III.K.13.B VISIBILITY AND IMPROVE PROGRAM

1. 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 it 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. The term "regional haze" refers to the air pollution released by human activities or natural sources, whether local or from a long distance, that reduces visibility in specific national parks and wilderness areas identified as Class I areas under the CAA.

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 (e.g., plume blight); and

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

While this RH 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 from natural and anthropogenic sources.

2. VISIBILITY IMPAIRING POLLUTANTS

The direct and precursor pollutants that can impair visibility include sulfur dioxide (SO_2), nitrogen oxides (NO_x), fine and coarse particulate matter (PM), volatile organic compounds (VOC), and ammonia. EPA 2019 RH SIP guidance states that when selecting sources for analysis of control measures, a state may focus on the PM species that dominate visibility impairment at the Class I areas affected by emissions from the state and then select only sources with emissions of those dominant pollutants and their precursors. Also, it may be reasonable for a state to not consider measures for control of the remaining pollutants from sources that have been selected on the basis of their emissions of the dominant pollutants.

Haze-causing PM species are classified by whether they were released directly or were formed in the atmosphere. Fine or coarse particulate matter ($PM_{2.5}$ or PM_{10}) emitted directly into the atmosphere is referred to as primary particulate, which includes crustal materials (soil), elemental carbon (EC), sea salt, and coarse mass (CM). PM 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 (NH_4NO_3) and ammonium sulfates ((NH_4)$_2SO_4$). Organic mass carbon (OMC) can be either primary or secondary. Secondary $PM_{2.5}$ is generally smaller size distribution 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. Secondary NH_4NO_3 and (NH_4)$_2SO_4$ $PM_{2.5}$ are also hygroscopic, and their extinction efficiency increases as they take on water so the light scattering efficiency increases with increasing relative humidity. 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.

3. SOURCES OF VISIBILITY IMPAIRMENT

Pollutants that cause haze may be naturally occurring (e.g., from windstorms, wildfire, or volcanic activity), or they may be released directly or indirectly as the result of human activities (referred to as human-caused or 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 they 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. This is especially true in Alaska, where Arctic haze, Asian dust, and international pollutant transport are known sources of visibility impairment at the state's Class I areas.[1] Nevertheless, their impact on visibility can be significant so it is important to assess their contribution to impairment.

A. 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 PM and its precursors. Natural emission impacts from within Alaska are seasonally driven with wildfire smoke in the summer, windblown dust in the spring and summer, and oceanic dimethyl sulfide (DMS; natural source of sulfate) in summer. Volcano eruptions are episodic while volcano off-gassing can occur year-round. Natural sources outside of Alaska can also contribute to visibility impairment at Alaska Class I areas. They are also seasonally driven with impacts in the winter (Eurasian Arctic haze), spring (Asian dust), and summer (fires).

Therefore, natural visibility conditions, for the purpose of Alaska's RH 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

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[1] Alaska Transboundary Pollution Monitoring Report, June 2012, study, available at: https://dec.alaska.gov/air/anpms/original-regional-haze/ (Accessed 11/15/2021).

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.

B. Human-Caused (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 of this include transportation, power generation, agricultural activities, mining operations, 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 and natural caused emissions cannot be regulated, controlled, or prevented by the states. Any reductions in international origin anthropogenic emissions would fall under the purview of the EPA through international diplomatic activities.

4. MEASURING OR QUANTIFYING VISIBILITY IMPAIRMENT

Visibility-impairing pollutants, so called haze species, reflect, scatter, and absorb light in the atmosphere. Each haze species has a different light extinction capability. 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.

