Chapter 3 Primer on Visibility

In order to better understand the information presented in the document, this chapter describes basic plan elements and key concepts.

3.1 Natural Sources of Visibility Impairment

Natural sources of visibility impairment include anything not directly attributed to human caused emissions of visibility impairing pollutants.

Natural events (e.g. windblown dust, wildfire, volcanic activity, biogenic emissions) also introduce pollutants that contribute to haze in the atmosphere. Specific natural events can lead to high short-term concentrations of visibility impairing particulate matter and its precursors.

Natural sources, particularly wildfire and windblown dust, can be major contributors to visibility impairment. However, these emissions cannot be realistically controlled or prevented by the states, and therefore the focus of the regional haze strategies in this document are on human-caused (anthropogenic) sources, as described below. While current methods of analysis of monitoring data do not provide a clear distinction between natural and anthropogenic emissions, certain pollutant species, such as Sulfur Dioxide (SO_2) and Nitrogen Oxide (NO_x) are more representative of anthropogenic sources, while Organic Carbon (OC) and Coarse Particulate Matter (PM_{10}) are more representative of natural sources such as wildfire and dust, respectively.

Even when there is an absence of emissions, visibility can be degraded by the scattering of light by air molecules. This is called Rayleigh scattering and is affected by the air molecules' temperature and density.

Therefore, natural visibility conditions, for the purpose of the Regional Haze (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 contemporary vegetated landscape, land use patterns, and meteorological/climatic conditions.

3.2 Human Caused Sources of Visibility Impairment

Anthropogenic, or human-caused, sources of visibility impairment include anything directly attributable to human-caused activities that produce emissions of visibility impairing pollutants. Some examples include industrial activities, transportation, agricultural activities, home heating, and managed outdoor burning. Anthropogenic sources can be local, regional, or international. Efforts to regulate anthropogenic emissions are mostly limited to inside the United States. Emissions from Mexico, Canada and off-shore marine shipping emissions in the Pacific Ocean are examples of anthropogenic sources that contribute to visibility impairment in Washington, but like natural sources, are beyond the scope of this planning document.

3.3 Emissions

Both natural sources and anthropogenic sources produce visibility impairing pollutants or emissions. Once particles and gases are emitted, they may go through chemical changes before they are captured by an air sampler. For this reason, the chemical species causing visibility impairment may not be the same species that are emitted by a pollution source.

3.4 The IMPROVE Program for Visibility Monitoring

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program is a cooperative effort with the primary purposes of protection of visibility in mandatory Class I areas and characterization of RH. The objectives of IMPROVE program are to:

- Establish current visibility and aerosol conditions in mandatory Class I Areas
- Identify chemical species and emission sources responsible for existing man-made visibility impairment
- Document long-term trends for assessing progress towards the national visibility goal
- Provide regional haze monitoring representing all visibility protected Class I Areas where practical in support of the Regional Haze Rule (RHR)

The IMPROVE monitoring sites are operated and maintained through a formal cooperative relationship between Environmental Protection Agency (EPA), National Parks Service, Fish and Wildlife Service, Bureau of Land Management, and Forest Service. In addition, 4 inter-state agencies have joined the IMPROVE Steering Committee.

The IMPROVE monitor is designed to obtain a complete signature of the composition of the airborne particles affecting visibility. Each IMPROVE monitor collects a 24-hour sample of these particles onto a set of filters to determine the standard chemical components causing visibility impairment at that site.

In order to simplify the data analysis, some elemental particles and compounds are grouped together (based on scientific principles) into seven standard components. The seven standard components aerosol components of light extinction are listed in Table 3-1 along with the default color used in graphics throughout this document.

Table 3-1 Interagency Monitoring of Protected Visual Environments Monitor Aerosol Composition

Aerosol Component	Abbreviation (Color)
1. Ammonium Sulfate	$(NH_4)SO_4$ (yellow)
2. Ammonium Nitrate	NH_4NO_3 (red)
3. Organic Mass Carbon	OMC (green)
4. Elemental Carbon	EC (black)
5. Fine Soil	Soil (orange)
6. Coarse Mass	CM (gray)
7. Sea Salt	Sea Salt (light blue)

The IMPROVE monitor consists of four independent modules with a common controller. Each module has a specific function though there is some redundancy between modules.

