4.0 VISIBILITY PROJECTIONS

This section presents the future-year visibility projections for Class I areas within and near the CENRAP states and their comparison with the 2018 Uniform Rate of Progress (URP) point. As noted in Chapter 1, the Regional Haze Rule (RHR) requires states with Class I areas to develop State Implementation Plans (SIPs) that include reasonable progress goals (RPGs) for improving visibility in each Class I area and emission reduction measures to meet those goals. For the initial SIPs due in December 2007, states are required to adopt RPGs for improving visibility from Baseline Conditions. The 2000-2004 five-year period is used to define Baseline Conditions and the first future progress period is 2018. A state is required to set RPGs for each Class I area in the state for two visibility metrics:

- Provide for an improvement in visibility for the most impaired visibility days (i.e., the worst 20 percent days); and

- Ensure no degradation in visibility for the least impaired visibility days (i.e., the best 20 percent days).

The goal of the RPGs is to provide for a rate of improvement sufficient to be on a course to attain “Natural Conditions” by 2064. States are to define controls to meet RPGs every 10 years, starting in 2018, which defines progress periods ending in 2018, 2028, 2038, 2048, 2058 and finally 2064. States will determine whether they are meeting their goals by comparing visibility conditions from one five-year period to another (e.g., 2000-2004 to 2013-2017). As stated in 40 CFR 51.308 (d) (1), baseline visibility conditions, reasonable progress goals, and changes in visibility must be expressed in terms of deciview (dv) units. The haze index (HI) metric of visibility impairment, in deciviews, is derived from light extinction ($b_{ext}$) as follows:

$$HI = 10 \ln \left( \frac{b_{ext}}{10} \right),$$

Where light extinction ($b_{ext}$) is expressed in terms of inverse megameters ($\text{Mm}^{-1} = 10^{-6} \text{ m}^{-1}$). Light extinction ($b_{ext}$) is calculated using the observed fine particulate concentrations from the IMPROVE monitors using either the original or the new IMPROVE aerosol extinction equation. Both equations are discussed below.

4.1 Guidance for Visibility Projections

EPA has published several guidance documents that relate to how modeling results should be used to project future-year visibility and how states should define RPGs:

“Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM$_{2.5}$ and Regional Haze” (EPA, 2007a).


The first EPA modeling guidance document listed above (EPA, 2007) discusses the use of modeling results to project future-year visibility. The second EPA guidance document (EPA, 2003a) focuses on monitored visibility, how to define the visibility Baseline Conditions and how to track visibility goals. The third EPA guidance document discusses procedures for defining Natural Conditions for a Class I area. Natural Conditions are the visibility goal for 2064. Although states may propose alternative approaches for defining Natural Conditions, in this section we use the default Natural Conditions at Class I areas (EPA, 2003b; Pitchford, 2006). The final EPA guidance document discusses how states should define their RPGs and their relationship to the 2018 URP point.

The EPA documents discussed above are followed for the visibility projections presented in this section with one notable exception. Some of the EPA documents are based on the original IMPROVE equation (e.g., EPA, 2003a, b). The CENRAP visibility projections are based on the new IMPROVE equation, although projections based on the original IMPROVE equation are also presented as an alternative approach in Chapter 5. EPA guidance allows for using either the original or the new IMPROVE equation (EPA, 2007a; Timin, 2007). CENRAP, along with the other RPOs, have elected to use the new IMPROVE equation for their visibility projections.

4.2 Calculation of Visibility and 2018 URP Point from IMPROVE Measurements

EPA guidance recommends using the model in a relative sense to project future-year visibility conditions (EPA, 2007a). This projection is made using Relative Response Factors (RRFs) that are defined as the ratio of the future-year modeling results to the base-year modeling results. The RRFs are applied to the baseline visibility conditions to project future-year visibility. The major features of EPA’s recommended visibility projection approach are as follows (EPA, 2003a,b; 2007a):

- Monitored data are used to define current visibility Baseline Conditions using IMPROVE monitoring data from the 2000-2004 five-year base period.

- Monitored concentrations of PM$_{10}$ are divided into six major components, the first five of which are assumed to be PM$_{2.5}$ and the sixth is coarse mass (CM or PM$_{2.5-10}$).
  - SO$_4$ (sulfate) that is assumed to be ammonium sulfate [(NH$_4$)$_2$SO$_4$];
  - NO$_3$ (particulate nitrate) that is assumed to be ammonium nitrate [NH$_4$NO$_3$];
  - OC (organic carbon) that is assumed to be total organic mass carbon (OMC)
  - EC (elemental carbon);
  - IP (other fine inorganic particulate or Soil); and
  - CM (coarse mass).

- Models are used in a relative sense to develop RRFs between baseline and future predicted concentrations of each component.
• PM component-specific RRFs are multiplied by observed Baseline monitored values to estimate future-year PM component concentrations.

• Estimates of future-year component concentrations are consolidated to provide an estimate of future-year air quality and visibility using either the original or new IMPROVE equation.

• Future-year model projected visibility is compared with the 2018 point on the URP glidepath to assist in evaluating the visibility improvements.

• It is assumed that all measured sulfate is in the form of ammonium sulfate \([\text{(NH}_4\text{)}_2\text{SO}_4]\) and all particulate nitrate is in the form of ammonium nitrate \([\text{NH}_4\text{NO}_3]\).

In order to facilitate tracking visibility progress, three important visibility concepts are required for each Class I area:

**Baseline Conditions:** Baseline Conditions represent visibility for the 20 percent best (B20%) and 20 percent worst (W20%) visibility days for the initial five-year baseline period of the regional haze program. Baseline Conditions are calculated using IMPROVE monitor data collected during the 2000-2004 five-year period and are the starting point in 2004 for the URP glidepath and 2018 visibility projections.

**Natural Conditions:** Estimates of natural visibility conditions for the best 20 percent and worst 20 percent days at a Class I area (i.e., visibility conditions that would be experienced in the absence of human-caused impairment). EPA has defined a set of default Natural Conditions for the original IMPROVE equation (EPA, 2003b) that has been updated to the new IMPROVE equation by the Natural Haze Levels II Committee (Pitchford, 2006) that we have used in this Chapter.

