Washington State Regional Haze State Implementation Plan

Appendix G

Western Regional Air Partnership's Technical Support System Road Map

TSS Roadmap and Users Guide – *Working Draft*
February 22, 2010

LIST OF ACRONYMS to be added

EXECUTIVE SUMMARY – highlight major technical products, supporting WRAP products, and how they built and relate to one another - protocols, QAPPs, scope of work documents, templates, work plans, et cetera, which form the collective planning and support structure. Purpose is to address need is to look at regional technical and planning analyses across the depth and breadth of work products, rather than focusing on modeling – in support of the "big picture" that will need to be explained in a federal Technical Support Document.

INTRODUCTION

The purpose of the TSS Roadmap and Users Guide is to provide a reference guide for users of the Western Regional Air Partnership (WRAP) Technical Support System (TSS). Beginning with a description of the TSS in Section 1, summary information about the data sources, quality assurance, and analysis results is then discussed in Sections 2, 3, and 4. The TSS contains data, information, and analysis results to support state, federal, and tribal agencies with the planning requirements of the EPA Regional Haze Rule (RHR), through the collaborative efforts of the WRAP organization. Much of the data and regional analysis results are also suitable, and has been used for other air quality analysis and planning purposes. A significant amount of more detailed data and/or analysis results also exist in data support systems or projects that feed into the RHR planning support provided by the TSS. These systems or projects are listed and linked to on the Projects page of the TSS. Also, many related reports for specific source sectors, analysis of regional impacts to Class I areas, and control strategy analyses are found under individual Committees, Forums, and Workgroups on the WRAP website – these results are generally not found on the TSS, and may be applied by the appropriate regulatory jurisdiction for RHR planning as that agency wishes. The current WRAP website will move into archive status in early 2010, but the links will remain accessible.

As with other Help and reference documents on TSS, this document will exist on TSS as a HTML page. The links in the HTML document will "jump to" the appropriate section of the HTML document on the TSS website, and include "Navigation Notes" to TSS tools, similar to those already in place for the Monitoring, Modeling, and Apportionment "buttons" on the TSS Resources page. *Note there are currently no Navigation Notes for tools under the Emissions button*. The tools and datasets on the TSS have linked "Help" for the user, via the master TSS "Getting Started" document. Also, under TSS Resources, the Monitoring, Emissions, Modeling, and Apportionment sections contain Methods descriptions, identifying how datasets and analysis tools were used, *these are in the process of being updated in the first quarter 2010..*

WRAP Technical Support System – RHR Technical Planning Elements & Roadmap Section Location

	Roadmap Section Location		
Required Technical Elements on TSS for Regional Haze Implementation Plans	**Data Sources**	**Quality Assurance**	**Analyses**
Monitored baseline visibility conditions (2000-04)	**2.2**	**3.2**	**4.2**
Natural conditions (2064 target)	**2.2**	**3.2**	**4.2**
Uniform glide slope	**2.2**	**3.2**	**4.2**

Baseline emissions (2000-2004)	**2.3**	**3.3**	**4.3**
Projected 2018 emissions	**2.3**	**3.3**	**4.3**
Source apportionment – 2002 baseline/2018 projections	**2.4, 2.5**	**3.4, 3.5**	**4.4, 4.5**
Projected 2018 visibility conditions	**2.5**	**3.5**	**4.5**

1.0 TECHNICAL SUPPORT SYSTEM DESCRIPTION

The purpose of this section is to provide a description of the:

- Structure of the TSS website pages and their content;
- RHR technical planning resources available on the TSS; and
- Access to the data support systems or projects that feed data and analysis results into the TSS.

EPA staff please add "any and all" comments on this 2/22 draft here, listed by subsection of Section 1 by Friday March 5th

1.1 OVERVIEW

The Technical Support System (TSS) (http://vista.cira.colostate.edu/tss/) has been developed by the Western Regional Air Partnership (WRAP) to provide a single portal to technical data and analytical results prepared by WRAP Forums and Workgroups. The data, results, an methods displayed on the TSS are intended to support the air quality planning needs of western state and tribes, and will be maintained and updated to support both the implementation of regional haze plans and other Western air quality analysis and management needs. The concept for the TSS is based on the final recommendations of the Attribution of Haze Phase I project (http://wrapair.org/forums/aoh/ars1/report.html).

The primary purpose of the TSS is to provide key summary analytical results and methods documentation for the required technical elements of the Regional Haze Rule, to support the preparation, completion, evaluation, and implementation of the regional haze implementation plans. The TSS provides technical results prepared using a regional approach, including summaries and analyses of the comprehensive datasets used to identify the sources and regions contributing to regional haze in the WRAP region.

The secondary purpose of the TSS is to offer a one-stop-shop for access, visualization, analysis, and retrieval of the technical data and regional analytical results prepared by WRAP Forums and Workgroups in support of regional haze planning in the West. Specifically, the TSS summarizes results and consolidates information about air quality monitoring, meteorological and receptor modeling data analyses, emissions inventories and models, and gridded air quality/visibility regional modeling simulations. These large and diverse data sets are integrated for application to air quality planning purposes by prioritizing and refining key information and results into explanatory tools.

1.2 HOME PAGE

The TSS Home Page is accessible at: http://vista.cira.colostate.edu/tss/. Navigation from this page includes the left-hand navigation and the buttons with yellow arrows in the center of the page. System log-in and user account options are readily accessible, though users are not required to log in. TSS-related news items are also featured on the Home page. Figure 1 shows the layout of the Home page. From the Home Page, users can directly access the Resources Page and the Projects Page, which are summarized in the sections below.

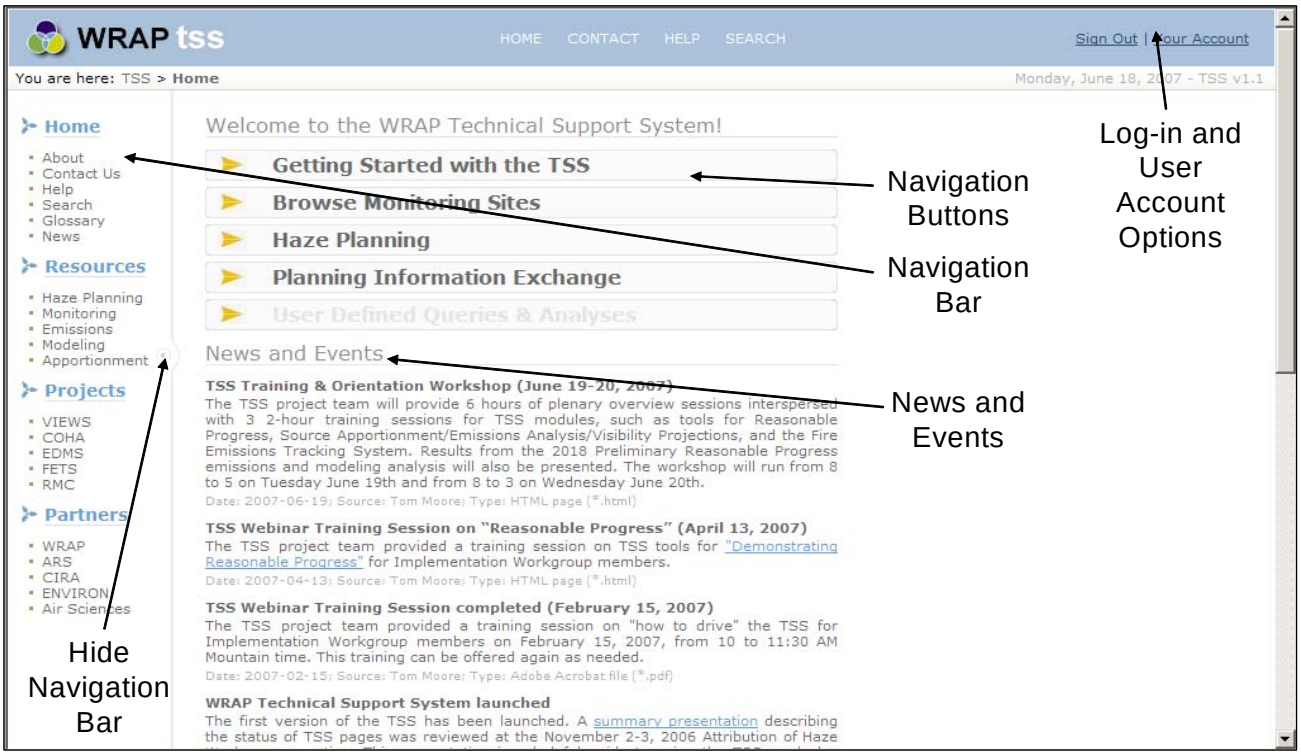


Figure 2-1. The TSS Home Page.

1.3 RESOURCES PAGE

The TSS Resources Page (http://vista.cira.colostate.edu/TSS/Results/Default.aspx) is the gateway to the site's analytical tools and methods documentation. From this page the user can choose to investigate the following topics:

- Haze Planning (http://vista.cira.colostate.edu/TSS/Results/HazePlanning.aspx) – This page integrates all of WRAP's major haze-related data sets and analyses, and provides review tools designed to support a reasonable progress demonstration. Detailed descriptions of these tools are presented in the on-line TSS Help Document (http://vista.cira.colostate.edu/TSS/Help/GettingStarted.aspx). Methods documentation for these tools and analyses can be found on the specific data type pages as indicated in the following bullets.

- Monitoring (http://vista.cira.colostate.edu/TSS/Results/Monitoring.aspx) – This page leads to monitoring data review tools and descriptive documents, including:
  - A detailed overview of the IMPROVE monitoring network;
  - An overview of WRAP data substitutions methods use for sites not meeting RHR data completeness guidelines;
  - An overview of how natural conditions were estimated for use with the revised IMPROVE algorithm;
  - A key to mapping parameters across monitoring, modeling, and emissions disciplines; and
  - Related monitoring data links.

- Emissions (http://vista.cira.colostate.edu/TSS/Results/Emissions.aspx) – This page leads to emissions data review tools and descriptive documents, including:
  - An overview of emissions inventory and processing activities;
  - Individual documents for each type of emissions inventory prepared for WRAP;
  - A key to mapping parameters across monitoring, modeling, and emissions disciplines; and
  - Related emissions data links.

- Modeling (http://vista.cira.colostate.edu/TSS/Results/Modeling.aspx) – This page leads to modeling review tools and descriptive documents, including:
  - A detailed overview of WRAP's air quality modeling;
  - An overview of WRAP's meteorological back trajectory modeling;

  - A key to mapping parameters across monitoring, modeling, and emissions disciplines; and
  - Related modeling links.

- Apportionment (http://vista.cira.colostate.edu/TSS/Results/SA.aspx) – This page leads to source apportionment analysis review tools and descriptive documents, including:
  - An overview of the PM Source Apportionment Technology (PSAT) air quality modeling technique used to trace Sulfur/SOx and Nitrate/NOx from source regions to Class I areas;
  - An overview of the Organic Aerosol Tracer technique used to distinguish between various types of organic aerosol modeled to arrive at Class I areas;
  - An overview of the Weighted Emissions Potential (WEP) technique, a qualitative analysis to investigate the potential for specific regional emissions to impact Class I areas; and
  - A key to mapping parameters across monitoring, modeling, and emissions disciplines.

Each of the documentation pages contains a link to the "Key to Monitoring-Modeling-Emissions Mapping" support file (http://vista.cira.colostate.edu/tss/help/parameterkey.aspx). This file summarized the often complex relationships among real-world visibility-related parameters and parameters defined by the IMPROVE program, the CMAQ and CAMx models, and WRAP emissions inventories. Specific parameter types, abbreviations, equations, and comments are presented. As an example, consider the following relationships among these disciplines for carbon species:

- **Organic Carbon (OC)** is measured by IMPROVE, but not modeled or directly represented in emissions inventories.
- **Organic Mass (OM or OMC)**, which is the sum total of all primary and secondary organic compounds, is calculated by IMPROVE from the OC measurement. Both models contain terms for specific OM constituents. OM is not directly represented in emissions inventories.
- **Primary Organic Aerosol (POA)**, which represents only organic carbon compounds emitted directly as particulates, cannot be distinguished in the IMPROVE measurements. However, both the models and the emissions inventories account for this portion of the total OM.
- **Volatile Organic Compounds (VOC)**, which are emitted in gaseous form but can condense to form particulate organic compounds, also cannot be directly accounted for by IMPROVE. VOCs are tracked in the models and emissions inventories.

1.4 PROJECTS PAGE

The TSS Projects Page (http://vista.cira.colostate.edu/TSS/Projects/Default.aspx) provides direct links to the key information resources, or data nodes that support WRAP's analyses. The value of the TSS is that it takes each of these separate data nodes and incorporates their key data sets, analysis results, and documentation. The data nodes currently supporting the TSS include:

- Visibility Information Exchange Web **System** (VIEWS) – VIEWS is an online exchange of air quality data, research, and ideas designed to support the Regional Haze Rule enacted by the U.S. EPA to reduce regional haze and improve visibility in national parks and wilderness areas.

- Causes of Haze Assessment (CoHA) **project** – The CoHA web site is an online report that answers questions about the chemical components that cause regional haze, relationships of haze to meteorology, the emissions that cause haze, and the effects of previous and future emissions reductions on the worst and best visibility levels.

- Emissions Data Management **System** (EDMS) – The WRAP EDMS is an emission inventory data warehouse and web-based application that provides a consistent approach to regional emissions tracking to meet the requirements for State Implementation Plan (SIP) and Tribal Implementation Plan (TIP) development and periodic review and updates.