- Module A, the primary module, collects fine particles ($PM_{2.5}$) on a Teflon filter. The mass of $PM_{2.5}$ on the filter is determined from the difference in the filter's weight before and after use in the module. The filter is also analyzed for a long list of elements. The analyses are used to determine concentrations of sulfate, nitrate, fine soil, and sea salt.
- Module B collects $PM_{2.5}$ on a nylon filter for sulfate, nitrate, and chloride analyses. If sulfate, nitrate, or sea salt measurements from Module A are missing. the less accurate measurements from Module B may be used in their place.
- Module C collects $PM_{2.5}$ on a quartz filter for total organic carbon and total elemental carbon analyses.
- Module D collects all particles up to 10 µm in size (PM_{10}) on a Teflon filter. Coarse Mass is estimated by subtracting the $PM_{2.5}$ mass measured on Module A from the PM_{10} mass measured on Module D.

The diagram of an IMPROVE monitor in Figure 3-1 shows the 4 modules, the size of particulates collected by each, the filter materials, and the analytical results..

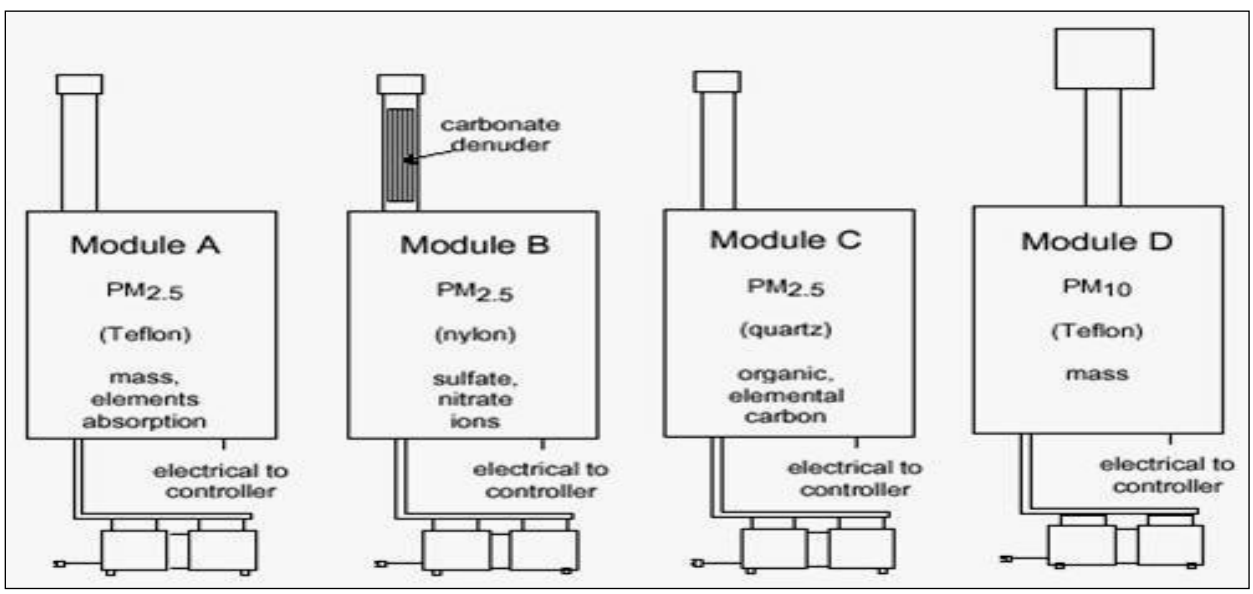

Figure 3-1 Diagram of the Interagency Monitoring of Protected Visual Environments Monitor

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

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.

3.5 The Revised Interagency Monitoring of Protected Visual Environments Equation and Measuring Visibility Impairment

Some of the particles that compose aerosols absorb light, while others reflect or scatter light. Both absorption and scattering of light result in light extinction, the technical term for visibility impairment between the viewer and the light source.

Each of the key components of particulate aerosols has characteristics that differ in terms of ability to affect light extinction. For example, the same amount of pure sulfates or nitrates are about three times more effective than fine soil at impairing visibility. Organic carbon is about four times more effective than fine soil and elemental carbon about ten times more effective than fine soil at impairing visibility. Conversely, PM_{10} is about half as effective as fine soil.