**2018 URP Point:** The 2018 Uniform Rate of Progress (URP) point is defined by defining a linear glidepath in deciviews starting with the 2000-2004 Baseline Conditions in 2004 and ending at Natural Conditions in 2064. Where the linear glidepath passes through 2018 is the 2018 URP point in deciviews.

### 4.2.1 Calculation of Visibility from IMPROVE PM Measurements

Baseline Conditions for Class I areas are calculated using the procedures in EPA’s guidance document (EPA, 2003a) and fine and coarse particulate matter concentrations measured at IMPROVE monitors (Malm et al., 2000; Debell et al., 2006). Currently, each Class I area in the CENRAP domain has an associated IMPROVE monitor. The IMPROVE monitors do not directly measure visibility, but instead measure speciated fine particulate (PM\(_{2.5}\)) and total PM\(_{2.5}\) and PM\(_{10}\) mass concentrations from which visibility is obtained through the IMPROVE equation.

Visibility conditions are estimated starting with the IMPROVE 24-hour average mass measurements for six PM species:
- Sulfate \([(\text{NH}_4)_2\text{SO}_4]\);
- Particulate Nitrate \([(\text{NH}_4\text{NO}_3)]\);
- Organic Matter Carbon or Organic Mass by Carbon [OMC];
- Elemental Carbon [EC] or Light Absorbing Carbon [LAC];
- Other fine particulate [Soil]; and
- Coarse Matter or Coarse Mass [CM].

The IMPROVE monitors do not directly measure some of these species so assumptions are made as to how the IMPROVE measurements can be adjusted and combined to obtain these six components of light extinction. For example, in the IMPROVE equation sulfate and particulate nitrate are assumed to be completely neutralized by ammonium. In addition, only the fine mode (PM$_{2.5}$) of PM is speciated by the IMPROVE monitor to obtain sulfate and nitrate measurements (that is, any coarse mode sulfate and nitrate in the real atmosphere may be present in the CM IMPROVE measurement). Concentrations for the above six components of light extinction in the IMPROVE equation are obtained from the IMPROVE measured species using the mappings shown in Table 4-1:

<table>
<thead>
<tr>
<th>IMPROVE Component</th>
<th>IMPROVE Measured Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate</td>
<td>1.375 x (3 x S)</td>
</tr>
<tr>
<td>Nitrate</td>
<td>1.29 x NO$_3^-$</td>
</tr>
<tr>
<td>OMC</td>
<td>1.4<em>OC (original IMPROVE) and 1.8</em>OC (new IMPROVE)</td>
</tr>
<tr>
<td>LAC</td>
<td>EC</td>
</tr>
<tr>
<td>Soil</td>
<td>2.2<em>AL + 2.49</em>SI + 1.63<em>CA + 2.42</em>FE + 1.94*TI</td>
</tr>
<tr>
<td>CM</td>
<td>MT – MF</td>
</tr>
</tbody>
</table>

Where:
- S is elemental sulfur as determined from proton induced x-ray emissions (PIXE) analysis of the IMPROVE Module A\(^1\). To estimate the mass of the sulfate ion (SO$_4^{2-}$), S is multiplied by 3 to account for the presence of oxygen. If S is missing then the sulfate (SO$_4^{2-}$) measured by ion chromatography analysis of the Module B is used to replace (3 x S). For the IMPROVE aerosol extinction calculation, Sulfate is assumed to be completely neutralized by ammonium (1.375 x SO$_4^{2-}$).
- NO$_3^-$ is the particulate nitrate measured by ion chromatography analysis of the Module B. For the IMPROVE aerosol extinction calculation, it is assumed to be completely neutralized by ammonium (1.29 x NO$_3^-$).
- The IMPROVE Organic Carbon (OC) measurements are multiplied by 1.4 to obtain Organic Mass Carbon (OMC) using the original IMPROVE equation and multiplied by 1.8 for the new IMPROVE equation. This adjustment of the measured OC accounts for mass due to other elements in the OMC besides Carbon.
- Elemental Carbon (EC) is also referred to as Light Absorbing Carbon (LAC).

\(^1\) The IMPROVE sampler consists of four independent modules (A, B, C and D). Each module incorporates a separate inlet, filter pack and pump assembly and are controlled by a common timing mechanism. Module A measures fine PM mass and elements. Module B measures sulfate and nitrate ions. Module C measures EC and OC. Module D measures PM$_{10}$ mass. (see http://vista.cira.colostate.edu/improve/ for more details.)
• Soil is determined as a sum of the masses of those elements (measured by PIXE) predominantly associated with soil (Al, Si, Ca, Fe, K and Ti), adjusted to account for oxygen associated with the common oxide forms. Since K and Fe are products of the combustion of vegetation, they are both represented in the formula by 0.6 x Fe and K is not shown explicitly.

• MT and MF are total PM$_{10}$ and PM$_{2.5}$ mass, respectively.

4.2.1.1 Original and New IMPROVE Equations

Associated with each PM species is an extinction efficiency that converts concentrations (in μg/m$^3$) to light extinction (in inverse megameters, Mm$^{-1}$). Sulfate and nitrate are hygroscopic which means that they can absorb water from the atmosphere which changes their extinction efficiency. This is accounted for through relative humidity adjustment factors [f(RH)] that increase the particle’s extinction efficiency with increasing RH to account for the particles taking on water. Note that some OMC may also have hygroscopic properties, but the IMPROVE equations assume OMC is non-hygrosopic.

There are currently two IMPROVE equations that are used to convert the measured PM concentrations to light extinction, the original (or old) and the new IMPROVE equations.