- Fire Emissions Tracking **System** (FETS) – The FETS is a database with a web interface for planned and unplanned fire events. Users can view fire data on-screen with a mapping tool and query the database for downloads of data into model-ready formats and CSV or DBF formats.

- WRAP Regional Modeling Center (RMC) **project** – now, completed, the WRAP RMC assisted State and Tribal agencies in conducting regional haze analyses over the western U.S. by operating regional scale, three-dimensional, photochemical grid air quality models that simulate the emission, transformation, and transport of pollutants and the effects on visibility in WRAP Class I Areas.

The **systems** are ongoing efforts with periodic data and analysis results' updates, while the **projects** are fixed term efforts with no ongoing updates.

2.0 DATA SOURCES

2.1 OVERVIEW

For 'Visibility metrics' [e.g., the various IMPROVE equations for calculating scattering from aerosol measurements] & 'Natural conditions estimates', the Roadmap should discuss the range of options available on the TSS, provide links to the science behind each, and if WRAP provides a default or recommendation on the TSS, then provide the rational for that.

In the discussion of Emissions, describe:

- *how each emissions sector is defined,*
- *provide links to documentation on how each sector's inventory was built,*
- *provide links that describe how those sectors' inventories were modified for the various 2018 emissions inventories*
- *priority on covering the following emissions sectors: point, area, mobile, biogenic.*

In the Modeling section, should focus on providing the following information for each model:

- *model description,*
- *documentation on input parameters chosen and rational,*
- *documentation on the modeling protocols that were followed.*

The list of models is:

- *CMAQ,*
- *CAMx & PSAT,*
- *SMOKE,*
- *MM5,*
- *CALPUFF,*
- *WEP,*
- *PMF*
- *priority on covering the following models: CAMx & PSAT, CMAQ, MM5, SMOKE.*

EPA staff please add "any and all" comments on this 2/22 draft here, listed by subsection of Section 2 by Friday March 5th

2.2 MONITORING DATA

- IMPROVE network and protocols
- Visibility metrics
- Natural conditions estimates *(find Scott Copeland journal article)*

As noted in Appendix A, the Technical Analysis Forum recommends the use of the following monitoring metrics by states, tribes, and EPA to assist in regionally consistent assessments of reasonable progress at all 118 visibility-protected Class I Federal areas of the WRAP region in the foundational regional haze implementation plans:

1) Apply the revised IMPROVE light extinction equation as developed and approved in 2005 by the IMPROVE Steering Committee to convert from mass concentration measurements to light extinction for visibility analysis and regional haze planning at each WRAP region Class I area. This revised equation is available for haze planning nationwide on the VIEWS and TSS websites.

2) Use the alternative Natural Conditions Estimates in combination with the 2000-04 Best and Worst Days' metrics as developed and recommended by the Inter-RPO Monitoring & Data Analysis Discussion Group,

as calculated and reported by VIEWS and TSS, utilizing the revised IMPROVE equation, for visibility analysis and regional haze planning at each WRAP region Class I area. These alternative Natural Conditions Estimates are available for all Class I areas, nationwide.

3) Use the 2000-04 Best and Worst Days' metrics as calculated and reported by VIEWS and TSS. Missing data will be substituted using the procedure described later in this document. Similar data substitutions have been performed and documented on VIEWS, to produce regional haze baseline period metrics for all Class I areas, nationwide. Individual WRAP region states should review the data completeness for Class I areas in their state, and any data substitutions for their CIAs.

The following recommendation is specific to the WRAP region.

4) Use a variety of visibility projection techniques, including the EPA default and the 2 WRAP alternatives, to analyze and assess the best method(s) to assist in demonstrating and explaining reasonable progress. All of these projection methods are available on the TSS and will draw upon the 2000-04 Best and Worst Days' metrics as calculated and reported by VIEWS and TSS. These projection method options utilize the revised IMPROVE equation and alternative Natural Conditions Estimates to:

- Project, analyze, and assess 2018 visibility conditions for the overall deciview Haze Index and total light extinction; and
- Project, analyze, and assess IMPROVE species-specific contributions to 2018 visibility conditions, to better understand the relationships to natural and anthropogenic as well as controllable and uncontrollable emissions. The visibility impact of coarse material and sea salt are assumed to be constant 2000-04 to 2018.

2.3 EMISSIONS DATA

- Subsections for individual sectors
- To include assumptions used to project 2018 emissions (growth, controls, etc.)

2.4 MODELING RESULTS

- Models used
- Input parameter
- Visibility projections

2.5 MAPPING MONITORING, EMISSIONS, AND MODELING DATA PARAMETERS

- Discussion of "Rosetta" stone currently on TSS
- Considerations in assessing 2018 visibility projections using EPA guidance

As noted in Appendix A, the Technical Analysis Forum recommends the use of the following monitoring metrics by states, tribes, and EPA to assist in regionally consistent assessments of reasonable progress at all 118 visibility-protected Class I Federal areas of the WRAP region in the December 2007 regional haze implementation plans:

The following recommendation is specific to the WRAP region.

5) Use a variety of visibility projection techniques, including the EPA default and the 2 WRAP alternatives, to analyze and assess the best method(s) to assist in demonstrating and explaining reasonable progress. All of these projection methods are available on the TSS and will draw upon the 2000-04 Best and Worst Days' metrics as calculated and reported by VIEWS and TSS. These projection method options utilize the revised IMPROVE equation and alternative Natural Conditions Estimates to:

- Project, analyze, and assess 2018 visibility conditions for the overall deciview Haze Index and total light extinction; and
- Project, analyze, and assess IMPROVE species-specific contributions to 2018 visibility conditions, to better understand the relationships to natural and anthropogenic as well as controllable and uncontrollable emissions. The visibility impact of coarse material and sea salt are assumed to be constant 2000-04 to 2018.

Monitoring Metrics for BART Determinations

The WRAP's recommendations for use of the revised IMPROVE equation and alternative Natural Conditions Estimates for assessing current haze conditions and projecting future haze trends for regional haze planning should not be seen as an endorsement for their use by individual state air programs for evaluation of BART modeling results and BART control level determinations for technical and process reasons.

3.0 DATA QUALITY ASSURANCE

3.1 OVERVIEW

This section to emphasize processes to assure data used in haze planning is comprehensive, complete, and regionally consistent

In the emissions section, describe:

- documentation on quality assurance protocols employed throughout the emissions inventory development process for each emissions sector,
- documentation on quality assurance protocols for SMOKE model output.
- priority on covering the following emissions sectors: point, area, mobile, biogenic

For modeling, provide documentation for the following information for each model listed:

- performance metrics WRAP used to evaluate model output (MM5, CAMx, CMAQ),
- performance benchmarks used for each metric evaluated (MM5, CAMx, CMAQ) and the rationale behind those benchmarks,
- model performance results (MM5, CAMx, CMAQ),
- quality assurance protocols employed on model outputs (MM5, CAMx & PSAT, CMAQ, CALPUFF, WEP, PMF)
- priority on covering the following models: CAMx & PSAT, CMAQ, MM5, SMOKE.

For the 'Key findings' section, provide links to the documentation backing up the finding or, if appropriate, reference the appropriate section(s) of the Roadmap that have those document link(s).

EPA staff please add "any and all" comments on this 2/22 draft here, listed by subsection of Section 3 by Friday March 5th

3.2 MONITORING DATA

The Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring program collects speciated PM2.5, and total PM2.5 and PM10 mass. IMPROVE is a nationwide network which began in 1988 and expanded significantly in 2000 in response to the EPA's Regional Haze Rule (RHR). The Regional Haze Rule specifically requires data from this program to be used by states and tribes to track progress in reducing haze. The network collects 24-hour integrated filter samples every three days (Wednesday and Saturday prior to 2000. Each monitoring location operates four samplers. Modules A through C employ PM2.5 size-cut devices, and Module D a PM10 size-cut device. An overview of the program with an emphasis on its application to the RHR can be found in the TSS document *IMPROVE Particle Monitoring* (http://vista.cira.colostate.edu/docs/wrap/Monitoring/IMPROVE_Particulate_Monitoring_May_2007.doc). Detailed information regarding the IMPROVE program, including history, sampling protocols, standard operating procedures, and data availability can be found on the IMPROVE web site (http://vista.cira.colostate.edu/improve/Default.htm) and the Visibility Information Exchange Web System (VIEWS) web site (http://vista.cira.colostate.edu/views/).

IMPROVE particulate data undergoes a variety of quality assurance procedures both at the laboratory level and at the data analysis level. The following sections provide a guide to specific quality assurance resources for the IMPROVE program.

3.2.1 Quality Assurance

There is a series of documents on the IMPROVE web site related to the program's quality assurance procedures. These documents can be accessed from IMPROVE's Home Page by clicking on the "Data Advisory, QA/QCX"

icon under *IMPROVE Resources* (direct link: http://vista.cira.colostate.edu/improve/Data/QA_QC/qa_qc_Branch.htm). Figure 3-1 presents a view of this web page.

This quality assurance page provides the following information:

Data Advisories

http://vista.cira.colostate.edu/improve/Data/QA_QC/Advisory.htm

This page provides a collection of data advisories written primarily by laboratory or analyst staff who have discovered data anomalies, potential problems, or new uses for the IMPROVE data. Each advisory is a concise (typically 1-4 page) statement of the problem and recommended solution. Approximately half of the advisories affect the RHR baseline period of 2000-04.

Figure 3-1. *Quality Assurance for the IMPROVE Network* page on the IMPROVE web site.

QA/QC Data Products

UC Davis reports: http://vista.cira.colostate.edu/improve/Data/QA_QC/QAQC_UCD.htm
NPS/CIRA reports: http://vista.cira.colostate.edu/improve/Data/QA_QC/QAQC_nps.htm

There pages provide a collection of routine QA/QC reports and data products prepared by UC Davis (the IMPROVE aerosol laboratory) and NPS/CIRA (the project data analysts). The UC Davis reports focus on QA for elemental analysis by XRF, beginning with 2005 data. The NPS/CIRA reports include an overview document which describes their QA procedures (http://vista.cira.colostate.edu/improve/Data/QA_QC/NPSProc/CIRA_QA_Overview.pdf) and a series of QA data products in the form of MS PowerPoint presentations. These reports cover data from 1988 to the present.

QA/QC Procedures

EPA requires monitoring programs to prepare several types of quality assurance/quality control documents, including a Quality Management Plan (QMP), a Quality Assurance Project Plan (QAPP), and Standard Operating Procedures (SOPs). These are considered living documents, and are updated periodically as instrument/laboratory procedures or configurations change. These documents for the IMPROVE program can be accessed from the *Quality Assurance* web page, but are also grouped together on the *IMPROVE Publications* page (http://vista.cira.colostate.edu/improve/Publications/publications.htm). Direct links to each set of documents is given below:

- **IMPROVE QMP** – describes the roles of each organization in the project. http://vista.cira.colostate.edu/improve/Publications/QA_QC/IMPROVEAerosolQMP_May2002.PDF
- **IMPROVE QAPP** – describes the specific steps taken by each organization to ensure data is collected and managed in a high quality manner. http://vista.cira.colostate.edu/improve/Publications/QA_QC/IMPROVE_QAPP_R0.pdf
- **IMPROVE SOPs** – describe in detail the steps followed to perform all activities in the monitoring program. http://vista.cira.colostate.edu/improve/Publications/IMPROVE_SOPs.htm

Note that there are SOPs for the particulate monitoring network (authored by UC Davis), carbon analysis (authored by Desert Research Institute), ion chromatography analysis (authored by Research Triangle Institute), and optical monitoring (authored by Air Resource Specialists).

3.2.1.1 IMPROVE Gray Literature

The *IMPROVE Gray Literature* page at: http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray_literature.htm offers a collection of ad-hoc analyses, reports and presentations conducted by members of the IMPROVE program and others. These documents contain important information concerning the monitoring, filter analysis, and data analysis that have not been formally published elsewhere.

3.2.2 Data Substitution Methods

Regional Haze Rule guidance outlines data completeness requirement designed to balance the need for data from individual days, seasons, and years to be reasonably representative of ambient aerosol concentrations at each monitoring site. For sites with incomplete data during the baseline years (fewer than 3 complete years), appropriate tracking metrics cannot be calculated. The WRAP, working with individual states, developed data substitution methods for sites that did not have the required baseline data. These methods were also applied at sites where incomplete years were desirable for modeling and planning purposes. Substitutions included estimating missing species from other on-site measurements, and appropriately scaling data collected from nearby donor sites which showed favorable long-term comparisons. Initially complete years were not changed, even though there may have been missing samples during those years. Multiple factors contributed to missing data at sites, including sampler installation late in the baseline period, the clogging of some modules (especially during fire events), and various equipment failures. In some cases, the bulk of individual species were available for the sites, and substitution for only minor components were required to complete individual days. A full description of the data substitution methods sanctioned by RHR guidance and WRAP's analyses, along with a list of WRAP sites requiring substitutions can be found in the TSS document *WRAP Data Substitution Methods* (http://vista.cira.colostate.edu/docs/wrap/Monitoring/WRAP_Data_Substitution_Methods_April_2007.doc).