Molecules naturally found in the atmosphere also reflect, scatter, and absorb light even in the absence of $PM_{2.5}$. 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 RH 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 (measured in dv), and visual range (km) are indicated by the scale below (Figure III.K.13.B-1). 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.13.B-1.Visibility measurement scale.
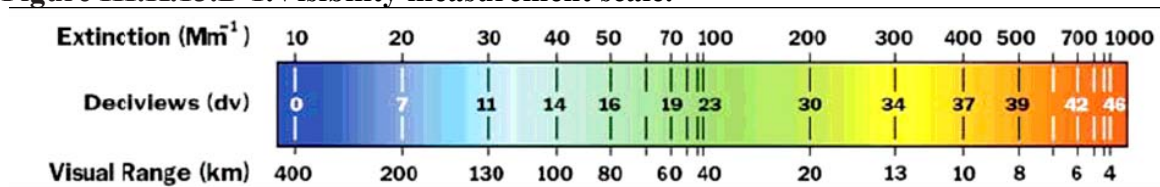
As the scale indicates, the deciview value gets higher as the amount of light extinction increases. The ultimate goal of the RH program is to reduce the amount of light extinction caused by haze species from anthropogenic emissions, until the deciview level for natural conditions is reached. That level is the deciview level corresponding to emission levels from natural sources only. The haze species concentrations are measured as part of the IMPROVE network deployed throughout the United States. Four IMPROVE sites are operated in Alaska: Denali Headquarters, Trapper Creek, Tuxedni/Kenai Peninsula Borough and Simeonof (more details in Section III.K.13.C Monitoring Strategy).

A. IMPROVE Program

The IMPROVE program was established in the mid-1980s to measure visibility impairment at Class I areas throughout the United States. This was part of the larger 1977 CAA Amendments reforms initiated to reduce air pollution and improve air quality throughout the United States and at designated national parks and wilderness areas. The monitoring sites are operated and maintained through a formal cooperative relationship among the EPA, NPS, FWS, Bureau of Land Management (BLM), and U.S. Forest Service (USFS). In 1991, several additional organizations joined the effort: State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials (now National Association of Clean Air Agencies/NACAA), Western States Air Resources Council (WESTAR), Mid-Atlantic Regional Air Management Association (MARAMA), and Northeast States for Coordinated Air Use Management (NESCAUM). The primary monitoring data available within Alaska's Class I areas are from the IMPROVE program.

There are several objectives of the IMPROVE program: 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.

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/).

B. IMPROVE Measurements

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, and organics. Light extinction is estimated from measurements of PM components (sulfate, nitrate, organic carbon), light absorbing carbon, fine soil, sea salt, and coarse material; assumptions about relative humidity at the monitoring site; and the use of the "revised" (also called "second") IMPROVE equation[2]. The parameters used in regional haze analysis are described in Table III.K.13.B-1, in terms of both mass and extinction.

Table III.K.13.B-1. IMPROVE Parameters Contributing to Regional Haze and Descriptions

Code	Description
aerosol_bext	Total Aerosol Extinction
ALf	Aluminum (Fine)
ammNO3f	Ammonium Nitrate (Fine)
ammSO4f	Ammonium Sulfate (Fine)
AnthBext	Anthropogenic Extinction
AnthEammNO3	Anthropogenic ammNO3 extinction
AnthEammSO4	Anthropogenic ammSO4 extinction
AnthECM	Anthropogenic CM extinction
AnthELAC	Anthropogenic ELAC extinction
AnthEOMC	Anthropogenic OMC extinction
AnthESoil	Anthropogenic Soil extinction
C_Rat	C Rat
CAf	Calcium (Fine)
CBEXT	Carbon Extinction
CHLf	Chloride (Fine)
CLf	Chlorine (Fine)
CM_calculated	Mass, PM2.5 - PM10 (Coarse)
DUSTBEXT	Dust Extinction
dv	Deciview
E_Rat	E Rat
ammNO3f_bext	ammNO3 Extinction (Fine)
EammNO3_AM	Annual Mean Of ammNO3 Extinction
ammSO4f_bext	ammSO4 Extinction (Fine)

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[2] Pitchford, M., W. Malm, B. Schichtel, N. Kumar, D. Lowenthal and J. Hand, 2007. Revised algorithm for estimating light extinction from IMPROVE particle speciation data, J. Air & Waste Manage. Assoc., 57, 1326-1336.