4.2.1.1.1 Original IMPROVE Equation

The original IMPROVE equation that converts PM species concentrations to light extinction is given as follows:

\[
\begin{align*}
    b_{\text{Sulfate}} &= 3 \times f(\text{RH}) \times [\text{Sulfate}] \\
    b_{\text{Nitrate}} &= 3 \times f(\text{RH}) \times [\text{Nitrate}] \\
    b_{\text{EC}} &= 10 \times [\text{EC}] \\
    b_{\text{OMC}} &= 4 \times [\text{OMC}] \\
    b_{\text{Soil}} &= 1 \times [\text{Soil}] \\
    b_{\text{CM}} &= 0.6 \times [\text{CM}]
\end{align*}
\]


The total light extinction ($b_{\text{ext}}$) is assumed to be the sum of the light extinction due to the six PM species listed above plus Rayleigh (blue sky) background ($b_{\text{Ray}}$) that is assumed to be 10 Mm$^{-1}$.

\[
b_{\text{ext}} = b_{\text{Ray}} + b_{\text{Sulfate}} + b_{\text{Nitrate}} + b_{\text{EC}} + b_{\text{OMC}} + b_{\text{Soil}} + b_{\text{CM}}
\]

The total light extinction ($b_{\text{ext}}$) in Mm$^{-1}$ is related to visual range (VR) in km using the following relationship:

\[
\text{VR} = \frac{3912}{b_{\text{ext}}}
\]
for $b_{ext}$ in Mm$^{-1}$.

The Regional Haze Rule requires that visibility be expressed in terms of a haze index (HI) in units of deciviews (dv), which is calculated as follows:

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

### 4.2.1.1.2 New IMPROVE Equation

The new IMPROVE equation is nonlinear in SO$_4$, NO$_3$ and OMC concentrations accounting for the different light scattering efficiency characteristics as a function of concentrations for these three species. It is expressed as follows:

- \( b_{Sulfate} = 2.2 \times f_S(RH) \times [Small \ Sulfate] + 4.8 \times f_S(RH) \times [Large \ Sulfate] \)
- \( b_{Nitrate} = 2.4 \times f_S(RH) \times [Small \ Nitrate] + 5.1 \times f_S(RH) \times [Large \ Nitrate] \)
- \( b_{EC} = 10 \times [Elemental \ Carbon] \)
- \( b_{OMC} = 2.8 \times [Small \ Organic \ Mass] + 6.1 \times [Large \ Organic \ Mass] \)
- \( b_{Soil} = 1 \times [Fine \ Soil] \)
- \( b_{CM} = 0.6 \times [Coarse \ Mass] \)
- \( b_{NaCl} = 1.7 \times f_{SS}(RH) \times [Sea \ Salt] \)
- \( b_{NO2} = 0.33 \times [NO_2 \ (ppb)] \)

The total Sulfate, Nitrate and OMC are each split into two fractions, representing small and large size distributions of those components. As noted in Table 4-1, the OMC is 1.8 times the IMPROVE OC measurement in the new IMPROVE algorithm, compared to 1.4 times the IMPROVE OC measurement in the original IMPROVE equation. New terms have been added for Sea Salt (important for coastal areas and possibly other areas) and for light absorption by NO$_2$ (only used where NO$_2$ observations are available). As none of the CENRAP Class I area IMPROVE sites measure NO$_2$ concentrations, then this component of the new IMPROVE equations was not used. Site-specific Rayleigh scattering for each IMPROVE monitoring site is used in the new IMPROVE equation, as compared to a constant 10 Mm$^{-1}$ value assumed in the original IMPROVE equation.

The apportionment of the Small and Large components of Sulfate, Nitrate and Organic Mass is done as follows:

- \([Large \ Sulfate] = [Total \ Sulfate] / 20 \times [Total \ Sulfate], \ for \ [Total \ Sulfate] < 20 \ \mu g/m^3 \)
- \([Large \ Sulfate] = [Total \ Sulfate], \ for \ [Total \ Sulfate] \geq 20 \ \mu g/m^3 \)
- \([Small \ Sulfate] = [Total \ Sulfate] - [Large \ Sulfate] \)

The same equations are used to apportion Total Nitrate and Total OMC among their Large and Small components.

The total extinction ($b_{ext}$) in the new IMPROVE equations is the sum of all the extinction components associated with each PM species. The new IMPROVE equation adds Sea Salt and...
NO\textsubscript{2} as noted above. In addition, site-specific Rayleigh background is used with the new IMPROVE equation:

\[ b_{\text{ext}} = b_{\text{Ray}} + b_{\text{Sulfate}} + b_{\text{Nitrate}} + b_{\text{EC}} + b_{\text{OMC}} + b_{\text{Soil}} + b_{\text{CM}} + b_{\text{NaCl}} + b_{\text{NO2}} \]

The Haze Index (HI) and Visual Range (VR) are calculated from the total extinction from the new IMPROVE equation using the same formulas as given above for the original IMPROVE equation.

4.2.1.1.3 Justification for Using the New IMPROVE Equation

The new IMPROVE equation was developed using the latest scientific information on PM species extinction properties combined with fitting reconstructed light extinction based on IMPROVE measured PM and NO\textsubscript{2} concentrations with actual co-located measured light extinction (e.g., nephelometer measurements). Figure 4-1 displays example comparisons of 24-hour light extinction using the original and new IMPROVE equations compared against 24-hour nephelometer measurements of light extinction at the Great Smoky Mountains Class I area IMPROVE monitor. The original IMPROVE equation has a bias toward understating light extinction at the high end and overstating it at the low end, whereas the new IMPROVE equation does a better job in estimating light extinction from measured PM at all extinction levels. Because the new IMPROVE equation is based on more recent science and fits the observed light extinction values better, the CENRAP states have elected to perform their primary visibility projections using the new IMPROVE equation. Results using the original IMPROVE equation are presented in Section 5 as an alternative approach.