3.3 EMISSIONS DATA

Overview of emissions applied in regional analysis scenarios for CMAQ/CAMx visibility modeling for Regional Haze Planning in the WRAP region

1. The table and links below provide an overview of the emissions analyzed and applied in the CMAQ and CAMx regional air quality models for regional haze planning in the WRAP region. These emissions data

are displayed on the TSS. Generally, emissions inputs were prepared by individual states and tribes for point, area, and most dust emissions categories. With input and review by states, tribes, and FLMs, WRAP Forums and Workgroups prepared consistent and comparable WRAP region emissions data for the mobile, fire, ammonia, area source oil and gas, eastern Pacific offshore shipping, some dust, and biogenics emissions categories. The WRAP Regional Modeling Center gathered the latest, best, and most representative emissions estimates at the time from the CENRAP, Eastern U.S., Canada, and Mexico regions in executing the sequence of modeling simulations summarized below. Boundary conditions reaching North America from the rest of the world were jointed prepared by all 5 RPOs from the GEOS-Chem global model.

Model Scenario & Date	**Emissions Input**	**Point**	**Area**	**Mobile (On- & Off-Road)**	**Fire**	**Ammonia, Dust, & Biogenics**	**Offshore shipping & remainder of North America**	**North American Domain Boundary Conditions**
Base02b (Spring 2006)	2002 best available actual data	SSJF/EF from state/tribal EIs[P1]	SSJF/EF from state/tribal EI[A1], Phase I O&G [A2]	EF project[M1]	FEJF - actual 2002[F1]			
Plan02c (Summer 2006)	2000-04 planning data (2002 data in WRAP region except fire)	SSJF/EF from state/tribal EIs[P1]	SSJF/EF from state/tribal EIs[A1], Phase I O&G[A2]	EF project[M1]	FEJF - average 2000-04[F2]			
Plan02d (October 2007)	2000-04 planning data (2002 data in WRAP region except fire)	SSJF/EF detailed state updates [P3]	SSJF/EF detailed state updates [A4], Phase II O&G [A5]	EF project[M1]	FEJF - average 2000-04[F2]			
Base18b (Summer 2006)	2018 Base Case data (see footnotes by sector)	SSJF/EF from state/tribal EIs[P2]	SSJF/EF from state/tribal EIs[A3], Phase I O&G [A2]	EF project[M1]	FEJF - average 2000-04[F3]			
Preliminary Reasonable Progress. Version A - PRP18a (June 2007)	2018 PRP Version A data (Base18b except for footnotes noted by sector)	SSJF/EF, detailed state updates [P4]	SSJF/EF detailed state updates [A6], Phase II O&G[A5]	EF project[M1]	FEJF - average 2000-04[F3]			

Preliminary Reasonable Progress – Version B PRP18b (July 2009)					FEJF - average 2000-04[F3]			
Preliminary Reasonable Progress – Version CMV sensitivity PRP18cmv (July 2009)					FEJF - average 2000-04[F3]			

Emissions Control Programs included in the WRAP region modeling scenarios

- Smoke Management Programs accounted for using Emissions Reduction Techniques applied to 2000-04 average Fire emissions
- New permits and state/EPA consent agreements since 2002 reviewed with each state
- Ozone and PM2.5 SIPs (California)
- State Oil and Gas Emissions control programs
- Mobile sources
    - Heavy Duty Diesel (2007) Engine Standard
    - Tier 2 Tailpipe
    - Large Spark Ignition and Recreational Vehicle Rule
    - Nonroad Diesel Rule
- Combustion Turbine and Industrial Boiler/Process Heater/RICE MACT
- VOC 2-, 4-, 7-, and 10-year MACT Standards
- In PRP18a, PRP18b, and PRP18cmv, known BART emissions rates by source by pollutant as determined at that time by State or EPA
- In PRP18a, presumptive SO2 BART emissions rates on EGUs where states and EPA had not yet determined SO2 BART emissions rates, no non-EGU SO2 BART assumptions, also no NOx BART assumptions on either EGUs or non-EGUs
- In PRP18b and PRP18cmv, limited application of presumptive SO2 and presumptive NOx BART emissions rates to a few EGU sources where BART was not yet determined

Point Sources – these projects were commissioned by the Stationary Sources Joint Forum and the Emissions Forum.

P1. 2002 actual data reported by states, locals, tribes, and EPA databases. See: http://www.wrapair.org/forums/ssjf/documents/eictts/docs/QA_of_the_2002_WRAP_Stationary_Sources_Emissions_Inventory.pdf.pdf

P2. http://wrapair.org/forums/ssjf/documents/eictts/docs/WRAP_2018_EI-Version_1-Report_Jan2006.pdf

P3. Plan02d memo to be added to WRAP website

P4. http://wrapair.org/forums/ssjf/documents/eictts/Projections/PRP18_EI_tech%20memo_061607.pdf

Area Sources – these projects were commissioned by the Stationary Sources Joint Forum and the Emissions Forum.

A1. 2002 actual data reported by states, locals, tribes, and EPA databases. See: http://www.wrapair.org/forums/ssjf/documents/eictts/docs/QA_of_the_2002_WRAP_Stationary_Sources_Emissions_Inventory.pdf.pdf

A2. http://wrapair.org/forums/ssjf/documents/eictts/OilGas/WRAP_Oil&Gas_Final_Report.122805.pdf

A3. http://wrapair.org/forums/ssjf/documents/eictts/docs/WRAP_2018_EI-Version_1-Report_Jan2006.pdf

A4. Plan02d memo to be added to WRAP website

A5. http://wrapair.org/forums/ssjf/documents/eictts/OilGas/2007-10_Phase_II_O&G_Final_Report_v10-07.pdf

A6. http://wrapair.org/forums/ssjf/documents/eictts/Projections/PRP18_EI_tech%20memo_061607.pdf

Mobile Sources – this project was commissioned by the Emissions Forum.

M1. This project prepared EPA Mobile6 and NONROAD emissions modeling results for 2002 and 2018, taking into account federal and state mobile emissions rules. The project also included emissions from airplanes landings and takeoffs, railroads, and road dust for the WRAP region. The emissions were calculated from state reports of activity data and profiles. The project is documented at: http://wrapair.org/forums/ef/UMSI/index.html. State-reported port activity and river shipping emissions are in the states' area source EIs.

Fire Emissions – these projects were commissioned by the Fire Emissions Joint Forum.

F1. This 2-phase project (Phases 1 and 2) collected 2002 actual fire emissions data from federal, state, and tribal databases. See: http://www.wrapair.org/forums/fejf/documents/WRAP_2002_PhII_EI_Report_20050722.pdf

F2. The Phase 3 project scaled 2002 actual data from their Phase 2 project by average fire activity data by state for the 2000-04 period, location and dates of fires in 2002 were held constant. See: http://www.wrapair.org/forums/fejf/documents/task7/Phase3-4EI/WRAP_Fire_Ph3-4_EI_Report_20070515.pdf

F3. The Phase 4 project built on Phase 3, to scale 2002 actual data by average fire activity data by state for the 2000-04 period, location and dates of fires in 2002 were held constant, then applying Emission Reduction Techniques to agricultural and prescribed fire by season and region across the WRAP region to represent implementation of Enhanced Smoke Management Programs. This project also produced three 2018 emissions scenarios, which have NOT been used in regional emissions analysis or regional modeling, as 2000-04 data are thought to be the most representative estimates of 2018 emissions for haze planning purposes. See: http://www.wrapair.org/forums/fejf/documents/task7/Phase3-4EI/WRAP_Fire_Ph3-4_EI_Report_20070515.pdf

Ammonia, Dust, & Biogenic Emissions – these projects were commissioned by the Dust Emissions Joint Forum and the Modeling Forum.

ADB1. RMC prepared land-use data-based fugitive ammonia, natural biogenics, and windblown dust emission inventories, driven by meteorological data from the CMAQ air quality model. See:

ADB2. Dust

Emissions from Pacific offshore shipping & remainder of North America – these projects were

Eastern Pacific Offshore Shipping –

Mexico –

Canada –

CENRAP and Eastern U.S. –

Boundary conditions reaching North America from the rest of the world – this project was

3.4 MODELING RESULTS

The WRAP Regional Modeling Center (RMC) was responsible for performing regional air quality modeling simulations for the contiguous WRAP region; the WRAP states and tribes then use the analytical results to develop SIPS or TIPs under the RHR. Key RMC visibility modeling work elements include the following:

1. Evaluation of the visibility model for a historical episode—in this case, for calendar year 2002. Output from the model simulation is compared with ambient air quality data for the historical episode as part of a model performance evaluation (MPE).

2. Development of visibility planning scenarios for the regional haze baseline period of 2000-04 and for the initial regional haze future projection period, calendar year 2018.

3. Modeling a variety of emissions sensitivity, emissions source apportionment, and emissions control strategies to assess whether planned future regional emissions reductions will be sufficient to demonstrate reasonable progress toward achieving visibility goals.

The RMC used MPEs to assess the suitability of two modeling systems for simulating air quality and visibility for the 2002 calendar year, so that the models could be used for subsequent planning, sensitivity, and emissions control strategy modeling. The two models are EPA's Community Multiscale Air Quality (CMAQ) modeling system and ENVIRON's Comprehensive Air quality Model with extensions (CAMx).

The visibility modeling work included developing emissions inventories for 2002, developing meteorology data for 2002 using a meteorology model, operating the air quality and visibility models, and developing tools and procedures for comparing the model results to ambient monitoring data as part of the model evaluation exercise.

3.4.1 Emissions Modeling

For the emissions modeling work conducted for WRAP the RMC used improved 2002 emissions data for the United States, Mexico, and Canada to create a final base 2002 annual emissions database that was used in the CMAQ and CAMx model performance evaluations. Sources for emissions inventory and ancillary modeling data included WRAP emissions inventory contractors, other Regional Planning Organizations (RPOs), and EPA. Building from the WRAP preliminary 2002 modeling cases completed earlier, the RMC integrated several updates to the inventories and ancillary data to create final 2002 emissions input files. The RMC used the Sparse Matrix Operator Kernel Emissions (SMOKE) version 2.1 processing system. RMC performed all modeling and quality assurance (QA) work based on the WRAP RMC emissions QA protocol (need link). http://pah.cert.ucr.edu/aqm/308/emissions.shtml, http://pah.cert.ucr.edu/aqm/308/cmaq.shtml, http://pah.cert.ucr.edu/aqm/308/docs.shtml

3.4.2 MM5 Modeling

Meteorology data are key input data required for running any air quality model. These data include information on wind speed and direction, atmospheric stability and vertical motion in the atmosphere, sunlight intensity, clouds and precipitation, and vertical mixing. For photochemical grid models, such as CMAQ and CAMx, meteorology data are typically developed by operating a prognostic numerical simulation model that solves the fundamental equations governing conservation of mass, energy, and momentum. For the WRAP modeling the RMC applied the Fifth-Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5) for both a 36-km continental domain and a fine-resolution, nested 12-km domain in the western U.S.

Based on the upper-air soundings, one of the most serious problems is the difficulty MM5 has in establishing the observed planetary boundary layer (PBL) structure. The model has trouble getting the PBL depth correct, particularly in the stable nocturnal case. Also, MM5's difficulty in simulating the observed fine structure of the dew point temperature profile and the overall level of saturation in the lower troposphere is cause for concern. It is important that the model produce cloud decks at the correct height. Errors in humidity and cloud prediction have a negative impact on the accuracy of downwelling solar radiation, cause errors in the temperature profile and the surface fluxes, affect the atmospheric chemistry, and make it difficult for the particulate matter (PM) model to perform properly.

The RMC concluded that the final 36-km and 12-km WRAP MM5 runs exhibited reasonably good performance and were within the bounds of other meteorological databases used for prior air quality modeling efforts, and that it was therefore reasonable to proceed with their use as inputs for the RMC visibility modeling. http://pah.cert.ucr.edu/aqm/308/mm5.shtml

3.4.3 Visibility Modeling

Visibility impairment occurs when fine particulate matter ($PM_{2.5}$) in the atmosphere scatters and absorbs light, thereby creating haze. $PM_{2.5}$ can be emitted into the atmosphere directly as primary particulates, or it can be produced in the atmosphere from photochemical reactions of gas-phase precursors and subsequent condensation to form secondary particulates. Examples of primary $PM_{2.5}$ include crustal materials and elemental carbon; examples of secondary PM include ammonium nitrate, ammonium sulfates, and secondary organic aerosols (SOA). Secondary $PM_{2.5}$ is generally smaller than primary $PM_{2.5}$, and because the ability of $PM_{2.5}$ to scatter light depends on particle size—with light scattering for fine particles being greater than for coarse particles—secondary $PM_{2.5}$ plays an especially important role in visibility impairment. Moreover, the smaller secondary $PM_{2.5}$ can remain suspended in the atmosphere for longer periods and transported long distances, thereby contributing to regional-scale impacts of pollutant emissions on visibility.

The sources of $PM_{2.5}$ are difficult to quantify because of the complex nature of their formation, transport, and removal from the atmosphere. This makes it difficult to simply use emissions data to determine which pollutants should be controlled to most effectively improve visibility. Photochemical air quality models provide a better understanding of the sources of $PM_{2.5}$ by simulating the emissions of pollutants and the formation, transport, and deposition of $PM_{2.5}$. If an air quality model performs well for a historical episode, the model may then be useful for identifying the sources of $PM_{2.5}$ and helping to select the most effective emissions reduction strategies for attaining future visibility goals.

The RMC compared two Eulerian air quality models, CMAQ and CAMx. Both models were operated for calendar year 2002 for the RPO Unified Continental 36-km Modeling Grid domain, shown in Figure 3-2. In addition, the RMC compared CMAQ results from the 36-km model domain with those from a high resolution, nested 12-km domain in the WRAP region.

For each of these model simulations, the RMC performed extensive comparisons of the model-simulated $PM_{2.5}$ with measured $PM_{2.5}$ from several ambient monitoring networks, including: speciated $PM_{2.5}$ data from IMPROVE, CASTNet, NADP/NTN, and STN; and gas-phase data from the AQS network.

