPROVE Parameters Contributing to Regional Haze, Algorithms and Descriptions

Parameter	Name	Algorithm	Description
MF	$PM_{2.5}$: Mass	Measured quantity	Gravimetric measurement of aerosol fine mass ($PM_{2.5}$)
MT	PM_{10}: Mass	Measured quantity	Gravimetric measurement of aerosol total mass (PM_{10})
aerosol_bext	Aerosol extinction	ammSO4f_bext + ammNO3f_bext + OMCf_bext + ECf_bext + SOILf_bext + CM_bext	Sum of major aerosol species mass extinction
ammNO3f	Ammonium nitrate	1.29*NO3f	Ammonium nitrate from nitrate ion
ammNO3f_bext	Ammonium nitrate extinction	3*fRH*ammNO3f	Use mass extinction efficiency of 3m2/g for ammonium nitrate and fRH
ammSO4f	Ammonium sulfate	4.125*Sf	Ammonium sulfate from sulfur element
ammSO4f_bext	Ammonium sulfate extinction	3*fRH*ammSO4f	Use mass extinction efficiency of 3m2/g for ammonium sulfate and fRH
CM	$PM_{2.5-10}$: mass	MT-MF	Fine mass ($PM_{2.5}$) subtracted from PM_{10}
CM_bext	Coarse mass extinction	0.6*CM	Use mass extinction efficiency of 0.6 m2/g for coarse mass
dv	Deciview	10*ln((aerosol_bext+10)/10)	Perception based visibility metric
ECf	Carbon: total elemental	E1+E2+E3-OP	Sum of elemental carbon fractions from TOR - OP
ECf_bext	Elemental carbon extinction	10*ECf	Use mass extinction efficiency of 10m2/g for elemental carbon
F_CM_bext	Coarse mass extinction fraction	100*CM_bext/aerosol_bext	Contribution of coarse mass extinction to aerosol extinction
F_EC	Elemental carbon fraction	100*ECf/RCFM	Contribution of fine elemental carbon to reconstructed fine mass
F_EC_bext	Elemental carbon extinction fraction	100*ECf_bext/aerosol_bext	Contribution of fine elemental carbon extinction to aerosol extinction

Table III.K.2-1
IMPROVE Parameters Contributing to Regional Haze, Algorithms and Descriptions

Parameter	Name	Algorithm	Description
F_NO3	Nitrate fraction	100*ammNO3f/RCFM	Contribution of fine ammonium nitrate to reconstructed fine mass
F_NO3_bext	Nitrate extinction fraction	100*ammNO3f_bext/aerosol_bext	Contribution of fine ammonium nitrate extinction to aerosol extinction
F_OMC	Organic carbon mass fraction	100*OMCf/RCFM	Contribution of fine organic mass to reconstructed fine mass
F_OMC_bext	Organic carbon mass ext. fraction	100*OMCf_bext/aerosol_bext	Contribution of fine organic mass extinction to aerosol extinction
F_SO4	Sulfate fraction	100*ammSO4f/RCFM	Contribution of fine ammonium sulfate to reconstructed fine mass
F_SO4_bext	Sulfate extinction fraction	100*ammSO4f_bext/aerosol_bext	Contribution of fine ammonium sulfate extinction to aerosol extinction
F_SOIL	Soil	100*SOILf/RCFM	Contribution of fine soil to reconstructed fine mass
F_SOIL_bext	Soil extinction fraction	100*SOILf_bext/aerosol_bext	Contribution of fine soil extinction to aerosol extinction
fRHgrid	Relative humidity factor	gridded value	Gridded value
OMCf	Organic mass by carbon	1.4*(O1+O2+O3+O4+OP)	Organic carbon mass from OC
OMCf_bext	Organic carbon extinction	4*1.4*OCf	Use mass extinction efficiency of 4 m2/g for organic carbon
RCFM	Reconstructed fine mass	ammSO4f + ammNO3f + ECf + OMCf + SOILf	Fine mass reconstructed from major component species concentrations
RCTM	Reconstructed total mass	ammSO4f + ammNO3f + ECf + OMCf + SOILf + CM	Sum of major fine and coarse aerosol mass concentrations
SOILf	Fine Soil	2.2*Al+2.49*Si+1.63*Ca+2.42*Fe+1.94*Ti	Sum of common oxides of soil elements

Table III.K.2-1
IMPROVE Parameters Contributing to Regional Haze, Algorithms and Descriptions

Parameter	Name	Algorithm	Description
SOILf_bext	Fine soil extinction	1*SOILf	Use mass extinction efficiency of 1m2/g for fine soil
SVR	Standard visual range	3910/(aerosol_bext+Rayleigh)	Standard visual range in kilometers

Table III.K.2-2
Key to Haze Pollutant Species and Their Abbreviations
As Used Throughout This Document

	Pollutant	IMPROVE Abbreviation
	Ammonium Nitrate	ammno3f_bext
	Ammonium Sulfate	ammso4f_bext
	EC (Elemental Carbon)	ecf_bext
	OMC (Organic Mass Carbon)	omcf_bext
	CM (Coarse Mass)	cm_bext
	Soil (fine Soil)	soilf_bext
	Sea Salt	seasalt_bext

Source: Table 7-1 IMPROVE Monitor Aerosol Composition

Detailed information regarding the IMPROVE program, including history, sampling protocols, standard operating procedures, and data availability can be found on the IMPROVE web site (http://vista.cira.colostate.edu/improve/) and the Visibility Information Exchange Web System (VIEWS) Web site (http://vista.cira.colostate.edu/views/).

The IMPROVE website provides access to raw data and data products, and tools for data processing and aggregating. Also available are online are databases, publications, analysis tools, a graphic viewer, and photographs selected to capture the range of visual conditions at each site. IMPROVE has also been a key participant in visibility-related research, including the advancement of monitoring instrumentation, analysis techniques, visibility modeling, policy formulation and source attribution field studies.

2. IMPROVE Algorithms

The IMPROVE program has developed two algorithms for computing visibility from the mass concentrations provided by the monitoring program. Each first multiplies mass concentrations by light extinction efficiencies per unit mass for each aerosol species. Then, light extinction by all aerosol species is combined to estimate natural visibility, and converted to deciviews for purposes of regional haze analysis. Limitations of the original IMPROVE algorithm led to the development of the IMPROVE II algorithm, which has been used for all analyses in this document. A description of the two IMPROVE algorithms, and the estimates they produce, is found in Appendix III.K.2.

Use of the IMPROVE II algorithm also leads to revised estimates of natural conditions. A complete description of the default (original) approach for estimating natural haze levels is available in the Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule, at http://vista.cira.colostate.edu/improve/Publications/GuidanceDocs/guidancedocs.htm, as are the results of applying it all the IMPROVE monitoring sites. A description of the second IMPROVE algorithm may be found at http://vista.cira.colostate.edu/improve/Publications/GrayLit/019_RevisedIMPROVEeq/RevisedIMPROVEAlgorithm3.doc