![Figure 4-1. Comparisons of observed light extinction with reconstructed light extinction using the new (left) and original (right) IMPROVE equations at the Great Smoky Mountains National Park.](image-url)
4.2.2 Calculation of the Baseline Conditions

The visibility Baseline Conditions for the worst 20 percent and best 20 percent days is calculated from the IMPROVE observations from the 2000-2004 period for each Class I area following EPA’s guidance (EPA, 2003a). The basic procedures for calculating the Baseline Conditions are as follows:

1. Determine whether the observed IMPROVE data for each site and year satisfies EPA’s minimal data capture criteria (EPA, 2003a). If there are less than three years with valid data capture for the 2000-2004 Baseline then the Baseline Conditions can not be calculated and data filling is needed.
2. For each year in the 2000-2004 period with sufficient valid data, rank the visibility in terms of extinction or deciview using either the original or new IMPROVE equation and monthly average f(RH) factors (EPA, 2003a).
3. For the worst 20 percent days, extract the 20% most impaired visibility days for each year (similarly for best 20 percent days extract 20% cleanest days). With a complete yearly data capture of IMPROVE 1:3 day sampling frequency this would result in 24 worst 20 percent and 24 best 20 percent days in a year.
4. For each worst 20 percent (or best 20 percent) day in each year, calculate 24-hour average visibility extinction using the IMPROVE measurements and either the original and new IMPROVE equation, convert the daily extinction to daily deciview and then average across each year to get yearly average deciview extinction for the worst 20 percent (or best 20 percent) days for each valid year from the 2000-2004 period.
5. Average the annual average deciview worst 20 percent (or best 20 percent) days deciview across each valid year in the 2000-2004 period (minimum of 3 valid years required) to get the worst 20 percent (or best 20 percent) Baseline Conditions.

4.2.3 Data Filling for Sites with Insufficient Valid Data to Calculate Baseline Conditions

Three CENRAP Class I areas did not contain sufficient IMPROVE observations during the five-year 2000-2004 Baseline to have three valid years of data from which Baseline Conditions could be constructed: Breton Island (BRET), Louisiana; Boundary Waters (BOWA), Minnesota and Mingo (MING), Missouri. For these three Class I areas, data filling was used to obtain sufficient data so that at least three-years of valid data were available from which Baseline Conditions could be calculated. These data filled IMPROVE databases were prepared and made available on the VIEWS website. More information on the data filling procedures can be found at the VIEWS website: (http://vista.cira.colostate.edu/views/).

4.2.4 Natural Conditions

EPA has published default Natural Conditions for Annual Average and the worst 20 percent and best 20 percent days based on the original IMPROVE equation (EPA, 2003b). These default Natural Conditions have been updated to the new IMPROVE equation by the Natural Haze Levels II Committee (Pitchford, 2006). These default Natural Conditions are used as the anchor point for the glidepaths in 2064 and are provided in Appendix D for the CENRAP Class I areas.
4.2.5 2018 URP Point

The 2018 point on the Uniform Rate of Progress (URP) glidepath is constructed by generating a linear glidepath in deciviews from the Baseline Conditions in 2004 to Natural Conditions in 2064. Where the linear glidepath crosses 2018 is the 2018 point on the URP glidepath or the 2018 URP point. Figure 4-2 displays an example linear glidepath for the Caney Creek Class I area in Arkansas. There are three years of sufficient valid IMPROVE data during the 2000-2004 Baseline (2002, 2003 and 2004) with values of 27.21, 26.52 and 25.34 dv resulting in worst 20 percent Baseline Conditions of 26.36 dv that is placed as the starting point in 2004 for the glidepath. The ending point for the glidepath is 11.58 dv which is the default Natural Conditions for the worst 20 percent days (EPA, 2003b; Pitchford, 2006). The linear glidepath crosses 2018 at 22.91 dv which becomes the 2018 URP point.

Figure 4-2. Linear Glidepath for Caney Creek (CACR), Arkansas that linearly connects the 26.36 dv Baseline Conditions in 2004 with the 11.58 dv Natural Conditions in 2064 resulting in a 22.91 dv 2018 URP Point.

4.3 EPA Default Approach to Visibility Projections

For CENRAP’s model application for a single year (2002), EPA’s regional haze modeling guidance recommends developing Class I area-specific and PM species-specific RRFs based on the average concentrations for the worst 20 percent days from 2002 (EPA, 2007). Thus, this is
the methodology used to project 2018 visibility estimates in this section. For example, if SO4(2002)_i and SO4(2018)_i are the model estimated sulfate concentrations for the 2002 worst 20 percent days (i=1…N) at a given Class I area for the 2002 and 2018 emission scenarios then the RRF for sulfate and this Class I area is given by:

\[
RRF(SO4)_i = \frac{\sum SO4(2018)_i}{\sum SO4(2002)_i}
\]

4.3.1 Mapping of Modeling Results to the IMPROVE Measurements

As noted above, to project future-year visibility at Class I areas the modeling results are used in a relative sense to scale current observed visibility for the worst 20 percent and best 20 percent visibility days using RRFs that are the ratio of modeling results for the future-year to current-year. This scaling is done separately for each of the six components of light extinction in the IMPROVE equations. The CMAQ modeled species do not necessarily exactly match up with the IMPROVE PM species, thus assumptions must be made to map the modeled species to the IMPROVE PM species for the purpose of projecting visibility improvements. For example, CMAQ explicitly simulates ammonium and sulfate may or may not be fully neutralized in the model by ammonium, whereas the IMPROVE equations assume sulfate is fully neutralized by ammonium. For the CMAQ Version 4.5 (September 15, 2005 release) model, the mapping of modeled species to IMPROVE equation PM species is listed in Table 4-2.

Table 4-2. Mapping of CMAQ V4.5 modeled species concentrations to IMPROVE PM components.