RMC reports are available at: http://pah.cert.ucr.edu/aqm/308/cmaq.shtml and http://pah.cert.ucr.edu/aqm/308/docs.shtml.

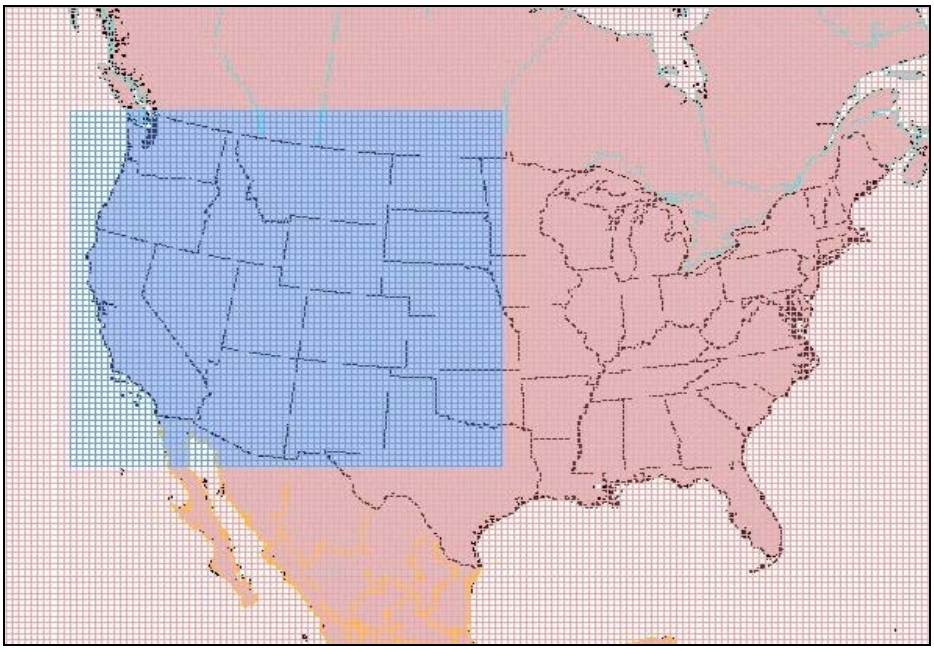


Figure 3-2. RPO Unified Continental 36-km Modeling Grid Domain.

3.4.x Key Findings From the Model Performance Evaluation Study

Key findings from the Model Performance Evaluation study include:

- Model performance does not appear to benefit significantly from using the finer-resolution grid for modeling the lower concentrations of $PM_{2.5}$ that typically occur in the Class I areas.
- The RMC did not recommend the routine application of additional 12-km modeling as part of the WRAP regional haze planning effort, due to the substantially higher resources and costs associated with performing high-resolution modeling.
- The 2002 model results are significantly improved compared to results from the Section 309 modeling that was performed for calendar year 1996.
- The CMAQ and/or the CAMx 36-km modeling can be used, in combination with the RRF approach, to evaluate the benefits of emissions reduction strategies for all PM species other than CM, in order to project visibility changes at Class I areas for regional haze planning purposes.
- Both CMAQ and CAMx are acceptable for visibility modeling. The choice of model should be based in part on factors other than model performance, such as computer run times, disk storage requirements, and source apportionment and/or sensitivity analysis needs.

3.5.x Visibility Projections From the Regional Photochemical Modeling

3.5.1.1 2018 Planning Milestone Visibility Projection Values

2018 visibility projections at Class I areas are used to assess visibility improvements and assist in the Reasonable Progress determination for the December 2007 Regional Haze Rule (RHR) Implementation Plans prepared by states, EPA, and possibly tribes. The model projected 2018 visibility is compared against a 2018 Uniform Rate of Progress (URP) goal that is obtained through construction of a linear Glide Path from the observed 2000-2004 Baseline Period to Natural Conditions in 2064 using the Haze Index metric in deciviews.

3.5.1.2 Difficult to Meet 2018 URP Goal at Western U.S. Class I Areas

2018 visibility projections at western Class I areas fail to achieve the URP goal for several reasons:

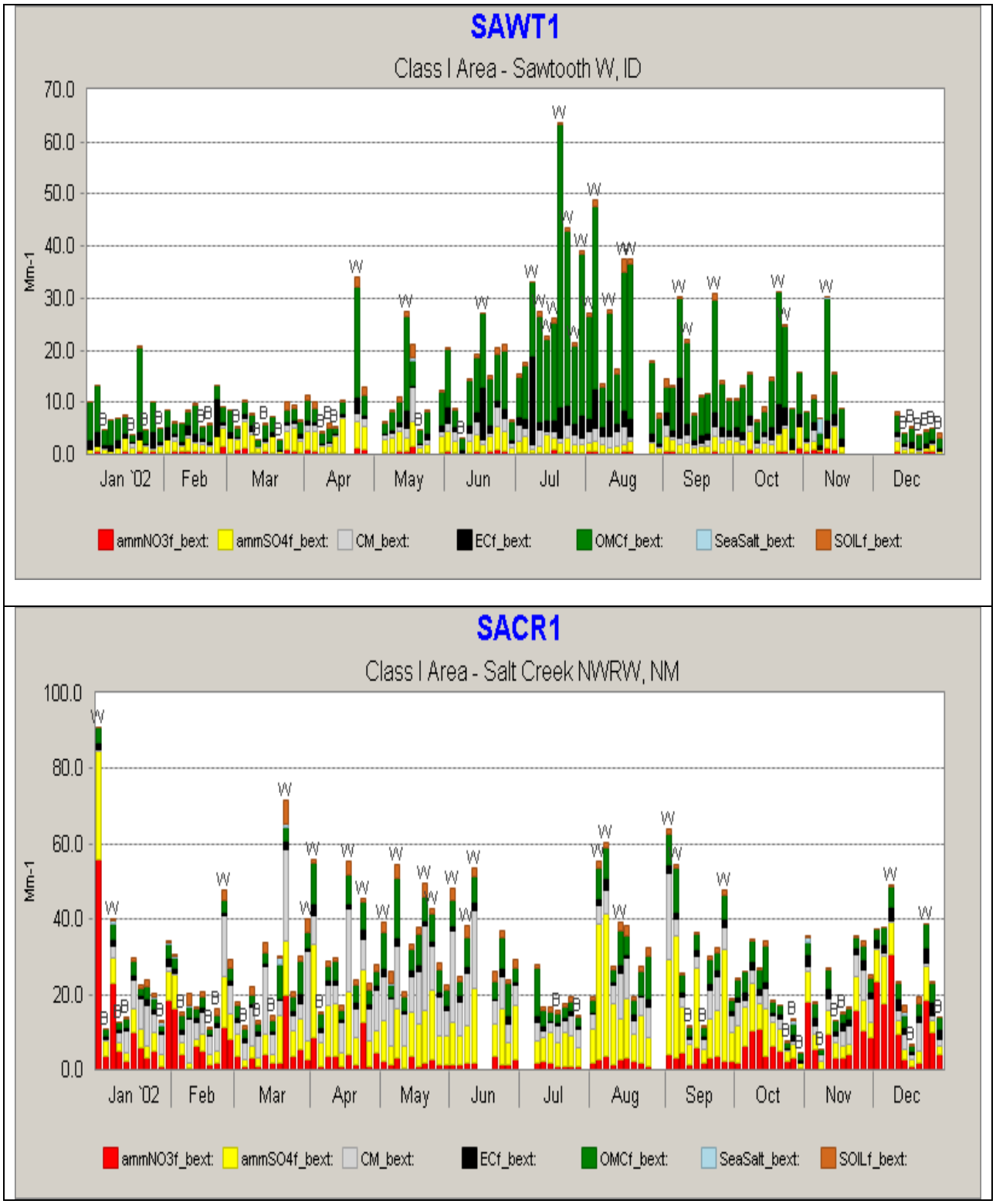
- High contributions from fires (EC and OC) at some Class I areas that are assumed to remain unchanged from 2002 to 2018.
- High contributions from dust (Soil and CM) at some Class I areas, especially in the Desert Southwest, much of which is natural and remains unchanged from 2002 to 2018 (e.g., wind blown dust).
- High contributions of International Transport (e.g., Canada, Mexico and Global) and Offshore Marine Vessels that are assumed unchanged.
- Relatively clean visibility conditions at many Class I areas where the contribution of United States anthropogenic sources is small.

Most of these sources are uncontrollable, unpredictable and difficult to forecast. For example, Figure 10 displays the 2002 daily extinction at the Sawtooth, Idaho and Salt Creek, New Mexico Class I areas where the Worst 20% monitored visibility days are dominated by fires and dust, respectively. Because it is impossible to accurately forecast future-year emissions for these source categories, many of them were held constant from 2000-04 Baseline period to 2018 Base Case conditions:

- Biogenics;
- Natural Fires (wildfire, wildland fire use, and non-federal rangeland fire in the WRAP region);
- Wind blown dust (from WRAP model);
- Ammonia (from WRAP model);
- Mexico and Canada;
- Boundary Conditions (global transport from 2002 simulation of GEOS-CHEM global model); and
- Offshore Marine Vessels.

Thus, modeled visibility reductions would come from reductions in on-road and non-road mobile sources (NOx, EC, OC and SO2), controlled large stationary point sources (SO2 and NOx), potentially other sources in nonattainment areas (mainly NOx and VOC in California), and applying Emissions Reduction Techniques to anthropogenic prescribed and agricultural fire sources' 2000-04 activity patterns in the WRAP region (mainly OC and EC). Other source categories are assumed to remain relatively unchanged, or even increase in some cases due to increased activity between 2002 and 2018 (e.g., road dust, oil and gas, etc.).

Daily observed extinction at the Sawtooth (top) and Salt Creek (bottom) Class I area IMPROVE monitors for 2002 showing Worst 20% days that are dominated by fires (EC and OC) and dust (Soil and CM), respectively.



3.5.1.3 EPA Guidance for Projecting Visibility

EPA released revised guidance for using models to project future-year visibility as part of the RP determination in September 2006 (EPA, 2006). The EPA default guidance method is to use "2002 worst monitored days" (Worst 20 %) to develop scaling factors to project future visibility conditions in 2018. The RHR requires monitoring data from the 2000-04 Baseline period to be used as the basis of the regional haze implementation plans. The modeling results for the 2002 Base Case and 2018 emissions scenarios using the 2002 meteorology are used to project PM concentrations for each of the Worst 20 % days from the 2000-2004 5-year Baseline to obtain estimates of PM concentrations for the Worst 20 % days in 2018 from which visibility is estimated using the revised IMPROVE equation. The ratio of the 2018 to 2002 modeling results that are used to scale the observed PM concentrations for the Worst 20 % days from the 2000-04 Baseline are called Relative Response Factors (RRFs). EPA's default guidance for projecting future-year visibility is in the same document and is closely linked to guidance for interpreting the modeling results for $PM_{2.5}$ and 8-hour ozone National Ambient Air Quality Standard (NAAQS) attainment demonstrations is found at: http://www.epa.gov/scram001/guidance/guide/draft_pm.pdf. The purpose of applying the EPA guidance to develop the RRFs for future visibility conditions is based on the assumption that the air quality model is better at predicting relative changes in concentration than absolute concentrations.

Basic steps for applying the EPA RRF guidance to project visibility conditions in 2018 at each CIA (i.e., IMPROVE monitoring site associated with a CIA) are:

- Model species concentrations for a 2000-04 Baseline case;
- Model species concentrations for a 2018 emissions scenario;
- Determine a species-specific and CIA-specific RRF for the average of the Worst 20 % monitored days (selected from 2002 IMPROVE data), where, for example:
  - RRF sulfate = 2018 sulfate/2002 sulfate
- Using the RRFs based on the 2002/2018 modeling results for Worst 20 % days from 2002, apply the RRFs to the observed PM concentrations from the Worst 20 % days in the 2000-04 5-year Baseline to obtain the 2018 projected PM concentrations:
  - [2018 concentrations] = RRF x [2000-04 Baseline Worst 20 % days concentrations]
- Calculate projected 2018 visibility values for Worst 20 % days from the 5 years and for each Class I area using deciviews and compare the 2018 projected deciviews with the 2018 URP goal to assess how closely the URP goal is achieved.

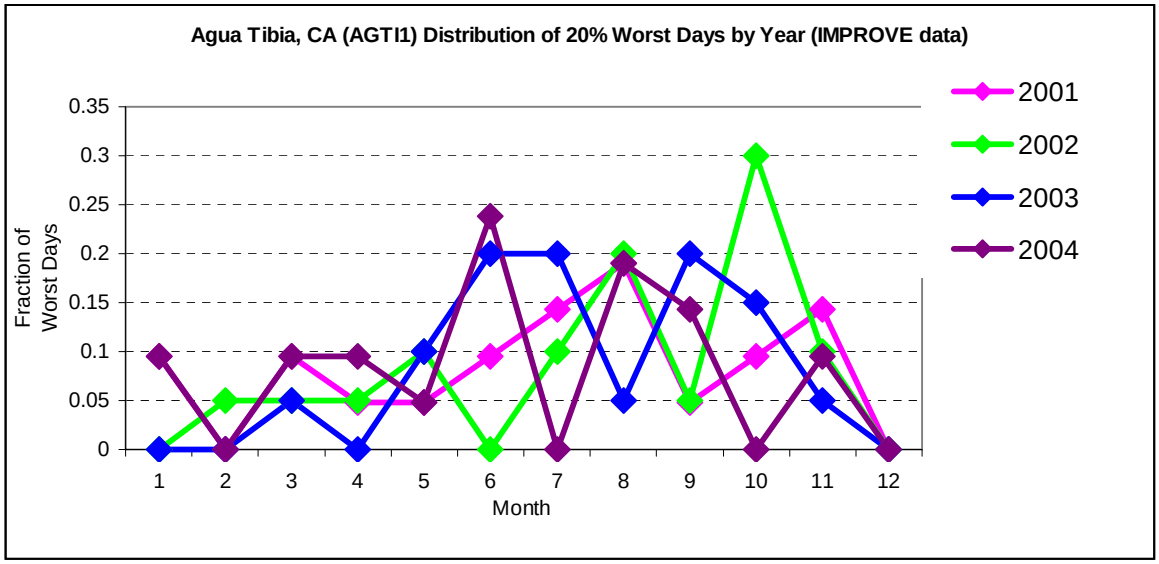
The 20% best visibility days are projected in the same manner, selecting the 20% best monitored days from 2002 IMPROVE data. Several issues with this approach are evident when analyzing the regional haze monitoring data and modeling results.

