Recommended Refinements to EPA's Guidance for Estimating Natural Conditions and Tracking Progress under the Regional Haze Rule

SUMMARY The regional haze rule (RHR) requires States with mandatory Federal Class I areas to develop implementation plans that include reasonable progress goals for improving visibility in each of those areas, with an ultimate goal of achieving "natural conditions" by 2064. The Environmental Protection Agency (EPA) has released guidance documents that describe a method that States may follow in implementing the reasonable progress portion of the RHR. Several recent studies have identified certain shortcomings in EPA's approach for meeting requirements of the RHR. These shortcomings are listed below, and are discussed in more detail later:

- EPA's default annual average natural condition estimates (the 2064 end point) are too low in certain cases, and are not representative of the true background conditions in the U.S., as they ignore the transboundary pollution of anthropogenic origin from Mexico, Canada, and overseas.
- EPA's default procedure for calculating natural conditions for 20% worst and best days is incorrect.
- The IMPROVE (Interagency Monitoring of Protected Visual Environments) equation that is used for estimating light extinction from PM species measurements is based on various simplifying assumptions, and does not predict the measured light extinction very well at all the IMPROVE sites. In particular, the constant dry extinction efficiency of 3 m^2/g assumed for ammonium sulfate and ammonium nitrate appears to be too high in many areas, and the factor of 1.4 used to convert OC (Organic Carbon) measurements to OCM (Organic Carbon Mass) is too low.
- There may be some problems in how the climatological f(RH) has been estimated that need to be investigated.

This paper addresses the inherent limitations in the steps/methods recommended by the EPA that can have an impact on the extent and level of controls that would otherwise be needed to meet reasonable progress goals. Based on the results from recent studies, this paper offers recommended modifications to the EPA approach, that are also summarized here:

- The IMPROVE equation should be modified to correct for overpredictions at lower extinction and underpredictions at higher extinction values. It is recommended that a factor of 2.0 be used to convert OC to OCM, and that a varying dry extinction efficiency be used for ammonium sulfate and ammonium nitrate.
- Additional work needs to be done for a rigorous definition of "natural" conditions (2064 end point) that should also include transboundary pollution in its definition.
- The equation used to estimate the average of the 20% best and worst cases is simply incorrect and must be replaced.
- EPA should investigate why climatological relative humidity data are not representative of the actual conditions

INTRODUCTION

The RHR requires States with mandatory Federal Class I areas to develop implementation plans that include reasonable progress goals for improving visibility in each of those areas, with an ultimate goal of achieving "natural conditions" by 2064. The reasonable progress goals must provide for an improvement in visibility for the most impaired (20% worst) days over the period of the implementation plan, and ensure no degradation in visibility for the least impaired (20% best) days over the same period. The first implementation plan must establish a reasonable progress goal for the year 2018, and include emission reduction regulations to achieve either that goal or another 2018 end point that is determined to be reasonable to achieve.

The EPA has released two guidance documents that describe a method that States may follow in implementing the reasonable progress portion of the RHR. One guidance document addresses how to estimate natural conditions (U.S.EPA, 2003a), while the second guidance document addresses how to track progress (U.S.EPA, 2003b). The major tasks involved in fulfilling the reasonable progress portion of the RHR are as follows:

1. Collect and analyze filter samples for mass concentrations of select components from IMPROVE network sites for each Class I area. From these measurements, for each Class I area, calculate the annual average light extinction in deciviews for the 20% most impaired and 20% least impaired days for the five consecutive years 2000-2004. Average the five annual values to establish the baseline condition for each area.
2. Determine the 2064 natural conditions goal in deciviews for each Class I area. This can be done by relying on EPA's default values or by refining those default values.
3. Determine the 2018 (end of the first implementation period) reasonable progress goal by assuming uniform visibility impairment improvements in the 2005-2064 period. Next, develop and adopt emission reduction requirements needed to satisfy the 2018 reasonable progress goal or some other 2018 end point that is determined by the State to be reasonably achievable, considering the statutory factors. See **Figure 1** (adopted from EPA, 2003a) for an illustration of this process.