<table>
<thead>
<tr>
<th>IMPROVE Component</th>
<th>CMAQ V4.3 Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate</td>
<td>1.375 x (ASO4J + ASO4I)</td>
</tr>
<tr>
<td>Nitrate</td>
<td>1.29 x (ANO3J + ANO3I)</td>
</tr>
<tr>
<td>LAC</td>
<td>AECJ + AECI</td>
</tr>
<tr>
<td>OMC</td>
<td>AORGAJ + AORGAI + AORGPAJ + AORGPAI + AORGBJ + AORGBI</td>
</tr>
<tr>
<td>Soil</td>
<td>A25J + A25I</td>
</tr>
<tr>
<td>CM</td>
<td>ACORS + ASEAS + ASOIL</td>
</tr>
</tbody>
</table>

For the CENRAP visibility projections using the 2002 Typical and 2018 base case Base G emission scenarios, the secondary organic aerosol (SOA) module in CMAQ V4.5 was modified (SOAmods) to include additional processes related to the generation of SOA from biogenic emissions. In particular, three new species have been added that represent SOA products from biogenic emission compounds that is not included in the standard version of CMAQ V4.5 (Morris et al., 2006c):

- **ASOC1** – SOA from biogenic sources (e.g., terpenes and isoprene) that has become polymerized so is no longer volatile.
- **ASOC2** – SOA from biogenic sesquiterpene and higher reactivity and higher yield monoterpene emissions.
- **ASOC3** – SOA from biogenic isoprene emissions.
Thus, the species mapping for Organic Mass Carbon (OMC) and the CMAQ V4.5 SOAmods version of the model used in CENRAP 2018 visibility projections is as given in Table 4-2 only with the addition of the three new biogenic SOA species to OMC as follows:

$$OMC = AORGAJ + AORGAI + AORGPAJ + AORGPAI + AORGBJ + AORGBI + ASOC1 + ASOC2 + ASOC3$$

### 4.3.2 Using Modeling Results to Project Changes in Visibility

Modeling results are used in a relative fashion to project future-year visibility using relative response factors (RRFs). RRFs are expressed as the ratio of the modeling results for the future-year to the results of the base year (2018/2002) and are Class I area and PM species specific. RRFs are applied to the Baseline Condition observed PM species to project future-year PM levels from which visibility can be assessed using the IMPROVE equations listed above. The following six steps are used to project future-year visibility for the worst 20 percent and best 20 percent visibility days (discussion is for worst 20 percent days but also applies to best 20 percent days):

1. For each Class I area and each monitored day, daily visibility is ranked using IMPROVE data and IMPROVE equation (either original or new IMPROVE equation) for each year from the five-year baseline period (2000-2004) to identify the worst 20 percent visibility days for each year from the five-year baseline (see Baseline Conditions discussion above).

2. Use an air quality model to simulate a base year period (ideally the five-year Baseline period of 2000-2004, but for CENRAP just the 2002 annual period was simulated) and a future-year (e.g., 2018) and use the resulting information to develop Class I area-specific RRFs for each of the six components of light extinction in the IMPROVE equation (SO4, NO3, EC, OMC, Soil and CM).

3. Multiply the RRF times the measured 24-hour PM concentration data for each day from the worst 20 percent days in each year from the five-year Baseline period to obtain projected future-year 24-hour PM concentrations for the worst 20 percent days and the five-year Baseline.

4. Compute the future-year daily extinction using the IMPROVE equation and the projected PM concentrations for each of the worst 20 percent days in the five-year baseline from Step 3.

5. For each of the worst 20 percent days within each year of the five-year baseline, convert the future-year daily extinction to deciview and average the daily deciview values within each of the five years separately to obtain five-years (or as many years with valid data in the 2000-2004 Baseline) of average deciview visibility for the worst 20 percent days.

6. Average the five-years of average deciview visibility to obtain the future-year visibility Haze Index estimate that is the future-year estimated visibility.
In calculating the RRFs, EPA draft guidance recommends selecting estimated PM species concentrations “near” the monitor by taking a spatial average of PM concentrations across a grid cell resolution dependent NX by NY array of cells centered on the grid containing the monitor. The NX x NY array of cells is grid resolution specific with EPA recommending that NX=NY=1 for 36 km grids, NX=NY=3 for 12 km grids and NX=NY=7 for 4 km grids (EPA, 2007). For the CENRAP 2002 36 km modeling, just the model estimates for the grid cell containing the monitor was used (i.e., NX=NY=1).

4.4 EPA Default 2018 Visibility at CENRAP and Nearby Class I areas and Comparisons to 2018 URP Goals

Using the EPA default visibility projection procedure described in Section 4.3 and the CENRAP 2002 Typical Base G and 2018 Base Case Base G CMAQ modeling results, 2018 visibility projections were made for CENRAP and nearby Class I areas. Appendix D details the 2018 Base G visibility projections for each Class I area in the CENRAP region using the new IMPROVE equation. Results for the Caney Creek (CACR), Arkansas Class I area are discussed in Section 4.4.1 below. Displays for other CENRAP Class I areas are provided in Appendix D and summarized in Section 4.4.2.

4.4.1 Example 2018 Base G Visibility Projections for Caney Creek, Arkansas

The 2018 visibility projections for the Caney Creek (CACR), Arkansas Class I area given in Figure D-1 in Appendix D are reproduced in Figure 4-3 and described below.

4.4.1.1 EPA Default 2018 Visibility Projections

The 2018 Base G visibility projection using the EPA default method (EPA, 2007a) and comparison with the 2018 URP point for the worst 20 percent days and the CACR Class I area is shown in Figure 4-3a. The 2000-2004 Baseline Conditions for CACR is 26.36 dv and the 2018 URP point is 22.91 dv so that a 3.45 dv reduction in visibility for the worst 20 percent days is needed to meet the 2018 URP point. The 2018 Base G CMAQ projected visibility is 22.48 dv so that the modeling predicts more visibility improvements (3.88 dv reduction) than required to meet the 2018 URP point (3.45 dv reduction). When looking at visibility projections across several Class I areas, it has been useful to present the 2018 visibility projections as a percentage of meeting the 2018 URP point; where 100% is meeting the point, greater than 100% surpassing the point (i.e., below the glidepath) and less than 100% means that less visibility improvement is achieved than needed to meet the 2018 URP point. For 2018 Base G CMAQ modeling at CACR, we achieve 112% of the visibility reduction needed to meet the 2018 URP point. Note that meeting the 2018 URP point is not a requirement of the RHR SIPs, rather it just serves as a benchmark to compare progress toward Natural Conditions in 2064 and is designed to help states in selecting their 2018 RPGs. As clearly stated in EPA guidance “The glidepath is not a presumptive target, and States may establish a RPG that provides for greater, lesser, or equivalent improvement as that described by the glidepath” (EPA, 2007b).
The 2018 Base G CMAQ visibility projections for the best 20 percent days and CACR is shown in Figure 4-3b. Recall the RHR goal for this visibility metric is no worsening of the visibility for the best 20 percent days. The Baseline Conditions for the best 20 percent days at CACR is 11.24 dv. The 2018 Base G projected visibility for the best 20 percent days is 10.35 dv, which represents a 0.89 dv visibility improvement for the best 20 percent days at CACR and demonstrating no worsening in visibility for the best 20 percent days.