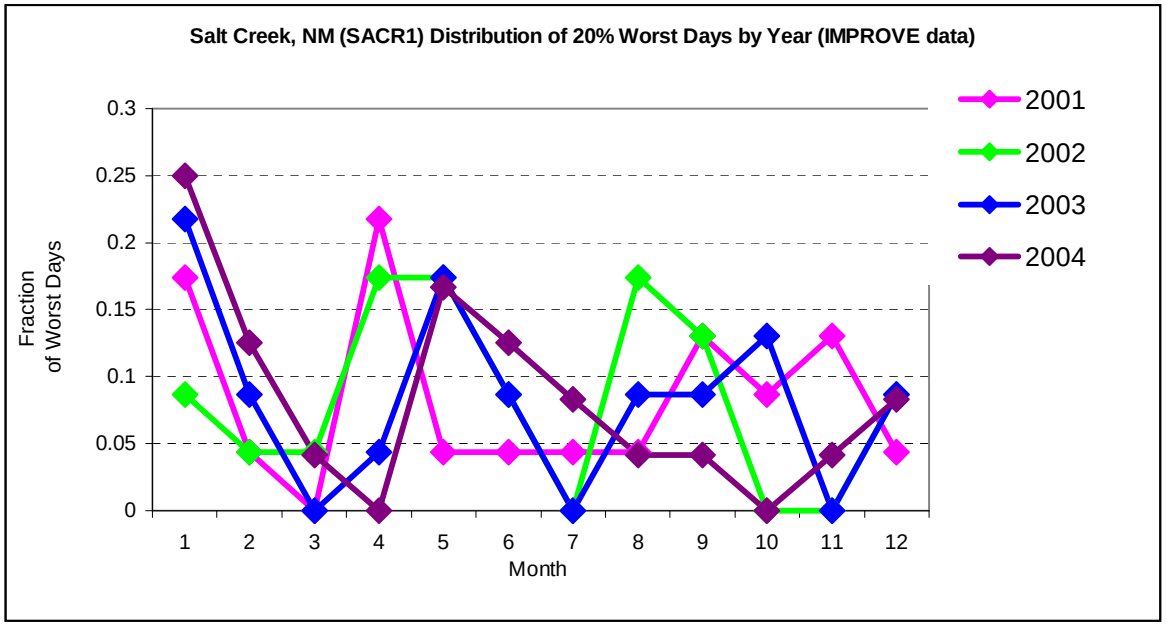
Representativeness of 2002 Worst 20 % Days for W20% Days for Other Years in the 2000-04 Baseline: The RRFs based on 2002 Worst 20% days may not be representative of Worst 20% days from other years in the 2000-04 Baseline period. For example, they may occur at different times of the year and represent different conditions and/or chemical constituents. For example, Figures 11 through 15 display the distribution of Worst 20 % days for the 2000-2004 Baseline at 5 CIAs. At Agua Tibia (Figure 11, top) we see that 30% of the Worst 20 % days in 2002 occur in October, but none did in 2004 and 10-15% did in 2001 and 2003. On the other hand, in June there are no Worst 20 % days in 2002 at Agua Tibia, yet there are 10% (2001) and 20% (2003 and 2004) of the Worst 20 % days in other years of the Baseline period. Similar seasonal variations in the Worst 20 % days for 2002 versus the other years in the Baseline are seen at Salt Creek, Badlands, Sawtooth, and Mount Rainier CIAs. Accounting for the differences of monthly and seasonal variations in the Worst 20 % days between 2002 and all 5 years in the Baseline period may be important in projecting 2018 visibility conditions.

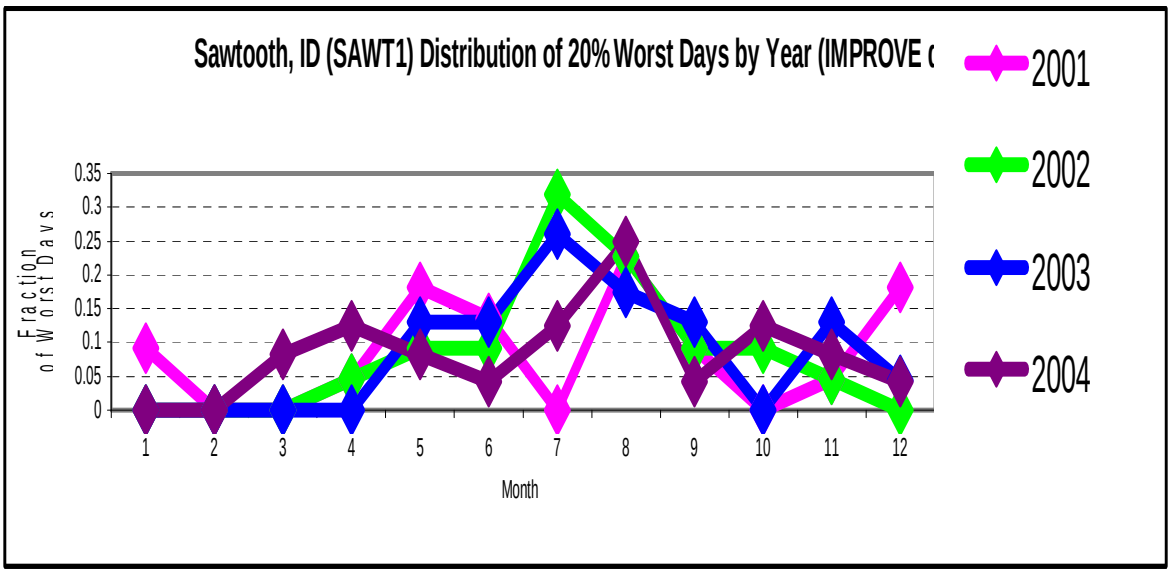
Episodic Events: Another issue associated with the representativeness of the RRFs derived from the 2002 Worst 20 % days is the occurrence of episodic events that may dominate the Worst 20 %. For example, if fires

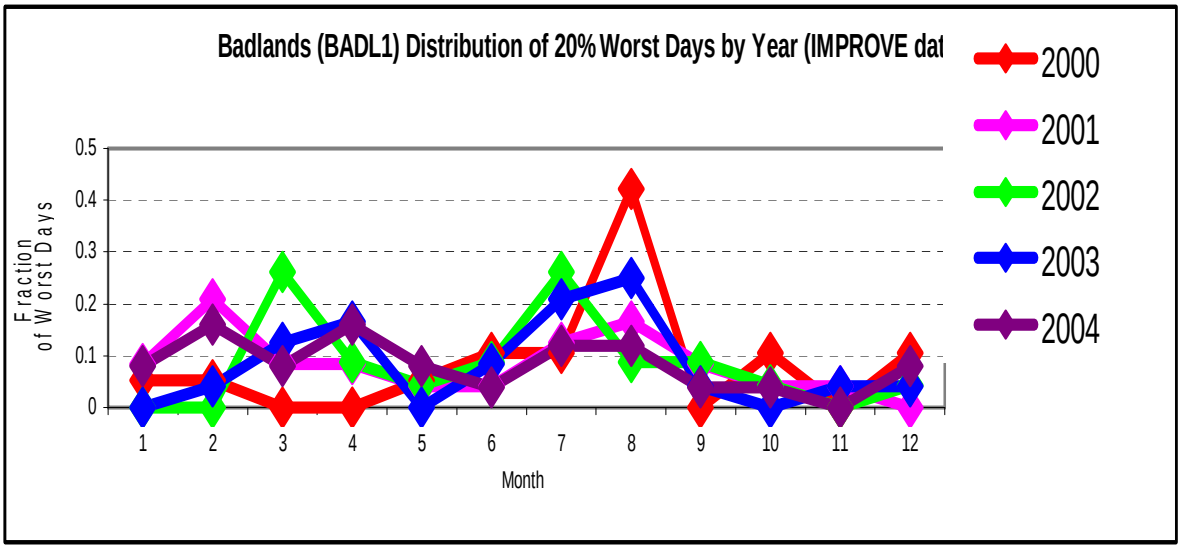
dominate the Worst 20 % days in 2002 and they are kept constant in 2018 the resultant RRFs will be very stiff and project little change in future-year PM concentrations for all W20% days in the Baseline even though fires may not have dominated the Worst 20 % days in other years of the Baseline. Conversely, if fires occur in other years of the Baseline and not in 2002, then the RRFs will reflect changes in anthropogenic emissions that are applied to PM concentrations due to fires which is also not appropriate. Again, accounting for monthly or seasonal variations in the RRFs may help alleviate this issue since prescribed burns, agricultural burning and wild fires each generally occur during the same time periods of the year.

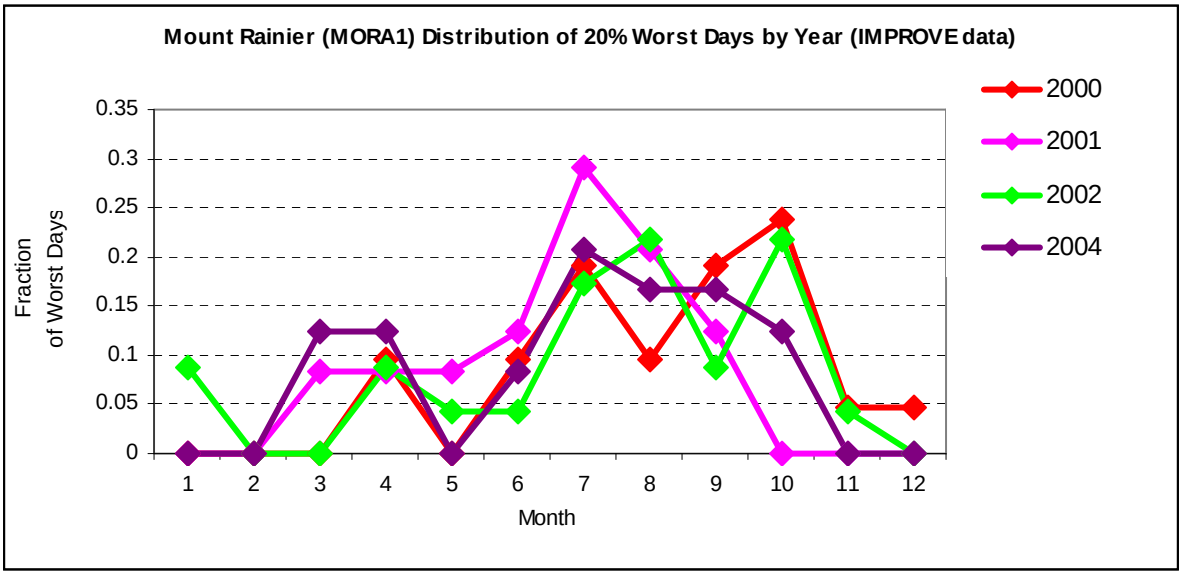
Time Series of Monthly Variation in the Fraction Variation of the 20% Worst Monitored Days at randomly-selected WRAP region Class I areas.






Sawtooth, ID (SAWT1) Distribution of 20% Worst Days by Year (IMPROVE d
2001
2002
2003
2004
Fraction of Worst Days
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12
Month


Badlands (BADL1) Distribution of 20% Worst Days by Year (IMPROVE dat
2000
2001
2002
2003
2004
Fraction of Worst Days
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12
Month


Mount Rainier (MORA1) Distribution of 20% Worst Days by Year (IMPROVE data)
2000
2001
2002
2004
Fraction of Worst Days
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12
Month

4.0 DESCRIPTION OF WRAP ANALYSES

EPA staff please add "any and all" comments on this 2/22 draft here, listed by subsection of Section 4 by Friday March 5th

4.1 OVERVIEW

The WRAP performed a series of analyses in support of regional haze implementation plans. These analyses were designed to directly or indirectly address topics posed by Regional Haze Rule guidance documents, and include:

- Class I Area Summary Table
- Glide Slope Analyses
- Visibility Projections
- Attribution Analyses

The following sections provide a guide to these analyses and resources containing further information about them.

4.2 CLASS I AREA SUMMARY TABLE

The Class I Area Summary Table (accessible via the TSS Haze Planning page: http://vista.cira.colostate.edu/tss/Results/HazePlanning.aspx) calculates metrics to support regional haze analysis by species, total light extinction, and deciview. The results presented with this tool are derived from many of the other Haze Planning tools. An example of a completed Class I Area Summary Table is presented in Figure 4-1 at the end of this section.