As discussed above, two key parameters used in establishing the 2018 reasonable progress requirements are the baseline visibility condition and the natural visibility condition for each Class I area. The annual average baseline and natural conditions are calculated based on the IMPROVE equation (derived empirically). The IMPROVE equation provides a relationship between light extinction and the IMPROVE chemical composition data determined from filter analysis, and is as follows:

$$b_{ext} = 3 \times f(RH) \times [(NH_4)_2SO_4 + NH_4NO_3] + 4 \times [OCM] + 1 \times [PM_{2.5}\ Soil] + 0.6 \times [Coarse\ Mass] + 10 \times [EC] + Rayleigh\ Scattering \quad \textbf{(1)}$$

where b_{ext} is the light extinction expressed in units of Mm^{-1}, Rayleigh Scattering is the scattering caused by atmospheric gases (assumed to have a constant value of 10 Mm^{-1}), a factor of 1.4 is used to convert organic carbon (OC) to organic compound mass (OCM), EC is the elemental carbon, and sulfate and nitrate are assumed to be in the form of ammonium sulfate and ammonium nitrate, respectively.

The EPA regional haze rule states that baseline visibility conditions, progress goals, and changes in visibility must be expressed in terms of deciviews. The deciview (dv) is a haze index expressed by the following equation:

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

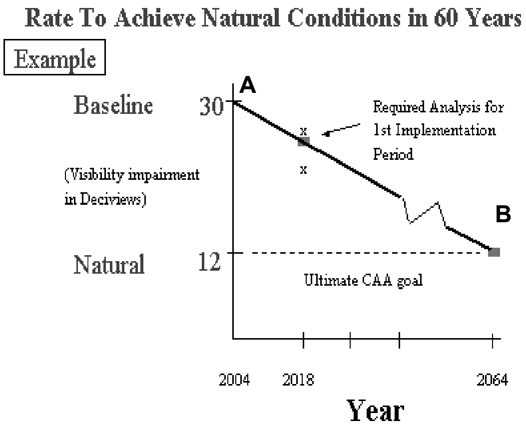

Figure 1. Required analysis for 1st implementation period

Table 1 presents the EPA default annual average estimates of natural concentrations of the particulate species for the eastern and the western United States. To determine default natural conditions levels for each Class I area, these values can be used with **Equation 1**. Alternatively, States can develop refined, area-specific annual average estimates for these particulate species and use those refined values in **Equation 1**.

Table 1. Natural annual average levels of aerosol components

Aerosol component	**West ($\mu g/m^3$)**	**East ($\mu g/m^3$)**
Ammonium sulfate	0.11	0.23
Ammonium nitrate	0.10	0.10
Organic Carbon Mass	0.47	1.40
Elemental Carbon	0.02	0.02
Soil	0.50	0.50
Coarse Mass	3.00	3.00

Once the annual average extinction is calculated pursuant to **Equation 1** and is converted to deciviews, EPA's guidance indicates that the deciviews associated with the 20% best and 20% worst natural condition days can be estimated based on Ames and Malm (2000) using the following equations:

$$\text{20\% Best Visibility (dv)} = \text{Annual Average (dv)} - 1.28\,\sigma \quad \textbf{(3)}$$

$$\text{20\% Worst Visibility (dv)} = \text{Annual Average (dv)} + 1.28\,\sigma \quad \textbf{(4)}$$

The EPA (2003b) recommends σ (standard deviation) to be set to 2 dv for sites in the West and 3 dv for sites in the East.

Several recent studies have identified certain shortcomings in EPA's recommended approach for determining natural conditions and tracking progress. Moreover, EPA's default values (**Table 1**) in many cases deviate significantly from expected values for specific Class I areas. This paper addresses the inherent limitations in the steps/methods recommended by the EPA that can have an impact on the extent and level of controls that would otherwise be needed to meet reasonable progress goals. Furthermore, this paper offers recommended modifications, based on technical and scientific principles, to the EPA suggested default approach to correct the deficiencies.