A complex calculation called the revised IMPROVE equation addresses the components' differing effects on light extinction.(see Figure 3-2). The revised IMPROVE equation also accounts for site-specific Rayleigh scattering values based on altitude. Rayleigh scattering is the scattering of light by the molecules of air and causes the blue color of the sky.

$b_{ext} \approx$	2.2 x f_s(RH) x [Small Sulfate] + 4.8 x f_L(RH) x [Large Sulfate] + 2.4 x f_s(RH) x [Small Nitrate] + 5.1 x f_L(RH) x [Large Nitrate] + 2.8 x [Small Organic Mass] + 6.1 x f_L(RH) x [Large Organic Mass] + 10 x [*Elemental Carbon*] + 1 x [*Fine Soil*] + 1.7 x f_s(RH) x [Sea Salt] + 0.6 x [*Coarse Mass*] + Rayleigh Scattering (site specific) + 0.33 x [NO_2 (ppb)]

Figure 3-2 Revised Interagency Monitoring of Protected Visual Environments Equation

The result of the revised IMPROVE equation is referred to as the reconstructed light extinction (denoted as b_{ext}). It represents the light extinction due to the aerosol particulates measured at the IMPROVE monitor and is proportional to the mass measured at the monitor.

Additional information including characterization of the IMPROVE equation's performance and a summary of the rationale for the changes in the algorithm is available in the "Revised IMPROVE Algorithm for Estimating Light Extinction from Particle Speciation Data" report prepared by the IMPROVE Steering Committee's Technical Subcommittee for Algorithm Review.

Reconstructed light extinction is expressed in units of inverse Megameters (1/Mm or Mm^{-1}). The RHR requires the tracking of visibility conditions in terms of the Haze Index (HI) metric

expressed in the Deciview (dv) unit[1]. Generally, a one deciview change in the haze index is considered a humanly perceptible change under ideal conditions, regardless of background visibility conditions. The relationship between extinction (Mm^{-1}), haze index (dv) and visual range (mi) is shown in Figure 3-3.

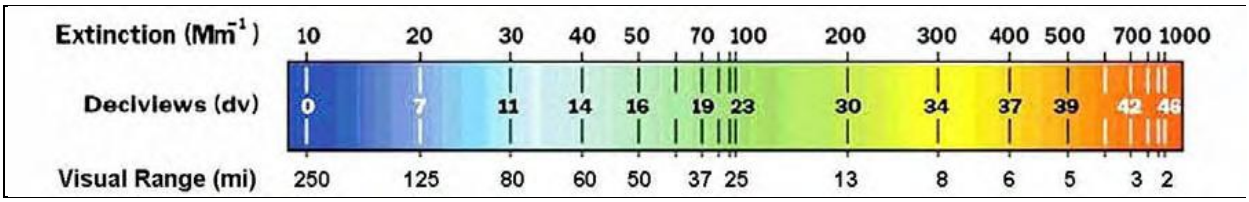

Figure 3-3 Comparison of extinction, deciview, and visual range
Source: William Malm, *Introduction to Visibility*, 1999.

3.6 Baseline Conditions

The RHR requires the calculation of baseline conditions for each mandatory Class I Area. Baseline conditions are defined as the five year average (annual values for 2000 - 2004) of IMPROVE monitoring data (expressed in deciviews) for the Most Impaired and the Least Impaired Days. For this first regional haze plan submittal, the baseline conditions are the reference point against which visibility improvement is tracked.

3.7 Natural Conditions

The visibility that would exist under natural conditions (absent any man-made impairment) would vary based on the contribution of natural sources and meteorological conditions on a given day. For that reason, natural conditions, as defined in this document, consists of a level of visibility (in deciviews) for both the Most Impaired and Least Impaired Days. Since no visibility monitoring data exists from the pre-manmade impairment period, these estimates of natural conditions are based on EPA guidance on how to estimate natural conditions (EPA Document: *Guidance for Estimating Natural Visibility Conditions under the Regional Haze Rule*).

3.8 Uniform Rate of Progress

The Uniform Rate of Progress (URP) is the calculation of the uniform slope, or glide path, of the line between baseline visibility conditions and natural visibility conditions over the 60-year period. For the first regional haze plan, the first benchmark is the dv level that should be achieved in 2018 (Figure 3-4). This is the 2018 Milestone, and applies to both the Most Impaired and Least Impaired Days. The glide path is one of the indicators used to set reasonable progress goals for achieving natural visibility conditions.