The summary data begins with monitored values on the left, and progresses through estimated and projected values moving toward the right. All species extinction values are calculated based on the revised IMPROVE algorithm (see the TSS document *IMPROVE Particulate Monitoring*: http://vista.cira.colostate.edu/docs/wrap/Monitoring/IMPROVE_Particulate_Monitoring_May_2007.doc). The data in each column are calculated as follows:

- **2000-04 Baseline Conditions (Mm^{-1}) [Monitored]** – This field is taken directly from the TSS Visibility Projections tool. It represents the monitored average Baseline extinction by aerosol species, total light extinction, and deciview for the selected site. A discussion of the selection of best and worst 20% IMPROVE days is presented in the EPA *Guidance for Tracking Progress Under the Regional Haze Rule* (http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf).
- **2064 Natural Conditions (Mm^{-1}) [Estimated]** – This field is taken directly from the TSS Visibility Projections tool. It represents the estimated 2064 Natural Conditions. A discussion of the estimation of natural conditions is presented in the EPA *Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule* (http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_envcurhr_gd.pdf). WRAP chose to refine the original EPA estimates for natural conditions, and a presentation of the revised approach is given in *Natural Haze Levels II: Application of the New IMPROVE Algorithm to Natural Species Concentrations Estimates* (http://vista.cira.colostate.edu/docs/wrap/Monitoring/NaturalHazeLevelsIIReport.ppt)
- **2018 Uniform Rate of Progress Target (Mm^{-1}) [Estimated]** – This field is taken directly from the TSS Visibility Projections tool. It represents the Uniform Rate of Progress estimated for 2018, based on the calculated glide slope between the 2000-04 Baseline period and 2064 Natural Conditions. A discussion of the uniform rate of progress and glide slope can be found in Section 4.3 of this document.
- **2018 Projected Visibility Conditions (Mm^{-1}) [Projected]** – This field is taken directly from the TSS Visibility Projections tool. It represents the projected extinction for each species, total light extinction, and

deciview for 2018, based on air quality model results combined with the Baseline visibility conditions. A discussion of the visibility projection analyses can be found in Section 4.4 of this document.

- **Baseline to 2018 Change In Statewide Emissions (tons / %) [Projected]** – This field is calculated from data in the TSS Emissions Review tool, and is the absolute and percentage difference between primary emissions estimated for 2018 and the Baseline period for the home state of the Class I Area under review. A negative number represents an estimated decrease in emissions by 2018. The emissions parameters (from the TSS Emissions Review tool) presented in this field include: sulfur oxides, nitrogen oxides, primary organic aerosol, elemental carbon, fine particulate matter, and coarse particulate matter. It is important to keep in mind that since this field represents the change in emissions for only a single state, it does not provide complete information on all impacts of changes in estimated emissions throughout WRAP and the modeling domain.
- **Baseline to 2018 Change In Upwind Weighted Emissions (%) [Projected]** – This field is calculated from data in the TSS Weighted Emissions Potential (WEP) tool, and is the percentage difference between meteorological back trajectory- and distance-weighted emissions estimated for 2018 and the Baseline period. A discussion of the WEP analysis can be found in Section 4.5 of this document. This field provides a semi-quantitative value for the change in emissions from across the entire modeling domain expected to impact the Class I Area under review. However, since the WEP analysis does not take into account emissions chemistry and removal processes its results should be used only in conjunction with other WRAP analyses.
- **Baseline to 2018 Change In Anthropogenic Upwind Weighted Emissions (%) [Projected]** – This field is calculated from data in the TSS Weighted Emissions Potential (WEP) tool, and is the percentage difference between meteorological back trajectory- and distance-weighted anthropogenic emissions estimated for 2018 and the Baseline period. These results are calculated in a manner identical to the previous field, but omitting the following natural emissions source categories: Natural Fires, Biogenic, and Wind Blown Dust.

The Class I Area Summary Table can be generated for the best and worst IMPROVE days based on several pre-defined pairs of emissions scenarios, and for multiple relative response factor calculation methods. For more information, use the TSS Help Document (http://vista.cira.colostate.edu/TSS/Help/GettingStarted.aspx).

Class I Area Summary Table

Class I Area Visibility Summary: Agua Tibia W, CA
Visibility Conditions: Worst 20% Days
RRF Calculation Method: Specific Days (EPA)
Emissions Scenarios: 2000-04 Baseline (plan02d) & 2018 PRPcmv (prp18cmv)

	Monitored	Estimated		Projected			
	2000-04 Baseline Conditions (Mm-1)	2064 Natural Conditions (Mm-1)	2018 Uniform Rate of Progress Target (Mm-1)[1]	2018 Projected Visibility Conditions (Mm-1)	Baseline to 2018 Change In Statewide Emissions (tons / %)	Baseline to 2018 Change In Upwind Weighted Emissions[2] (%)	Baseline to 2018 Change In Anthropogenic Upwind Weighted Emissions[2] (%)
Sulfate	31.82	0.99	20.62	19.98	-6,243 -8%	-40%	-46%
Nitrate	29.91	0.94	19.5	13.59	-591,119 -45%	-46%	-48%
Organic Carbon	17.55	2.98	13.11	16.28	-10,792 -7%	-5%	-14%
Elemental Carbon	6.37	0.26	4.68	3.59	-12,961 -28%	-28%	-49%
Fine Soil	1.25	0.83	1.15	1.36	250 0%	7%	9%
Coarse Material[3]	8.64	2.98	7.13	Not Applicable	29,666 13%	13%	16%
Sea Salt[3]	0.82	1.68	1.01		Not Applicable		
Total Light Extinction	107.36	21.66	73.56	75.25			
Deciview	23.5	7.64	19.8	19.93			

WRAP TSS - 12/01/2009

1) 2018 Uniform Rate of Progress Target for Best 20% Days is not defined.
2) Results based on Weighted Emissions Potential analysis using the 2000-04 Baseline (plan02d) & 2018 PRPcmv (prp18cmv) emissions scenarios.
3) Visibility projections not available due to model performance issues.

Figure 4-1. Example Class I Area Summary Table.

4.3 GLIDE SLOPE ANALYSES

The Regional Haze Rule program goals include remedy of the haziest days and protection of the cleanest days in Class I areas, or more specifically:

- For each Class I area, states are required to improve the visibility on the 20% haziest days in the baseline period (defined as 2000-2004) to so-called natural conditions by 2064.
- For each Class I area, states are required to ensure that the visibility on the 20% cleanest days in the baseline period does not degrade by 2064. (If the baseline cleanest days are dirtier than the determined natural conditions, they do not have to be improved.)

To characterize baseline conditions and track progress, states must follow a series of prescribed steps to assemble the IMPROVE aerosol data in such a way that daily extinction values can be calculated, and these extinction values converted to a Haze Index measured in deciviews. The Haze Index is the mandated visibility metric of the RHR. Once baseline and natural conditions are determined for a given Class I area, it is possible to generate a glide slope or glide path which graphically represents the progress in terms of the Haze Index necessary to achieve the RHR goal. The glide slope is calculated as a linear interpolation for each year between the baseline (represented by 2004) and natural conditions (2064). From the glide slope states can calculate the uniform rate of progress (URP), typically expressed in terms of "deciviews per decade." The point along the glide path at 2018 becomes the target or URP goal for improvement at the Class I area by that year. A glide

slope schematic is presented in Figure 4-2 (taken from *Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule*, http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf).

Note that EPA guidance defines the glide slope only for the Haze Index (deciviews) and not for any other parameter or unit of measure. The choice of deciviews is appropriate for several reasons:

- The deciview is approximately linear with respect to human perception.
- A given deciview change is the same on clean and dirty days, which allows for economic valuation studies to be performed.
- The deciview is simple for policy use and the public can understand it.

However, the Haze Index lumps all species' contributions to visibility degradation into a single number, thus hindering understanding of the relative impact of each species (and ultimately emission types). WRAP developed "species glide slopes" to allow a better understanding of species contributions. Species glide slopes "look and feel" like deciview glide slopes but are calculated somewhat differently: each baseline and natural conditions species extinction (expressed as Mm-1) undergoes a logarithmic transformation, interpolated values for intervening years (in 5 year increments) are calculated, then each value undergoes in inverse logarithmic transformation to return to units of Mm-1. The end result is a species glide slope this is similar though not identical in character to the deciview glide slope. The species glide slope carries no regulatory weight, but is very useful in characterizing each species impact on visibility and projected changes in visibility. Figure 4-3 presents example species glide slopes for several parameters at Bridger. Note that visibility projections for each species are also shown.

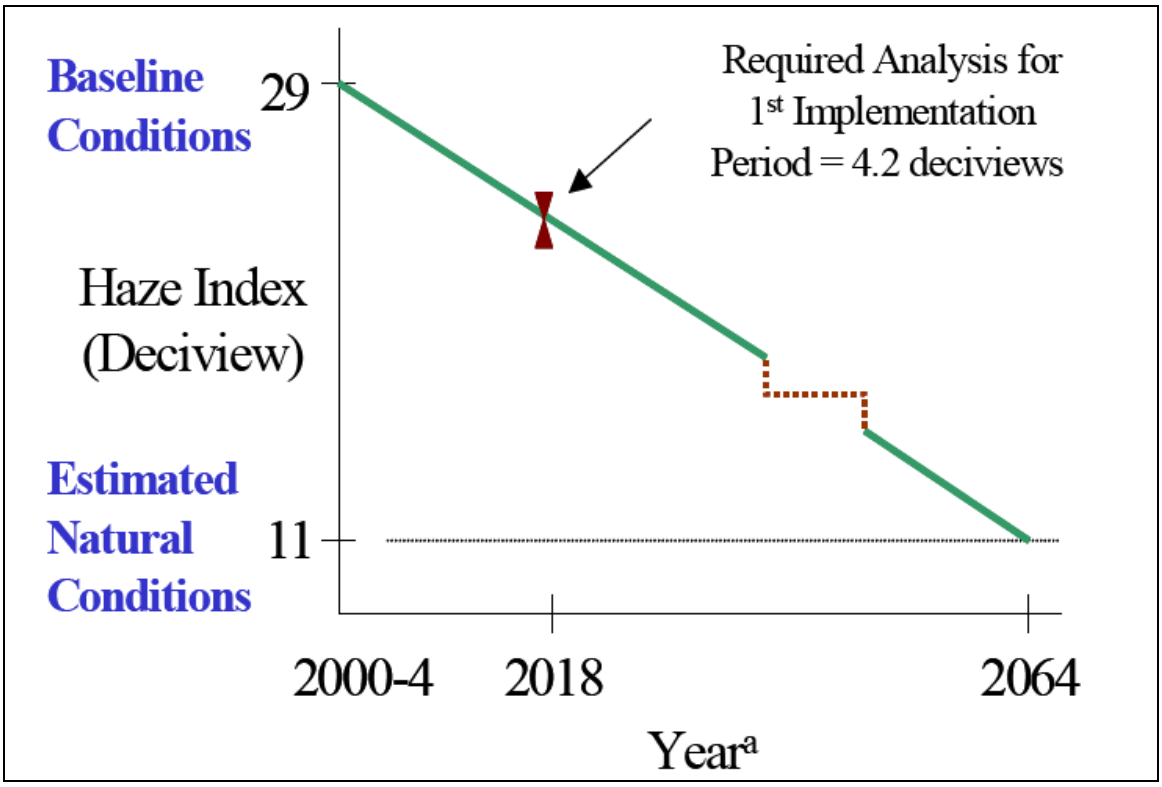


Figure 4-2. Glide slope schematic. (Source: *Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule*, EPA 2003.)

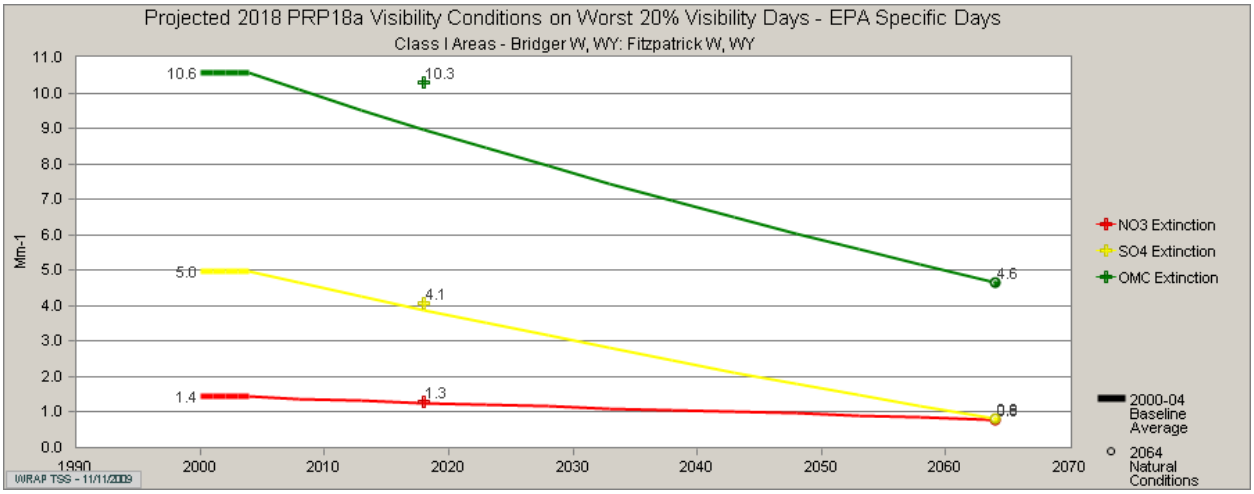


Figure 4-3. Example species glide slopes for several parameters at Bridger. Note that visibility projections for each species are also shown.