A. SHORTCOMINGS IN THE EQUATIONS FOR CALCULATING THE 20% WORST AND BEST DAYS

EPA's default procedure for calculating natural conditions for 20% worst and best days (**Equations 3 and 4**) is based on the assumption that the 10th and 90th percentile values of a normal distribution correspond to the averages of the 20% best and 20% worst values. However, for a true normal distribution, the 8th (8.07) and 92nd (91.93) percentile values actually correspond to the average of the 20% best and 20% worst values, which would mean that a factor of 1.40 and not 1.28 should be used in **Equations 3 and 4**.

In addition, an analysis of 20 IMPROVE sites for different years (a total of 141 site years) by Sonoma Technology, Inc. (STI) (Ryan, 2004) shows that the reconstructed visibility data (in deciviews) do not follow a normal distribution. Moreover, according to Ryan (2004) the standard deviation for sites in the West is about 3 dv (compared to 2 dv assumed by EPA) and for sites in the East it is about 3.5 dv (compared to 3 dv assumed by EPA).

Table 2 shows 20% worst day average natural visibility condition estimates using the EPA default approach and by the STI approach at six Class I sites. The STI approach used actual visibility data in its estimate of 20% worst day average natural visibility conditions, and thus did not need to make any assumption about how the data were distributed (i.e., normal or otherwise). The natural condition values estimated by the STI approach are 1.2 to 2.0 dv greater than those determined by EPA's default method.

Table 2. 20% worst-day average natural visibility predictions by the EPA default approach and the STI alternative approach at six Class I sites

Class I Site	EPA Default Approach (dv)	STI Recommendation (dv)	Increase (dv)
Acadia	11.48	13.09	1.61
Big Bend	6.99	8.84	1.85
Boundary Waters	11.21	12.36	1.15
Grand Canyon	6.97	8.81	1.84
Great Smoky	11.51	12.72	1.21
Mount Rainier	7.85	9.87	2.02

The implication of using an incorrect average natural visibility for 20% worst days can be determined by calculating concentrations reduction in PM species concentrations for the first implementation period. The concentrations reductions are calculated only for anthropogenic portion of the baseline concentrations, assuming uniform reductions in all species. **Table 3** shows such a calculation for the six sites, using IMPROVE data from 1995-1999[1] used for defining the baseline visibility conditions. The concentrations reductions needed to achieve the 2018 goal are 1-2 percentage points lower when the STI approach rather than the EPA approach is used for estimating natural conditions for the 20% worst days. This corresponds to 3-6 percent less total concentrations reductions needed for the first implementation period than what would be required if one used EPA's default approach for estimating natural conditions for the 20% worst days. **Table 3** also shows what would happen if only concentrations of ammonium sulfate and ammonium nitrate were reduced to achieve the 2018 goal. It can be seen that 2-6 percent less total concentrations reductions will be needed when the STI approach rather than the EPA approach is used for estimating natural conditions for the 20% worst days.

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[1] Except in the case of Boundary Waters where 1997-2001 data were applied.

Table 3. Concentrations reductions* needed for first implementation period

Class I site	Baseline (dv)	EPA Default 2018 Goal (dv)	All Species Reduction (EPA Default)	All Species Reduction (STI Approach)	Sulfate and Nitrate Reduction (EPA Default)	Sulfate and Nitrate Reduction (STI Approach)
Acadia	23.13	20.41	35%	33%	44%	42%
Big Bend	18.11	15.51	34%	32%	62%	59%
Boundary Waters	20.28	18.17	32%	31%	46%	45%
Grand Canyon	11.50	10.44	28%	26%	70%	66%
Great Smoky	29.80	25.54	41%	40%	49%	48%
Mount Rainier	19.48	16.75	35%	33%	60%	57%

*Assuming uniform reductions in anthropogenic portion of the baseline concentrations

B. SHORTCOMINGS IN EPA'S DEFAULT APPROACH FOR ESTIMATING PARTICULATE MATTER COMPONENTS IN DETERMINING NATURAL CONDITIONS.