Figure 4-3c displays “StackedBar Chart” plots of observed and model estimated extinction for each of the worst 20 percent days in 2002 and the 2002 Typical Base G CMAQ simulation and the average across the worst 20 percent days. This figure allows a comparison of how well the model is reproducing the observed extinction at CACR for the worst 20 percent days in 2002 and the breakdown of the PM components that are contributing to visibility impairment (more details on model performance were presented in Chapter 3). The 2002 worst 20 percent days at CACR are dominated by SO4 days (yellow), although during the winter there are also three days dominated by NO3 (Julian Days 80, 320 and 341). For most of the worst 20 percent days at CACR, the model reproduces the observed extinction reasonably well, although it does tend to understate SO4 on a few days and overstate NO3 on the four winter days. The observed average extinction across the 2002 worst 20 percent days at CACR is 150 Mm\(^{-1}\), compared to a modeled value that is 23% lower (115 Mm\(^{-1}\)).

Figure 4-3d displays “Boxplots” of differences in modeled extinction for the 2002 worst 20 percent days between the 2018 Base G and 2002 Typical Base G CMAQ simulations. On most days SO4 is the largest component of the extinction that is estimated to be reduced at CACR on the worst 20 percent days. The exception to this is for the winter NO3 days where NO3 is the largest component of extinction that is reduced. The modeling results are not used directly in the visibility projections, rather they are used to develop the PM-species specific RRFs. That is, an important attribute in Figures 4-3c and 4-3d is the relative changes in the modeled PM species averaged across the worst 20 percent days that are represented by the last bar in each figure and provide insight into the RRFs used in the visibility projections. These results are summarized in Table 4-3 below. Table 4-3 compares the average extinction across the 2002 worst 20 percent days at CACR from the measured IMPROVE data, the modeled values and the modeled change in extinction between the 2018 and 2002 emissions scenarios. Although the results in Table 4-3 are not RRFs (RRFs are based on ratios of concentrations not extinction) they do show how the RRFs may magnify or deflate the importance of a modeled PM species. For example, the model estimates that approximately 23% (26.66 Mm\(^{-1}\)) of the visibility extinction average across the worst 20 percent days is due to NO3, whereas it is only 7% in the observed values (10.22 Mm\(^{-1}\)). So the modeled ~40% reduction in NO3 between the 2018 and 2002 scenarios is applied to the smaller observed NO3 value to obtain the 2018 projected NO3 value making NO3 a smaller portion of the 2018 projected visibility than the 2018 modeled visibility. On the other hand, the modeled SO4 extinction is less than observed so that its importance in the 2018 projections is much greater than in the modeled 2018 SO4 values.
Table 4-3. Observed and Modeled Extinction by Species Averaged Across the Worst 20 Percent Days in 2002 at CACR.

<table>
<thead>
<tr>
<th>Species</th>
<th>2002 Average Observed W20% (Mm⁻¹)</th>
<th>2002 Average Modeled W20% (Mm⁻¹)</th>
<th>2018-2002 Reduction (Mm⁻¹)</th>
<th>2018-2002 Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bSO4</td>
<td>109.50</td>
<td>67.90</td>
<td>-24.47</td>
<td>-36%</td>
</tr>
<tr>
<td>bNO3</td>
<td>10.22</td>
<td>26.66</td>
<td>-10.90</td>
<td>-41%</td>
</tr>
<tr>
<td>bOMC</td>
<td>19.65</td>
<td>16.68</td>
<td>-2.12</td>
<td>-13%</td>
</tr>
<tr>
<td>bEC</td>
<td>4.38</td>
<td>2.32</td>
<td>-0.67</td>
<td>-29%</td>
</tr>
<tr>
<td>bSOIL</td>
<td>1.43</td>
<td>1.04</td>
<td>+0.21</td>
<td>+20%</td>
</tr>
<tr>
<td>bCM</td>
<td>4.30</td>
<td>0.37</td>
<td>-0.01</td>
<td>-3%</td>
</tr>
</tbody>
</table>

Figure 4-3a. 2018 Visibility Projections and 2018 URP Glidepaths in Deciview for Caney Creek (CACR), Arkansas and Worst 20 Percent (W20%) days Using 2002/2018 Base G CMAQ 36 km Modeling Results.
Figure 4-3b. 2018 Visibility Projections and 2018 URP Glidepaths in Deciview for CACR, Arkansas and Best 20 Percent (B20%) days Using 2002/2018 Base G CMAQ 36 m Modeling Results.

Figure 4-3c. Comparison of Observed (left) and 2002 Base G Modeled (right) Daily Extinction for Caney Creek (CACR), Arkansas and Worst 20 Percent (W20%) days in 2002.
Figure 4-3d. Differences in Modeled 2002 and 2018 Base G CMAQ Results (2018-2002) Daily Extinction for Caney Creek (CACR), Arkansas and Worst 20 Percent (W20%) Days in 2002.