[1] 40 CFR 51.308(d)(2)

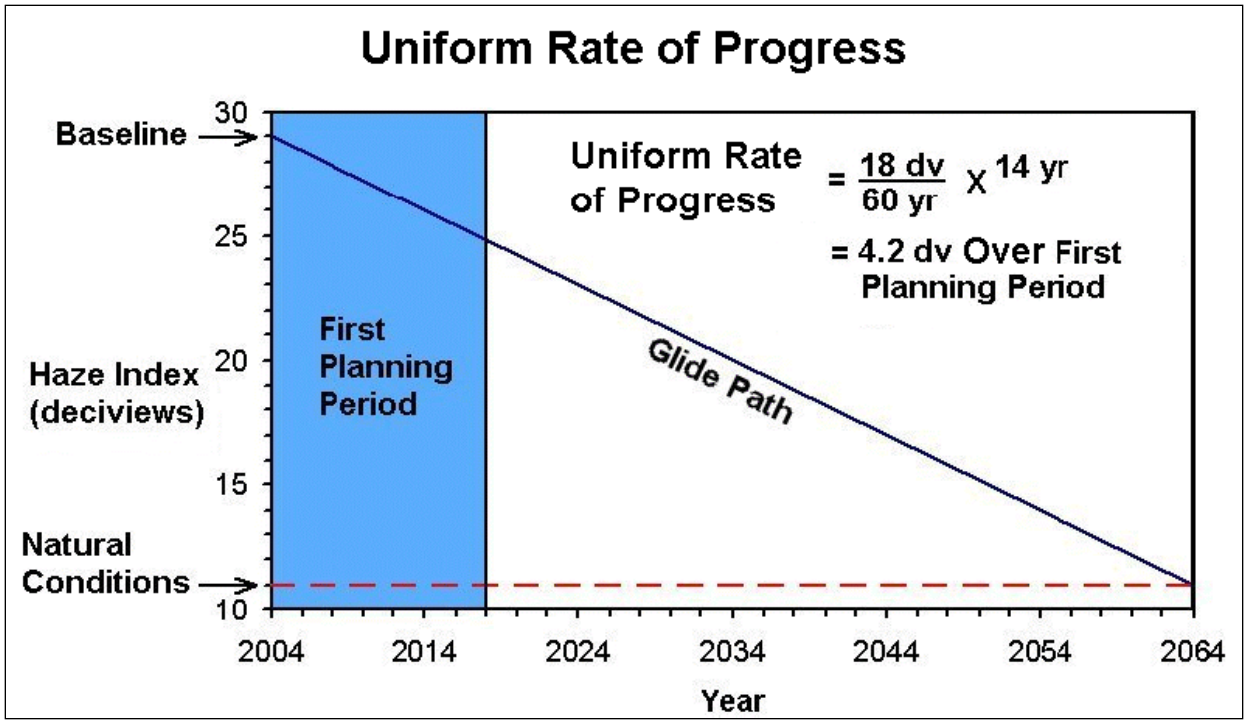

Figure 3-4 Example of How Uniform Rate of Progress is Determined
Source: EPA Guidance for Setting Reasonable Progress Goals under the Regional Haze Program

- Compare baseline conditions to natural conditions. The difference between these two represents the amount of progress needed to reach natural visibility conditions. In this example, the State has determined that the baseline for the Most Impaired Days for the mandatory Class I Area is 29 dv and estimated that natural background is 11 dv, a difference of 18 dv.
- Calculate the annual average visibility improvement needed to reach natural conditions by 2064 by dividing the total amount of improvement needed by 60 years (the period between 2005 and 2064). In this example, this value is 0.3 dv/yr.
- Multiply the annual average visibility improvement needed by the number of years in the first planning period (the period from 2005 until 2018). In this example, this value is 4.2 dv. This is the uniform rate of progress that would be needed during the first planning period to attain natural visibility conditions by 2064.

For the Most Impaired Days, the URP is expressed in deciviews per year (i.e. slope of the glide path) is determined by the following equation:

URP = [Baseline Condition - Natural Condition] / 60 years

The 2018 Progress Goal (i.e. the amount of reduction necessary for the first planning period) is determined by multiplying the URP by the number of years in the first planning period. The first planning period includes the 4 years between the baseline and the SIP submittal date plus the standard 10-year planning period.

2018 Progress Goal = [Uniform Rate of Progress] x [14 years]