The default annual natural levels of particulate matter (PM) components in EPA's guidance are based on values that were developed for the National Acid Precipitation Assessment Program (NAPAP) by Trijonis (1990). Trijonis provided error factors of about two on his estimates for each of the PM components, implying that the values were not very rigorous. Since the RHR has as its goal achieving natural conditions by 2064, a much more rigorous approach should have been applied to calculate that end point. Tombach (2003) has estimated that the annual average natural visibility conditions estimated for a typical VISTAS Class I area using EPA default values may be 5 Mm-1 lower than the actual natural conditions.

EPA's default natural conditions estimates also ignore the transboundary pollution of anthropogenic origin from Mexico, Canada, and overseas, which are not subject to U.S. regulation and thus need to be accounted for in estimating natural conditions in Class I areas. Park *et al.* (2003, 2004) have investigated the issue of natural conditions using a global chemistry model, GEOS-CHEM. They ran the model for a base year and then conducted different sensitivity simulations to estimate natural conditions analogous to the EPA default, and the transboundary impact on the background levels in the U.S. Table 4 shows results for two of the species from the model simulations, although estimates were made for other species too. The "background levels" from GEOS-CHEM were calculated by shutting off only the anthropogenic emissions in the U.S. The "natural levels" were calculated by shutting off the anthropogenic emissions all over the globe. According to GEOS-CHEM, the incorporation of transboundary emissions increases ammonium sulfate by 50% to 400% in class I areas relative to the EPA default approach. The GEOS-CHEM estimated OCM concentrations for sites in the West are higher by a factor of 2 to 3 relative to the EPA default approach. The OCM predictions by GEOS-CHEM and the EPA default approach for sites in the East are comparable.

Table 4. Background and natural levels of ammonium sulfate and organic carbon mass (OCM) using the GEOS-CHEM model compared to EPA's default estimates of natural levels

Class I Site	Ammonium Sulfate (μg/m^3)			Organic Carbon Mass (μg/m^3)		
	EPA Default	GEOS-CHEM Natural Level	GEOS-CHEM Background	EPA Default	GEOS-CHEM Natural Level	GEOS-CHEM Background
Acadia	0.23	0.13	0.39	1.4	0.95	1.01
Big Bend	0.11	0.13	0.54	0.47	1.44	1.50
Boundary Waters	0.23	0.11	0.51	1.4	1.26	1.32
Grand Canyon	0.11	0.12	0.49	0.47	0.87	0.93
Great Smoky	0.23	0.09	0.34	1.4	1.37	1.43
Mount Rainier	0.11	0.16	0.39	0.47	2.94	2.99

Figure 2 gives an example of a typical western site and the results determined using EPA's default values and using the work of Park *et al.* (2003, 2004). The top part of the figure shows linear progress towards the 2064 end point defined by three different approaches. The black line represents natural levels as defined by the EPA approach. The blue line represents natural levels as calculated by Park *et al.* (2003, 2004) using GEOS-CHEM model (referred to as "this work" in the figure). The red line represents transboundary pollution in addition to natural levels represented by the blue line. The bottom part of the figure shows required anthropogenic emissions reductions needed for all species (assuming a linear relationship between emissions reductions and concentrations reductions) to achieve the progress goals. It can be seen that the difference in emission reductions needed for the first implementation period is quite significant between using EPA default values (44%) and the background values calculated by Park *et al.* (29%). There is another interesting result that can be viewed from the figure: if one followed EPA default values for natural conditions, we would have reduced all the anthropogenic emissions in the U.S. by 2040, but reached nowhere near the EPA default natural conditions. In other words, EPA default natural conditions are an unreasonable goal that cannot be achieved solely by reducing U.S. anthropogenic emissions.