4.4.2 Summary 2018 Visibility Projections Across Class I Areas

Figure 4-4 displays a “DotPlot” of 2018 visibility projections using the 2002 Typical and 2018 base case Base G CMAQ 36 km modeling results. DotPlots present the 2018 visibility projections as a percentage of meeting the 2018 URP point. For example, at CACR the 2018 Base G modeling achieved 112% of the visibility reduction needed to meet the 2018 URP point so the dot under CACR is plotted at 112%. Class I areas’ with dots above 100% surpass the 2018 URP point (i.e., are below the glidepath), whereas Class I areas’ with dots that are under 100% fail to meet the 2018 URP point. Figure 4-4 summarizes the 2018 visibility projections using the EPA default “Regular RRF” and the two alternatives where CM is assumed to be natural (CM RRF=1) and both CM and Soil are assumed to be natural (CM&SOIL RRF=1). When CM or CM&SOIL are assumed to be natural that means that we assume the same CM or CM&SOIL occurs in the 2018 future-year as in the 2000-2004 Baseline Conditions. For the CENRAP sites, the EPA default and alternative projection, assuming CM alone or CM and Soil are natural, techniques produced similar results.

At the four eastern CENRAP Class I area sites close to the Mississippi River (CACR, UPBU, HEGL and MING), the 2018 visibility projections meet (HEGL) or surpass the 2018 URP point. Breton Island Class I area (BRET) comes up 6% short of meeting the 2018 URP point (i.e., 94% of the URP point). Wichita Mountains Class I area (WIMO) comes up approximately 40% short of the 2018 URP point. The two northern Class I areas (BOWA and VOYA) also come up about 40% short of meeting the 2018 URP point (i.e., achieve 69% and 53% of the visibility improvement needed to meet the 2018 URP point). The two Texas Class I areas only achieve...
26% (BIBE) and 34% (GUMO) of the visibility improvement needed to meet the 2018 URP point for the worst 20 percent days. As discussed in more detail in Chapter 5, much of the difficulty for the Texas and some of the other CENRAP Class I areas in meeting the 2018 URP point is due to large contributions due to international transport, much of which (e.g., Mexico and global transport) is assumed to remain unchanged from 2002 to 2018.

Figure 4-4. 2018 Base G CMAQ Visibility Projections for CENRAP and Nearby Class I areas Using DotPlots that Express 2018 Visibility as a Percentage of Meeting the 2018 URP Point On the Deciview Linear Glidepath.

Figure 4-5 displays the model estimated absolute change in extinction (Mm⁻¹) averaged across the 2002 worst 20 percent days at Class I areas in and near the CENRAP region. The largest modeled reductions are in SO4 extinction. Figure 4-6 displays the percent change in the projected PM extinction by PM species for each CENRAP and nearby Class I area average across the worst 20 percent days (i.e., the relative modeled change). The four CENRAP Class I areas that meet the 2018 URP point (CACR, UPBU, HEGL and MING) are characterized by large SO4, NO3 and EC extinction reductions (30-40%) with small Soil increases. At the other CENRAP Class I areas, however, there are lower levels of SO4, NO3 and EC extinction reductions and even some NO3 increases (BIBE). At the non-CENRAP Class I areas, the two VISTAS Class I areas (MACA and SIPS) have large reductions in SO4 extinction (~50%), whereas the WRAP Class I areas SO4 extinction reductions are much smaller.
Average change in extinction components from 2002 baseline to 2018 projected at CENRAP sites using base18g/typ02g RRFs

Average change in extinction components from 2002 baseline to 2018 projected at non-CENRAP sites using base18g/typ02g RRFs

Figure 4-5. Absolute Model Estimated Changes in Extinction (Mm⁻¹) by PM Species for Class I Areas in the CENRAP region (top) and Near the CENRAP region (bottom).
Figure 4-6. Percent Change In Modeled Extinction by PM Species Averaged Across the 2002 Worst 20 Percent Days for Class I areas in the CENRAP region (top) and Near the CENRAP region (bottom).
4.5 2018 Visibility Projections for Base G C1 Control Scenario

The 2018 visibility projections based on the CMAQ simulations for the 2018 Base G C1 Control Strategy simulations are presented in this section. The C1 Control Strategy results in reductions mainly in SO2 and NOx emissions from point sources in the CENRAP states. Consequently, PM improvements are limited to mainly SO4 and NO3 concentration reductions in the CENRAP states. Figure 4-7 displays the differences in CMAQ-estimated annual average SO4 and NO3 concentrations between the 2018 Base G base case and the 2018 Base G C1 Control Strategy case; the differences in all other PM species (with the exception of NH4) were negligible (see: http://pah.cert.ucr.edu/aqm/cenrap/cmaq.shtml#base18gc1vsbase18g). Annual average SO4 concentration reductions of over a quarter of a μg/m³ are estimated to occur in northeast Texas, east Oklahoma, Missouri, northeast Arkansas and up into Iowa and Illinois. There are much lower reductions in NO3 that cover a similar area.

Figure 4-7. CMAQ-Estimated Reductions in Annual Average SO4 (left) and NO3 (right) Fine Particle Concentrations Between the 2018 Base G Base Case and 2018 Base G C1 Control Strategy Case.

Figure 4-8 displays the DotPlot comparisons of the 2018 visibility projections for 2018 Base G and 2018 Base G C1 Control Strategy emission scenarios. The additional controls in the C1 Control Strategy are projected to result in visibility improvements for the worst 20 percent days at Class I areas throughout and near the CENRAP region. Sites are closer to being on the glide path by 10 to 30 percent. For Breton Island this makes a difference of not meeting the 2018 URP point in 2018 Base G (94%) to surpassing the URP point in the C1 Control Strategy (106%).

Table 4-4 presents a tabular summary of the information presented in Figure 4-8, including the Baseline, 2018 URP point, and 2018 projected visibility for the Base G and C1 Control Strategy simulations.
Figure 4-8. 2018 Visibility Projections as a Percentage of Meeting the 2018 URP Point (i.e., DotPlot) for the 2018 Base G and 2018 Base G C1 Control Strategy Emission Scenarios.
Table 4-4. 2000-2004 Baseline, 2018 URP Point, and Projected 2018 Visibility and Percent of Meeting the 2018 URP Point for the 2018 Base G and 2018 C1 Control Strategy CMAQ Simulations.

