Appendix 5-1: Discussion of the Original and Revised IMPROVE Algorithms

APPENDIX 5–1: DISCUSSION OF THE ORIGINAL AND REVISED IMPROVE ALGORITHMS

5.1 INTRODUCTION

Associated with each particulate matter (PM) species is an extinction efficiency that converts concentrations (in $\mu g/m^3$) to light extinction (in inverse megameters, Mm^{-1}). Sulfate and nitrate are hygroscopic so relative humidity (RH) adjustment factors [f(RH)] are used to increase the particle's extinction efficiency with increasing RH to account for the particles taking on water and having greater light-scattering efficiencies under higher RH conditions. Note that some organic matter compounds (OMC) may also have hygroscopic properties, but the IMPROVE aerosol extinction algorithms assume OMC is non-hygroscopic.

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

5.2 THE ORIGINAL IMPROVE ALGORITHM

The original IMPROVE algorithm converts PM species concentrations to light extinction as follows:

$b_{Sulfate} = 3 \times f(RH) \times [Sulfate]$

$b_{Nitrate} = 3 \times f(RH) \times [Nitrate]$

$b_{EC} = 10 \times [EC]$

$b_{OM} = 4 \times [OMC]$

$b_{Soil} = 1 \times [Soil]$

$b_{CM} = 0.6 \times [CM]$

Monthly average f(RH) factors are used as recommended in EPA guidance (EPA, 2003a). These values are available in the final EPA guidance document (EPA, 2003a).

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

$$b_{ext} = b_{Ray} + b_{Sulfate} + b_{Nitrate} + b_{EC} + b_{OMC} + b_{Soil} + b_{CM}$$

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

$$VR = 3912 / b_{ext},$$

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

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

DRAFT

5.3 THE REVISED IMPROVE ALGORITHM

The revised IMPROVE algorithm 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] + $4.8 \times f_L(RH) \times$ [Large Sulfate]

$b_{Nitrate}$ = $2.4 \times f_S(RH) \times$ [Small Nitrate] + $5.1 \times f_L(RH) \times$ [Large Nitrate]

b_{EC} = $10 \times$ [Elemental Carbon]

b_{OM} = $2.8 \times$ [Small Organic Mass] + $6.1 \times$ [Large Organic Mass]

b_{Soil} = $1 \times$ [Fine Soil]

b_{CM} = $0.6 \times$ [Coarse Mass]

b_{SS} = $1.7 \times f_{SS}(RH) \times$ [Sea Salt]

b_{NO2} = $0.33 \times$ [NO_2 (ppb)]

The total sulfate, nitrate and organic mass are each split into two fractions, representing small and large size distributions of those components. The organic mass is 1.8 times the IMPROVE OC measurement in the revised IMPROVE algorithm, compared to 1.4 times the IMPROVE OC measurement in the original IMPROVE algorithm. New terms have been added for sea salt (important for coastal areas) and for light absorption by NO_2 (only used where NO_2 observations are available). As none of the CENRAP Class I Area (CIA) IMPROVE sites measure NO_2 concentrations, this component of the revised IMPROVE algorithm was not used. Site-specific Rayleigh scattering for each IMPROVE monitoring site is used in the revised IMPROVE algorithm, as compared to a constant 10 Mm^{-1} value assumed in the original IMPROVE algorithm.

Apportionment of the small and large components of sulfate, nitrate and organic mass is done as follows:

[Large Sulfate] = [Total Sulfate]/20 × [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 organic mass among their large and small components.

As for the original IMPROVE algorithm, total extinction (b_{ext}) in the revised IMPROVE algorithm is the sum of all extinction components associated with each PM species and NO_2 plus the Rayleigh background, except, as noted above, a site-specific Rayleigh background is used with the revised IMPROVE algorithm:

$$b_{ext} = b_{Ray} + b_{Sulfate} + b_{Nitrate} + b_{EC} + b_{OMC} + b_{Soil} + b_{CM} + b_{SS} + b_{NO2}$$

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

The revised IMPROVE algorithm was developed by fitting reconstructed light extinction based on IMPROVE measured PM and NO_2 concentrations with actual co-located measured light extinction (e.g., nephelometer measurements). The original IMPROVE algorithm has a bias toward under estimating light extinction at the high end and over estimating it at the low end, whereas the revised IMPROVE algorithm better estimates light extinction from measured PM at all extinction levels.

5.4 TEXAS' CHOICE OF ALGORITHM

The choice between the original or the revised algorithm for calculating visibility metrics for each Class I area is made by the state in which the Class I area is located. According to 40 CFR §51.308(d)(2), the state determines baseline and natural visibility conditions. Calculations based on this choice of algorithm are used by the state to develop a "reasonable progress goal" for each Class I area, in consultation with other states whose emissions affect visibility in that park or wilderness area (40 CFR §51.308(d)(1)(iv)). Because it is based on more recent science and fits observed light extinction values better, the State of Texas and other CENRAP states have elected to perform primary visibility projections using the revised IMPROVE algorithm to calculate visibility metrics for developing reasonable progress goals.