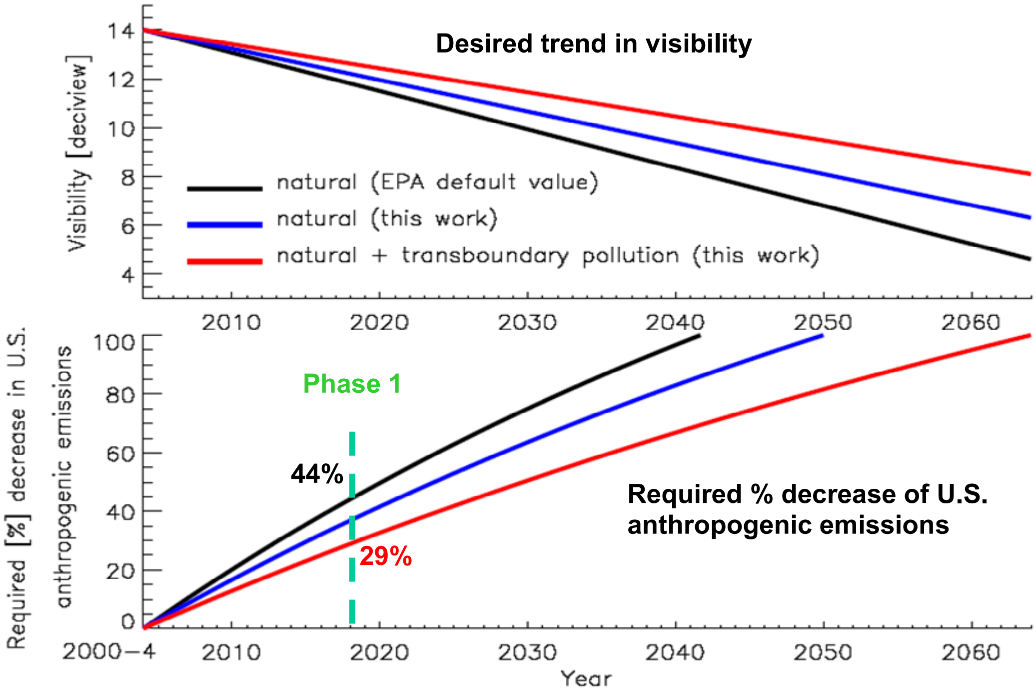

Figure 2. Comparison of emissions reductions needed for different estimates of 2064 end-point for a mean western site.

C. SHORTCOMINGS IN THE IMPROVE EQUATION FOR ESTIMATING B_{EXT} FROM PM COMPONENTS

Equation 1 (the IMPROVE Equation) is based on various simplifying assumptions. Two of the assumptions that are most critical are (1) the dry extinction efficiency for ammonium sulfate and ammonium nitrate, and (2) the multiplication factor used to convert OC to OCM. The IMPROVE "consensus" value adopted for the dry scattering efficiencies of ammonium sulfate and ammonium nitrate is 3 m^2/g. However, recent findings from special studies suggest values of 2.02, 2.2, 2.4, 2.47 and 2.63 m^2/g for different regions of U.S. (Malm and Pitchford, 1997; Malm *et al.*, 2000; Watson *et al.*, 2001). Watson (2002) reports the factor of 1.4 applied to OC measurements to estimate OCM is the least scientifically justified of all the multipliers in the IMPROVE equation. Turpin and Lim (2001), after a comprehensive review of experimental and theoretical research results, concluded that a factor of 2.1 ± 0.2 is more appropriate for non-urban aerosol. Malm *et al.* (2003) show that for the Yosemite National Park a factor of 1.8 is more appropriate for the IMPROVE equation than the current factor of 1.4. Lowenthal *et al.* (2003) suggest using an average value of 2.06 for OCM/OC ratio for the IMPROVE sites to explain the discrepancy between reconstructed and measured $PM_{2.5}$ mass.

Ryan (2004) looked at the effect of various assumptions on the performance of the IMPROVE equation compared to measured light extinction values. **Figure 3** shows the comparison of the IMPROVE reconstruction equation (left panel) to the form of reconstruction equation using 2.5 m^2/g as the dry scattering efficiency for ammonium sulfate and ammonium nitrate and a factor of 2.0 for converting OC to OCM (right panel). It is apparent that the predictions using the IMPROVE equation are biased high, particularly in the 10-25 dv range, whereas using the modified parameters results in a better overall comparison to the observations.