4.4 VISIBILITY PROJECTIONS

EPA regional haze guidance provides for a method to project future visibility metrics by combining air quality model results and monitored aerosol data. Since the absolute model results have been shown to contain biases with respect to monitoring data, it is not appropriate to use model results directly as future visibility projections. For example, modeled nitrate values may be only half of the monitored values, so any future projection based exclusively on the model results will imply a decrease in nitrate due to this bias. Instead, EPA guidance dictates using the ratio of model results from different years to serve as the basis for future projections. Using this method, a percent change in modeled nitrate between two different years becomes the indicator of the percent change expected in monitoring data over the same period. The EPA guidance document for using air quality model results for visibility projections *is ….. [need name and link for document]*

WRAP visibility projections are calculated by multiplying a species-specific relative response factor (RRF) by the Baseline period IMPROVE mass, and then converting to extinction and deciview. The RRF is defined as the ratio of future-to-current modeled mass. As an example, the projected sulfate extinction is calculated by the following generalized formulas:

- Sulfate RRF = [2018 Modeled Sulfate / Baseline Modeled Sulfate]
- Projected Sulfate Mass = Baseline IMPROVE Sulfate x Sulfate RRF
- Projected Sulfate Extinction = Conversion via IMPROVE Algorithm of Projected Sulfate Mass

The EPA method (also called "Specific Days" method on the TSS) for this calculation requires the selection of the observed (i.e., IMPROVE) best and worst 20% days in the Baseline period. Then the model results for the same days are averaged for the Baseline period and for 2018 to calculate the applicable RRFs. In an effort to potentially better capture the distribution of best and worst days as they appear in the model results (which may or may not coincide with IMPROVE best and worst days), WRAP defined two other methods for generating RRFs. The Quarterly Weighted method calculates quarterly RRFs based on the 20% best and worst IMPROVE days in each calendar quarter of the Baseline period, regardless of how those days compare to the over all annual best and worst days. The Monthly Weighted method calculates monthly RRFs based on the 20% best and worst days in each month, again, regardless of how those days compare to the overall annual best and worst days. A more detailed discussion of the visibility projection analysis and use of different RRF calculation methods can be found in Appendix A. 2018 visibility projections at Class I areas are used to assess visibility improvements and assist in the Reasonable Progress determination for the December 2007 Regional Haze Rule (RHR) Implementation Plans prepared by states, EPA, and possibly tribes. The model projected 2018 visibility is

compared against a 2018 Uniform Rate of Progress (URP) goal that is obtained through construction of a linear Glide Path from the observed 2000-2004 Baseline Period to Natural Conditions in 2064 using the Haze Index metric in deciviews.

4.5 ATTRIBUTION ANALYSES

The WRAP performed five types of attribution analyses to visibility-related data in an effort to better understand source region impacts of emissions on visibility. Discussed in the following subsections, those analyses include:

- PM Source Apportionment Technology analysis
- Weighted Emissions Potential analysis
- Organic Aerosol Tracer analysis
- Positive Matrix Factorization analysis
- Causes of Dust analysis

4.5.1 PM Source Apportionment Technology

WRAP's Regional Modeling Center performed a source apportionment analysis using the CAMx air quality model and the PSAT (PM Source Apportionment Technology) tool. Results from this analysis provide information regarding which source regions and source categories are responsible for particulate aerosol modeled at a receptor. Due to resource limitations, this analysis was restricted to SOx and NOx emissions resulting in sulfate and nitrate mass. The results do not directly represent actual sulfate and nitrate measurements, nor can they accurately be transformed into extinction values. Therefore, these results should be viewed in relative terms among source regions and between emissions scenarios. An example of PSAT results from the TSS is provided in Figure 4-4. Further information regarding the PSAT modeling technique can be found in the TSS document *PM Source Apportionment Technology (PSAT)* (http://vista.cira.colostate.edu/docs/wrap/attribution/PSATMethods.doc).

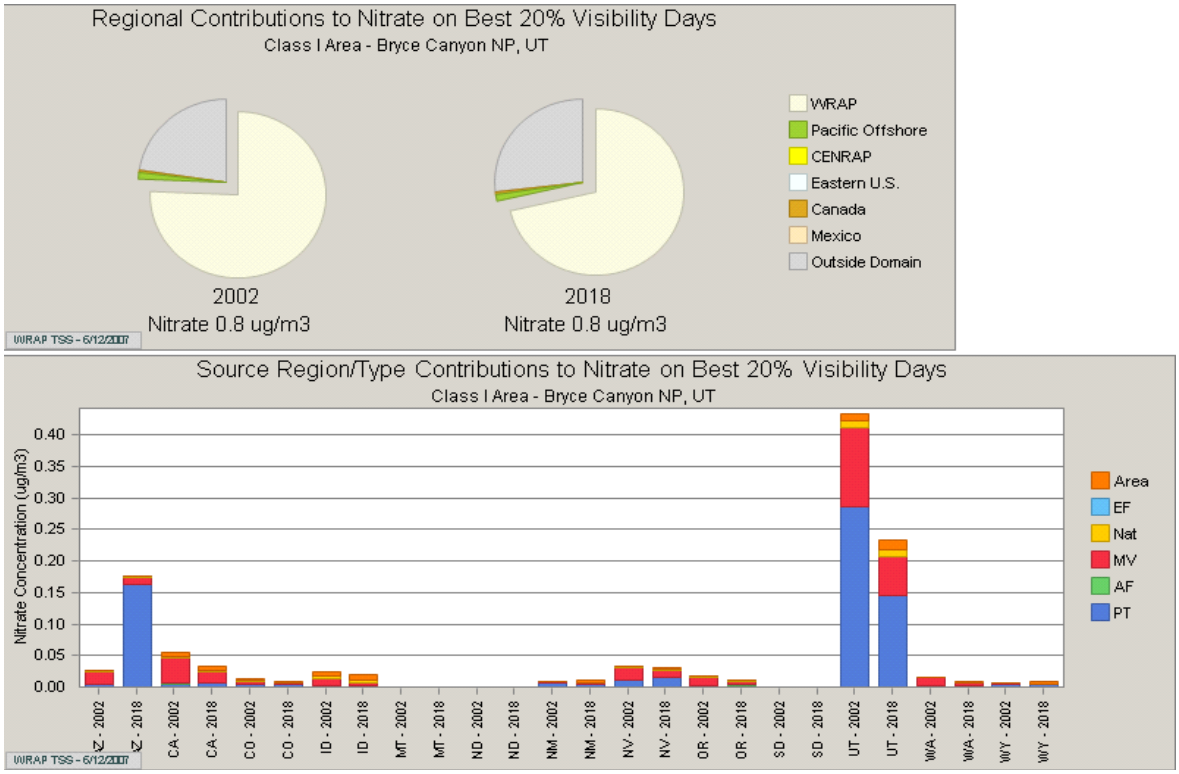


Figure 4-4. Example PSAT results for Bryce Canyon National Park, UT – annual nitrate concentrations by source region for best 20% IMPROVE days.

4.5.2 Weighted Emissions Potential

The Weighted Emissions Potential (WEP) analysis was developed as a screening tool for states to decide which source regions have the potential to contribute to haze formation at specific Class I areas, based on both the Baseline and 2018 emissions inventories. Unlike the PSAT analysis described above, this method does not account for chemistry and removal processes. Instead, the WEP analysis relies on an integration of gridded emissions data, meteorological back trajectory residence time data, a one-over-distance factor to approximate deposition, and a normalization of the final results. Residence time over an area is indicative of general flow patterns, but does not necessarily imply the area contributed significantly to haze at a given receptor. Therefore, users are cautioned to view the WEP analysis as one piece of a larger, more comprehensive weight of evidence analysis.

The WEP analysis was performed for the following six emissions categories: sulfur oxides, nitrogen oxides, organic carbon (primary), elemental carbon, fine particulate matter, and coarse particulate matter. An example of WEP results are provided as Figures 4-5 (source category bar chart) and 4-6 (series of WEP maps). Further information regarding the WEP analysis technique can be found in the TSS document *Weighted Emissions Potential Analysis* (http://vista.cira.colostate.edu/docs/wrap/attribution/WEPMethods.doc).

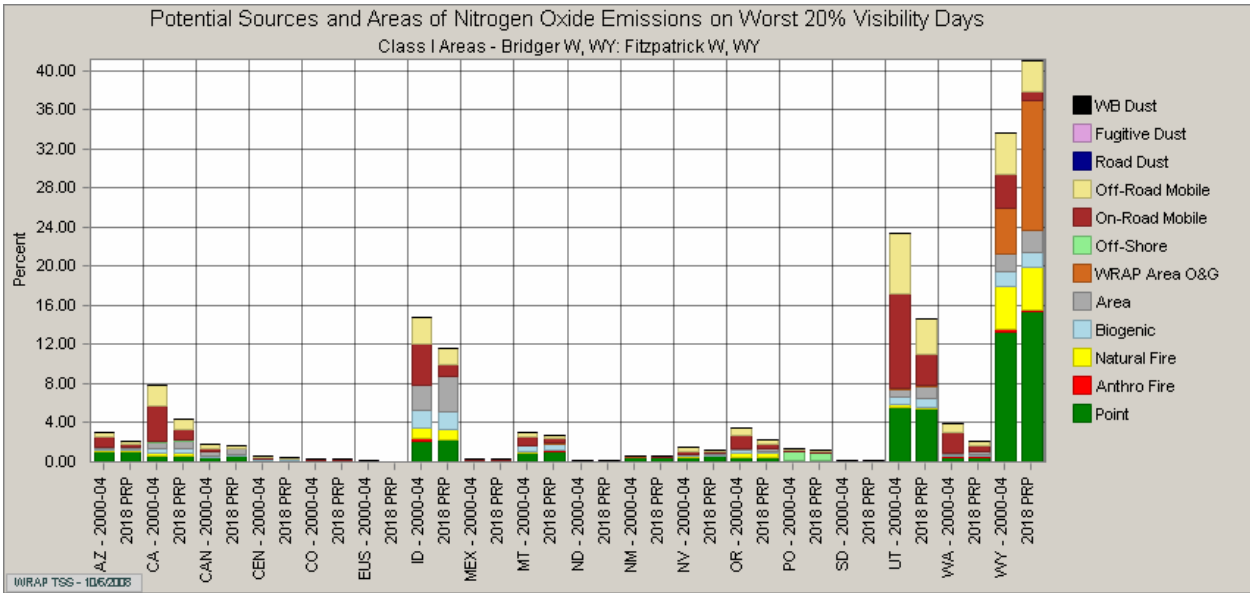
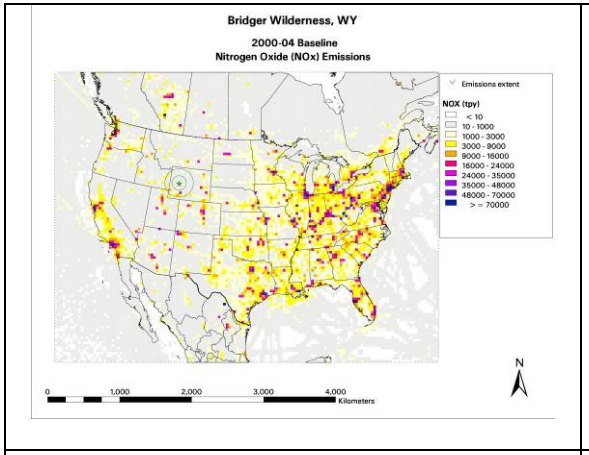
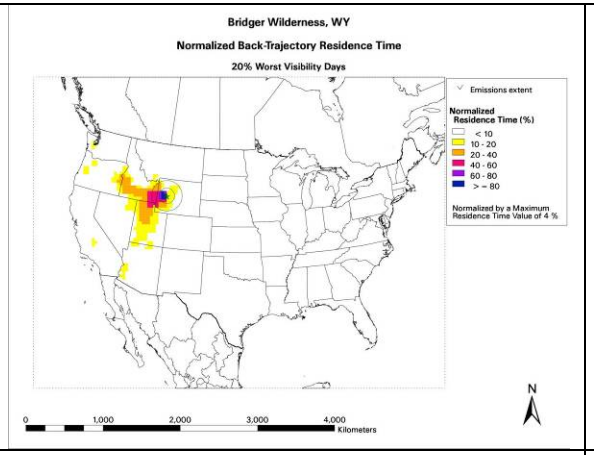


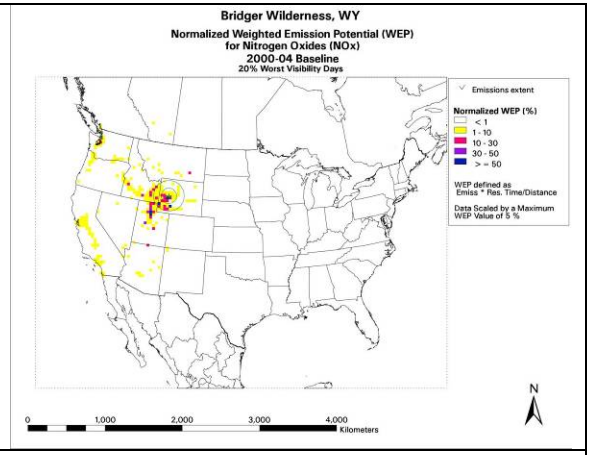
Figure 4-5. Example source category bar chart based on WEP analysis at Bridger Wilderness, WY. Since 2018 results are normalized to 2002 results, actual changes in weighted emissions between scenarios are evident.