<table>
<thead>
<tr>
<th>Class I Area Name</th>
<th>State</th>
<th>ID</th>
<th>Lat. (deg)</th>
<th>Lon. (deg)</th>
<th>00/04 Baseline Cond. (dv)</th>
<th>2018 URP Point (dv)</th>
<th>2018 Base G Base Case (dv)</th>
<th>2018 Base G C1 Control Strategy (dv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badlands NP</td>
<td>SD</td>
<td>BADL1</td>
<td>43.81</td>
<td>-102.36</td>
<td>17.14</td>
<td>15.02</td>
<td>16.53</td>
<td>29%</td>
</tr>
<tr>
<td>Big Bend NP</td>
<td>TX</td>
<td>BIBE1</td>
<td>29.33</td>
<td>-103.31</td>
<td>17.30</td>
<td>14.93</td>
<td>16.69</td>
<td>26%</td>
</tr>
<tr>
<td>Boundary Waters Canoe Area</td>
<td>MN</td>
<td>BOWA1</td>
<td>48.06</td>
<td>-91.43</td>
<td>19.58</td>
<td>17.72</td>
<td>18.30</td>
<td>69%</td>
</tr>
<tr>
<td>Breton</td>
<td>LA</td>
<td>BRET1</td>
<td>29.87</td>
<td>-88.82</td>
<td>25.73</td>
<td>22.51</td>
<td>22.72</td>
<td>94%</td>
</tr>
<tr>
<td>Caney Creek Wilderness</td>
<td>AR</td>
<td>CACR1</td>
<td>34.41</td>
<td>-94.08</td>
<td>26.36</td>
<td>22.91</td>
<td>22.48</td>
<td>112%</td>
</tr>
<tr>
<td>Great Sand Dunes NM</td>
<td>CO</td>
<td>GRSA1</td>
<td>37.77</td>
<td>-105.57</td>
<td>12.78</td>
<td>11.35</td>
<td>12.53</td>
<td>18%</td>
</tr>
<tr>
<td>Guadalupe Mountains NP</td>
<td>TX</td>
<td>GUMO1</td>
<td>31.91</td>
<td>-104.85</td>
<td>17.19</td>
<td>14.74</td>
<td>16.35</td>
<td>34%</td>
</tr>
<tr>
<td>Hercules-Glades Wilderness</td>
<td>MO</td>
<td>HEGL1</td>
<td>36.68</td>
<td>-92.9</td>
<td>26.75</td>
<td>23.14</td>
<td>23.06</td>
<td>102%</td>
</tr>
<tr>
<td>Isle Royale NP</td>
<td>MI</td>
<td>ISLE1</td>
<td>48.01</td>
<td>-88.83</td>
<td>20.74</td>
<td>18.78</td>
<td>19.36</td>
<td>71%</td>
</tr>
<tr>
<td>Lostwood</td>
<td>ND</td>
<td>LOST1</td>
<td>48.59</td>
<td>-102.46</td>
<td>19.57</td>
<td>16.87</td>
<td>19.27</td>
<td>11%</td>
</tr>
<tr>
<td>Mammoth Cave NP</td>
<td>KY</td>
<td>MACA1</td>
<td>37.20</td>
<td>-86.15</td>
<td>31.37</td>
<td>26.64</td>
<td>25.60</td>
<td>122%</td>
</tr>
<tr>
<td>Mingo</td>
<td>MO</td>
<td>MING1</td>
<td>37.00</td>
<td>-90.19</td>
<td>28.02</td>
<td>24.37</td>
<td>23.71</td>
<td>118%</td>
</tr>
<tr>
<td>Rocky Mountain NP</td>
<td>CO</td>
<td>ROMO1</td>
<td>40.35</td>
<td>-105.7</td>
<td>13.83</td>
<td>12.29</td>
<td>13.17</td>
<td>43%</td>
</tr>
<tr>
<td>Salt Creek</td>
<td>NM</td>
<td>SACR1</td>
<td>33.6</td>
<td>-104.41</td>
<td>18.03</td>
<td>15.41</td>
<td>17.25</td>
<td>30%</td>
</tr>
<tr>
<td>Sipsey Wilderness</td>
<td>AL</td>
<td>SIP51</td>
<td>34.32</td>
<td>-74.4</td>
<td>29.03</td>
<td>24.82</td>
<td>23.57</td>
<td>130%</td>
</tr>
<tr>
<td>Theodore Roosevelt NP</td>
<td>ND</td>
<td>THRO1</td>
<td>46.96</td>
<td>-103.46</td>
<td>17.74</td>
<td>15.42</td>
<td>17.40</td>
<td>15%</td>
</tr>
<tr>
<td>Upper Buffalo Wilderness</td>
<td>AR</td>
<td>UPBU1</td>
<td>36.17</td>
<td>-92.41</td>
<td>26.27</td>
<td>22.84</td>
<td>22.52</td>
<td>109%</td>
</tr>
<tr>
<td>Voyageurs NP</td>
<td>MN</td>
<td>VOYA2</td>
<td>48.47</td>
<td>-92.8</td>
<td>19.27</td>
<td>17.58</td>
<td>18.37</td>
<td>53%</td>
</tr>
<tr>
<td>White Mountain Wilderness</td>
<td>NM</td>
<td>WHIT1</td>
<td>33.48</td>
<td>-105.85</td>
<td>13.70</td>
<td>12.11</td>
<td>13.14</td>
<td>35%</td>
</tr>
<tr>
<td>Wheeler Peak Wilderness</td>
<td>NM</td>
<td>WHPE1</td>
<td>36.57</td>
<td>-105.4</td>
<td>10.41</td>
<td>9.49</td>
<td>10.34</td>
<td>8%</td>
</tr>
<tr>
<td>Wind Cave NP</td>
<td>SD</td>
<td>WICA1</td>
<td>43.58</td>
<td>-103.47</td>
<td>15.84</td>
<td>13.94</td>
<td>15.39</td>
<td>24%</td>
</tr>
<tr>
<td>Wichita Mountains</td>
<td>OK</td>
<td>WIMO1</td>
<td>34.75</td>
<td>-98.65</td>
<td>23.81</td>
<td>20.01</td>
<td>21.47</td>
<td>61%</td>
</tr>
</tbody>
</table>