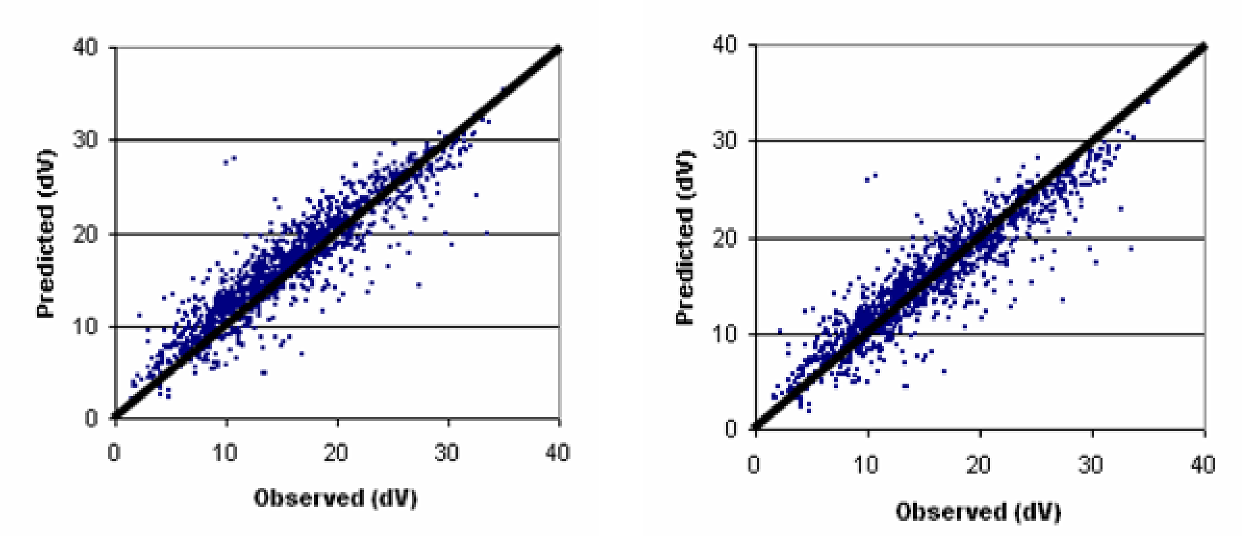

Figure 3. Comparison of predictions to Nephelometer observations when the contribution of ammonium sulfate and nitrate is 70% or greater - IMPROVE (left), 2.5 m^2/g ammonium sulfate and nitrate scattering efficiency predictions (right).

Although the factor of 2.5 m^2/g is statistically more accurate, it is apparent from looking at **Figure 3** that this factor overpredicts observations below 10 dv and underpredicts observations above 25 dv. Evidently a constant scattering efficiency is not the most representative for ammonium sulfate and ammonium nitrate. Using detailed data from the SEAVS (Southeastern Aerosol and Visibility Study) and the BRAVO (Big Bend Regional Aerosol and Visibility Observational) studies, Lowenthal and Kumar (2003b) have shown that mass scattering efficiencies increase with the degree of pollution at the Big Bend and Great Smoky Mountains National Parks, respectively. The shift of the ambient dry particle size distribution to larger size particles under more polluted conditions causes the increase in efficiency. Using statistical analysis, Ryan (2004) developed the following equation for calculating the dry extinction efficiency for ammonium sulfate and ammonium nitrate:

$$e_{(NH_4)_2SO_4+NH_4NO_3}\,(m^2/g) = 1.5\,\alpha^{0.3};\ \alpha = [(NH_4)_2SO_4] + [NH_4NO_3] \qquad \textbf{(5)}$$

The concentrations of ammonium sulfate and ammonium nitrate in **Equation 5** are in units of µg/m3 and the value of the dry extinction efficiency is limited to a range of 1.2 to 3.7 m^2/g. As illustrated in **Figure 4**, the effect of adopting a scattering efficiency for ammonium sulfate and ammonium nitrate that increases with concentration is to remove any biases in predictions over the range of nephelometer measured visibility impairment at the IMPROVE sites.