Code	Description
EammSO4_AM	Annual Mean Of ammSO4 Extinction
EC1f	Carbon, Elemental Fraction 1 (Fine)
EC2f	Carbon, Elemental Fraction 2 (Fine)
EC3f	Carbon, Elemental Fraction 3 (Fine)
CM_bext	Coarse Mass Extinction
ECf_bext	Carbon, Elemental Extinction (Fine)
OMCf_bext	Organic Mass Extinction (Fine)
EpiBext	Sum of Episodic Extinction
EpiCarbon	Episodic Carbon
EpiCarbon95Min	Lowest Annual 95th Percentile For OMC + LAC extinction
EpiDust	Episodic Dust
EpiDust95Min	Lowest Annual 95th Percentile For soil + CM extinction
EpiECM	Episodic CM extinction
EpiELAC	Episodic ELAC extinction
EpiEOMC	Episodic OMC extinction
EpiESoil	Episodic soil extinction
EpiRoutBext	Episodic Routine Extinction
EpiRoutDv	Episodic Routine Dv
SeaSaltf_bext	Sea Salt Extinction (Fine)
ESeaSalt_AM	Annual Mean Of sea salt extinction
SOILf_bext	Soil Extinction (Fine)
FEf	Iron (Fine)
flRH	Relative Humidity Factor, Large Particle Size
fRHgrid	Relative Humidity Factor (Climatological Monthly)
fsRH	Relative Humidity Factor, Small Particle Size
fssRH	Relative Humidity Factor, Sea Salt
Haze_Dv	Haze Dv
Impairment	Impairment
ECf	Carbon, Elemental Total (Fine)
ammNO3f_Large	Ammonium Nitrate (Fine), Large Fraction
ammSO4f_Large	Ammonium Sulfate (Fine), Large Fraction
OMCf_Large	Organic Carbon Mass (Fine), Large Fraction
MF	Mass, PM2.5 (Fine)
MT	Mass, PM10 (Total)
NC2SiaEammNO3	Natural Conditions 2 annual mean Ammonium Nitrate Extinction
NC2SiaEammSO4	Natural Conditions 2 annual mean Ammonium Sulfate Extinction
NC2SiaECM	Natural Conditions 2 annual mean Coarse Extinction

Code	Description
NC2SiaEEC	Natural Conditions 2 annual mean Elemental Carbon Extinction
NC2SiaESoil	Natural Conditions 2 annual mean Fine Soil Extinction
NC2SiaEOC	Natural Conditions 2 annual mean Organic Extinction
NO3f	Nitrate (Fine)
NonEpiECM	Non Episodic CM extinction
NonEpiECM_AM	Non Episodic CM extinction annual mean
NonEpiELAC	Non Episodic LAC extinction
NonEpiELAC_AM	Non Episodic LAC extinction annual mean
NonEpiEOMC	Non Episodic OMC extinction
NonEpiEOMC_AM	Non Episodic OMC extinction annual mean
NonEpiESoil	Non Episodic soil extinction
NonEpiESoil_AM	Non Episodic soil extinction annual mean
O_Rat	O Rat
OC1f	Carbon, Organic Fraction 1 (Fine)
OC2f	Carbon, Organic Fraction 2 (Fine)
OC3f	Carbon, Organic Fraction 3 (Fine)
OC4f	Carbon, Organic Fraction 4 (Fine)
OMCf	Carbon, Organic Mass (Fine) (1.8*OC)
OPf	Carbon, Organic Pyrolized (Fine), by Reflectance
RoutBext	Routine Extinction
RoutDv	Routine Deciview
RoutEammNO3	Routine ammNo3 extinction
RoutEammSO4	Routine ammSo4 extinction
RoutECM	Routine CM extinction
RoutELAC	Routine LAC extinction
RoutEOMC	Routine OMC extinction
RoutESeaSalt	Routine sea salt extinction
RoutESoil	Routine soil extinction
SeaSaltf	Sea Salt (Fine); 1.8 x [Chloride], or 1.8 x [Chlorine]if the chloride measurement is below detection limits, missing or invalid.
Sf	Sulfur (Fine)
SIf	Silicon (Fine)
ammNO3f_Small	Ammonium Nitrate (Fine), Small Fraction
ammSO4f_Small	Ammonium Sulfate (Fine), Small Fraction
OMCf_Small	Organic Carbon Mass (Fine), Small Fraction
SO4f	Sulfate (Fine)
SOILf	Soil (Fine)
S_Rayleigh	Site Rayleigh