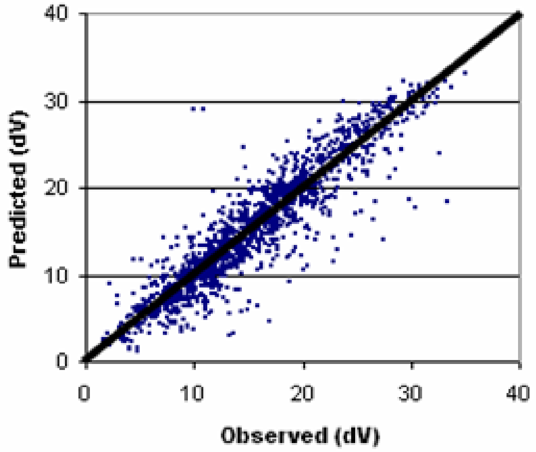

Figure 4. Comparison of predictions to observations when the contribution of ammonium sulfate and nitrate is 70% or greater, using a varying scattering efficiency for ammonium sulfate and ammonium nitrate (Equation 4).

Table 5 shows the impact of using different factors in the IMPROVE equation on the concentrations reductions needed for the first implementation period. The "STI Equation" (in the table) refers to use of 2.0 for the OCM/OC ratio and the use of **Equation 5** for calculating the dry extinction efficiency of ammonium sulfate and ammonium nitrate. The concentrations reductions needed to achieve the 2018 goal are 3-6 percentage points lower when the STI Equation rather than the IMPROVE equation is used. This corresponds to 10-18 percent less total concentrations reductions needed for the first implementation period than what would be required if one used the standard IMPROVE Equation. The results are mixed if only concentrations of ammonium sulfate and ammonium nitrate are reduced to achieve the 2018 goal. For Acadia, Big Bend, Boundary Waters, and Great Smoky, 7-22 percent less total concentrations reductions will be needed when the STI equation rather than the IMPROVE equation is used. However, for Mount Rainier, which is dominated by organics, 15 percent more total concentrations reduction will be needed when the STI equation rather than the IMPROVE equation is used. For Grand Canyon, sulfate and nitrate concentrations reduction alone will not be sufficient to achieve the 2018 goal if STI equation is used because concentrations of sulfate and nitrate there are already so low.

Table 5. The impact of using different factors in the IMPROVE equation on the concentrations reductions* needed for the first implementation period

Class I site	All Species Reduction (EPA Default)	All Species Reduction (STI Equation)	Sulfate and Nitrate Reduction (EPA Default)	Sulfate and Nitrate Reduction (STI Equation)
Acadia	35%	29%	44%	36%
Big Bend	34%	30%	62%	58%
Boundary Waters	32%	27%	46%	35%
Grand Canyon	28%	25%	70%	>100%#
Great Smoky	41%	36%	49%	41%
Mount Rainier	35%	31%	60%	69%

*Assuming uniform reductions in anthropogenic portion of the baseline concentrations

#Sulfate and nitrate concentration reductions alone will not be sufficient to achieve the first progress goal

D. SHORTCOMINGS FROM THE USE OF CLIMATOLOGICAL *f*(RH).

The function of relative humidity, *f*(RH), in **Equation 1** accounts for the enhancement of light scattering caused by hygroscopic growth of aerosol particles as a function of relative humidity (RH). EPA has recommended using monthly-averaged climatological *f*(RH) values calculated using hourly measured relative humidity data over a 10-year period (1988-1997). Lowenthal and Kumar (2003a) have shown that the use of these climatological relative humidity data gives much higher values of *f*(RH) compared to those calculated using actual relative humidity data from the IMPROVE monitoring sites, particularly at low RH. It is not clear why the climatological relative humidity values are higher than the actual data. One reason could be that the climatological values were calculated by interpolating data mostly from National Weather Sites (NWS), which on average are at lower elevation compared to the IMPROVE sites. The relative humidity is higher at lower elevation than at higher elevation. Secondly, the actual data used in the comparison by Lowenthal and Kumar (2003a) represented the period from 1993-1999, whereas the climatological data represents the period from 1988-1997.

The impact of using the climatological *f*(RH) rather than *f*(RH) derived from actual data obtained at the IMPROVE sites is that the relative contribution of different species to reconstructed extinction will not be represented correctly. For example, Lowenthal and Kumar (2003a) show that, for 36 IMPROVE sites, the use of climatological *f*(RH) results in a sulfate contribution to extinction of 32%, compared to 29% estimated using actual *f*(RH). This bias in the apportionment of light extinction to different particulate species could lead to misallocation of resources for emissions reductions.

E. CONCLUSIONS

The discussion in the previous sections highlights different issues related to EPA's recommended approach for estimating natural conditions and tracking progress under the RHR. **Table 6** shows the difference in concentrations reductions needed for the first implementation period at six Class I areas using the EPA approach versus a refined approach that considers:

1. Background concentrations of ammonium sulfate, ammonium nitrate, OCM and EC as estimated by Park *et al.* (2003, 2004)
2. STI approach to calculate natural visibility for the 20% worst days
3. A factor of 2.0 to convert OC to OCM
4. A varying scattering efficiency for ammonium sulfate and ammonium nitrate using **Equation 5**.

It can be seen that use of the refined approach rather than the IMPROVE equation predicts that the concentrations reductions needed to achieve the 2018 goal are 5-12 percentage points lower. This corresponds to 15-35 percent less concentrations reduction needed for the first implementation period than what would be required if one used the default approach. If only concentrations of ammonium sulfate and ammonium nitrate were reduced to achieve the 2018 goal, the total reductions needed would be 15-30 (except for Grand Canyon) percent lower using the refined approach rather than the EPA default approach. For Grand Canyon, sulfate and nitrate concentrations reduction alone will not be sufficient to achieve the 2018 goal if the refined approach is used.

Table 6. The impact of using a refined approach on the concentrations reductions[*] needed for the first implementation period

Class I site	All Species Reduction (EPA Default)	All Species Reduction (Refined Approach)	Sulfate and Nitrate Reduction (EPA Default)	Sulfate and Nitrate Reduction (Refined Approach)
Acadia	35%	30%	44%	37%
Big Bend	34%	26%	62%	49%
Boundary Waters	32%	26%	46%	33%
Grand Canyon	28%	23%	70%	>100%[#]
Great Smoky	41%	35%	49%	40%
Mount Rainier	35%	23%	60%	50%

[*] Assuming uniform reductions in anthropogenic portion of the baseline concentrations

[#] Sulfate and nitrate concentration reductions alone will not be sufficient to achieve the first progress goal

RECOMMENDATIONS

Given the large differences in emissions reductions needed for the first implementation period between the default EPA approach and the refined approach that addresses certain of the shortcomings identified in the EPA approach, it is recommended that the revised approach be used by regional planning organizations and States in implementation plan development. Specifically, the following recommendations are offered:

- The IMPROVE equation should be modified to correct for overprediction at lower extinction and underprediction at higher extinction values. Specifically, revisions should be made to the inaccurate 1.4 factor to convert OC to OCM, and the use of a constant value of 3 m^2/g for dry extinction efficiency for ammonium sulfate and ammonium nitrate. It is recommended that a factor of 2.0 be used to convert OC to OCM, and that a varying dry extinction efficiency (as calculated using **Equation 5**) be used for ammonium sulfate and ammonium nitrate. These recommendations are consistent with the latest scientific understanding and also correct the biases in the IMPROVE equation.
- The transboundary pollution should be included as part of the 2064 end point for the RHR. The work by Park *et al.* (2003, 2004) is a good start, but the simulations need to be conducted at a finer resolution within the United States. It seems that global chemistry models are the best tools for estimating background levels to be used as the end point for the RHR. However, better emissions estimates for fires and soil events are needed to better predict background levels for EC, OCM and soil.
- The equations used to calculate average natural conditions for the 20% best and 20% worst days from annual natural levels should be corrected. Standard deviations used in the calculations should represent the actual data. The value of 1.28 used to estimate the average of the 20% best and worst cases is simply incorrect even if the data are assumed to be normally distributed, and must be replaced.
- The upward bias in f(RH) calculated using climatological relative humidity data is problematic. EPA should investigate why climatological relative humidity data are not representative of the actual conditions.

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