Code	Description
SVR	Standard Visual Range
total_bext	Total extinction, aerosol + rayleigh
TIf	Titanium (Fine)

C. IMPROVE Equation

EPA's 2003 guidance on tracking progress and estimating natural conditions was based on the first IMPROVE algorithm[3]. Limitations of the original IMPROVE algorithm led to the development of a second IMPROVE algorithm which has been used for all analyses in this document.

The revised IMPROVE equation uses PM species concentrations and relative humidity data to calculate visibility impairment or beta extinction (Bext) in units of inverse megameters (Mm^{-1}):

$$Bext\_Total = Bext\_AmmSO4 + Bext\_AmmNO3 + Bext\_OA + Bext\_EC + Bext\_Soil + Bext\_Seasalt + Bext\_CM + Bext\_Rayleigh$$

where the light scattering efficiency each PM species is:

Bext_AmmSO4 = 2.2 x fs(RH) x [Small Sulfate] + 4.8 x fL(RH) x [Large Sulfate]
Bext_AmmNO3 = 2.4 x fs(RH) x [Small Nitrate] + 5.1 x fL(RH) x [Large Nitrate]
Bext_OA = 2.8 x {Small Organic Mass] + 6.1 x [Large Organic Mass]
Bext_EC = 10 x [Elemental Carbon]
Bext_Soil = 1 x [Fine Soil]
Bext_Seasalt = 1.7 x fss(RH) x [Sea Salt]
Bext_CM = 0.6 x [Coarse Mass]
Bext_Rayleigh = Rayleigh Scattering (site specific)

and fs(RH) = the unitless site-specific water growth factor for small particles as a function of relative humidity (RH),
fL(RH) = the site-specific water growth for large particles,
fss(RH) = the water growth factor for sea salt,
[ ] = particulate matter concentrations in μg/m^3.

Ammonium sulfate, ammonium nitrate, and organic mass are split into small and large modes based on their mass. For masses less than 20 μg/m^3, the fraction in the large mode is estimated by dividing the total concentration of the component by 20 μg/m^3. Rayleigh is the scattering of sunlight off the gas molecules of the atmosphere and is not measured by the IMPROVE monitors and is assumed to be constant but vary by site.

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[3] EPA. 2003. Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule; EPA-454/B-03-005; U.S. Environmental Protection Agency: Washington, DC, September 2003. Web Access: https://www.epa.gov/sites/production/files/2021-03/documents/tracking.pdf

The second IMPROVE algorithm has been used for all Alaska RH analyses. The limitations of the original IMPROVE algorithm are especially relevant to Alaska's remote and coastal Class I areas. The original IMPROVE algorithm tended to underestimate light extinction for the highest haze conditions and overestimate it for the lowest haze conditions. Alaska has very low haze levels compared to the rest of the United States. The original IMPROVE algorithm used a ratio of organic compound mass to total carbon mass of 1.4, though the literature indicated that the ratio is higher especially in remote areas, such as Alaska. The original algorithm also didn't include a term for sea salt, which is important for sites near the coasts. Other limitations include use of a single Rayleigh scattering estimate for all sites, and flawed assumptions used to estimate 20% best and worst conditions. The second IMPROVE algorithm addressed these limitations, so it is used here.