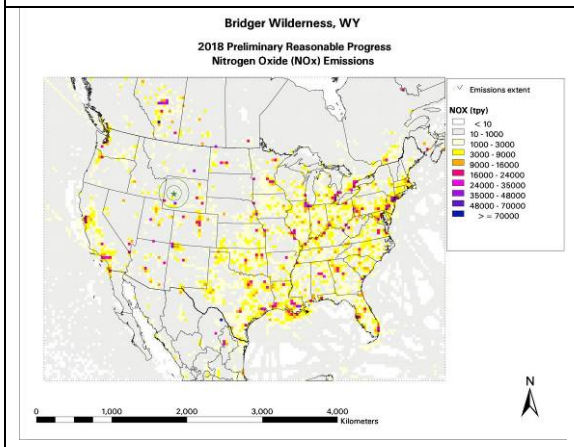
2002 NOx Emissions (TPY)



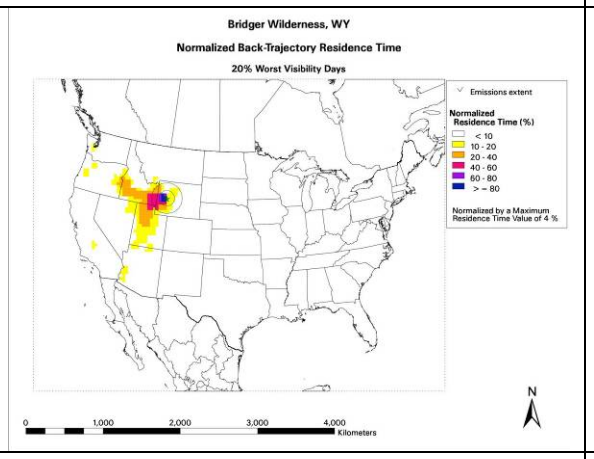
Residence Time Field, Worst 20% Monitored Days (2000-2005)



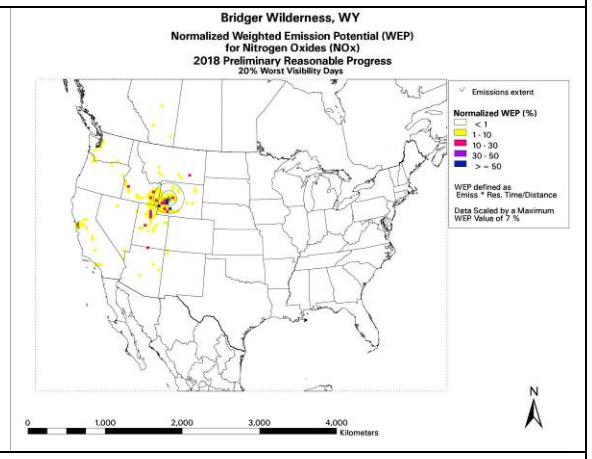
2002 NOx Emissions Weighted by Residence Time and One-Over-Distance



2018 NOx Emissions (TPY)



Residence Time Field, Worst 20% Monitored Days (2000-2005)



2018 NOx Emissions Weighted by Residence Time, One-Over-Distance, and 2002 Results

Figure 4-6. Example series of maps for WEP analysis at Bridger Wilderness, WY. From left to right: single-year annual emissions density map; five-year residence time map; emissions weighted by residence time, by one-over-distance, and normalized to the highest grid cell. Top row presents 2002 results, bottom row presents 2018 results.

4.5.3 Organic Aerosol Tracer

The CMAQ model results were analyzed to identify primary organic carbon aerosol source contributions as originating in one of three categories:

- Primary organics (anthropogenic and biogenic sources), resulting from direct organic aerosol emissions;
- Anthropogenic secondary organics, resulting from aromatic VOCs, such as xylene, toluene, and cresols; and
- Biogenic secondary organics, resulting from biogenic VOCs, such as terpenes.

This analysis did not include identification of emissions source regions or detailed source category information. An example of Organic Aerosol Tracer results is provided in Figure 4-7. Further information regarding the Organic Aerosol Tracer analysis technique can be found in the TSS document *xxx* (need link to final document).

Need additional description, to be based on final document.

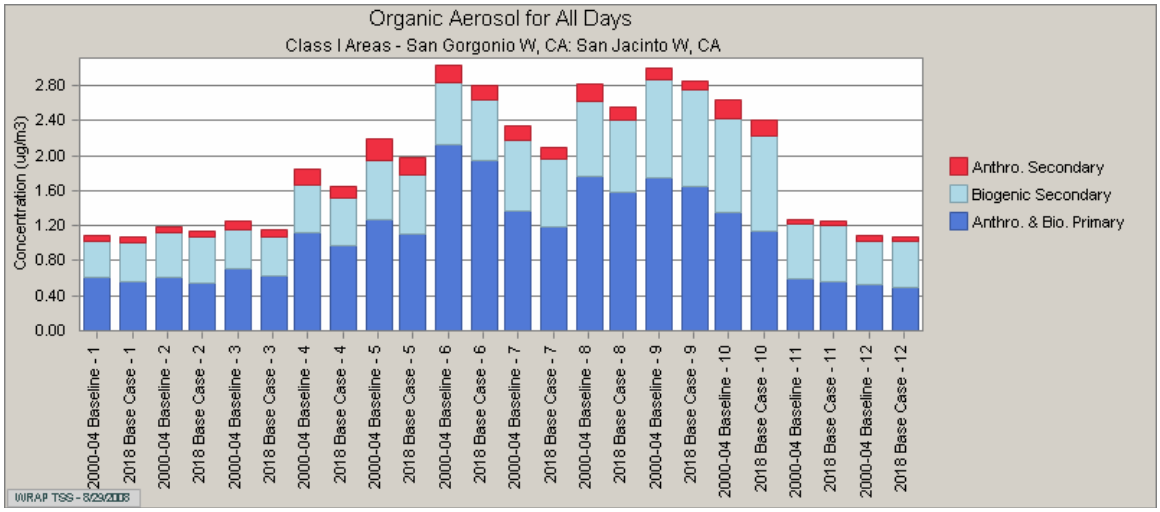


Figure 4-7. Example Organic Aerosol Tracer results for San Gorgonio Wilderness, CA. Monthly results for the Baseline and 2018 are shown.

4.5.4 Positive Matrix Factorization

As part of their Causes of Haze Analysis (CoHA) project for WRAP, Desert Research Institute (DRI) performed a Positive Matrix Factorization (PMF) analysis using the IMPROVE aerosol data set and meteorological back trajectories. The purpose of this analysis was to distinguish chemical source profiles which could describe aerosol contributions to IMPROVE monitoring sites within the WRAP region. Through a review of source profile characteristics, profiles were identified with general or specific emissions source categories, such as “Smoke” or “Urban/Diesel” or any of several other categories. Percent contributions of each profile to each IMPROVE site’s aerosol concentrations were derived and compared with emissions inventories to evaluate the level of confidence in the results. Further information regarding the PMF analysis can be found on the CoHA web site (http://www.coha.dri.edu/web/general/tools_PMFModeling.html).

4.5.5 Causes of Dust Analysis

As part of their CoHA project for WRAP, DRI performed a Causes of Dust Analysis, designed to characterize aerosol sampling days when coarse mass and fine soil combined constituted the dominant aerosol extinction species. These dust events were described as belonging to one of four categories:

- Transcontinental transport from Asia
- Windblown dust (generated locally, nominally with 10 km of the site)
- Upwind transport (does not involve significant windblown dust from local sources)
- Unknown (does not fit into the above three categories)

In addition to categorizing dust events, the project was also able to identify a number of temporal trends. Further information regarding the Causes of Dust analysis can be found on the CoHA web site (http://www.coha.dri.edu/dust/index.html).

Appendix A

Technical Analysis Forum's
Technical Recommendations on Monitoring Metrics for Regional Haze Planning
March 2007

Executive Summary

The Technical Analysis Forum recommends the use of the following monitoring metrics by states, tribes, and EPA to assist in regionally consistent assessments of reasonable progress at all 118 visibility-protected Class I Federal areas of the WRAP region in the December 2007 regional haze implementation plans:

6) Apply the revised IMPROVE light extinction equation as developed and approved in 2005 by the IMPROVE Steering Committee to convert from mass concentration measurements to light extinction for visibility analysis and regional haze planning at each WRAP region Class I area. This revised equation is available for haze planning nationwide on the VIEWS and TSS websites.

7) Use the alternative Natural Conditions Estimates in combination with the 2000-04 Best and Worst Days' metrics as developed and recommended by the Inter-RPO Monitoring & Data Analysis Discussion Group, as calculated and reported by VIEWS and TSS, utilizing the revised IMPROVE equation, for visibility analysis and regional haze planning at each WRAP region Class I area. These alternative Natural Conditions Estimates are available for all Class I areas, nationwide.

8) Use the 2000-04 Best and Worst Days' metrics as calculated and reported by VIEWS and TSS. Missing data will be substituted using the procedure described later in this document. Similar data substitutions have been performed and documented on VIEWS, to produce regional haze baseline period metrics for all Class I areas, nationwide. Individual WRAP region states should review the data completeness for Class I areas in their state, and any data substitutions for their CIAs.

The following recommendation is specific to the WRAP region.

9) Use a variety of visibility projection techniques, including the EPA default and the 2 WRAP alternatives, to analyze and assess the best method(s) to assist in demonstrating and explaining reasonable progress. All of these projection methods are available on the TSS and will draw upon the 2000-04 Best and Worst Days' metrics as calculated and reported by VIEWS and TSS. These projection method options utilize the revised IMPROVE equation and alternative Natural Conditions Estimates to:

   - Project, analyze, and assess 2018 visibility conditions for the overall deciview Haze Index and total light extinction; and
   - Project, analyze, and assess IMPROVE species-specific contributions to 2018 visibility conditions, to better understand the relationships to natural and anthropogenic as well as controllable and uncontrollable emissions. The visibility impact of coarse material and sea salt are assumed to be constant 2000-04 to 2018.

These technical methods are or will be available on the WRAP TSS at: http://vista.cira.colostate.edu/tss/

Monitoring Metrics for BART Determinations

The WRAP's recommendations for use of the revised IMPROVE equation and alternative Natural Conditions Estimates for assessing current haze conditions and projecting future haze trends for regional haze planning should not be seen as an endorsement for their use by individual state air programs for evaluation of BART modeling results and BART control level determinations for technical and process reasons.

Technical Analysis Forum's
Technical Recommendations on Monitoring Metrics for Regional Haze Planning
March 2007

Background

This document summarizes the recommended monitoring metrics for application by states and tribes for regional haze planning, for the December 2007 plans' due date. The intent of this document is to identify the currently available best technical monitoring metrics and reasons for using them. The motivation behind this consensus product from the Technical Analysis Forum is to lay out a regionally consistent approach for applying the following monitoring metrics at each WRAP region Class I area:

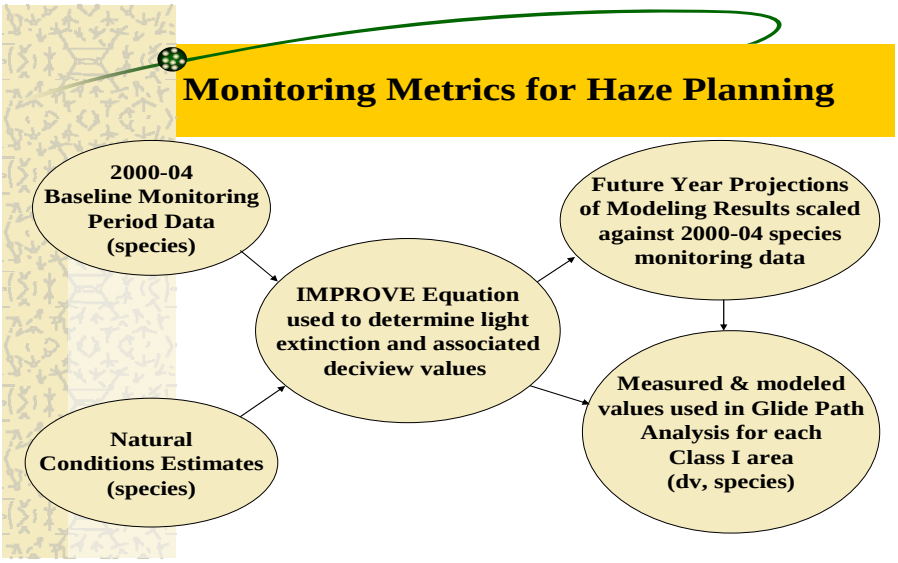
- The light extinction equation to convert from mass concentration measurements to visibility;
- Natural visibility conditions estimates – the 2064 goal to be defined in the 2007 haze plans;
- The 2000-04 baseline period visibility monitoring data; and
- The 2018 planning milestone projected visibility value (using the Relative Response Factor or RRF), a scaling factor from monitoring data to be applied to regional gridded air quality modeling results to assess the amount of visibility improvement expected from emissions reductions across all sources.

This document provides a protocol for applying the monitoring metrics, and can serve as a reference document for individual haze implementation plans.

Use of Monitoring Data in Support of Regional Haze Planning

The need for a consistent regional methodology for evaluating the WRAP region results from studying the nature and causes of light extinction and fundamental requirement to apply the best metrics to the regional haze planning process. Conceptually this process is shown in Figure 1.

Figure 1. Conceptual Diagram of Monitoring Metrics for Planning under the Regional Haze Rule



The Interagency Monitoring of PROtected Visual Environments (IMPROVE) national monitoring program has been designated by EPA to collect visibility impairment data representing the 156 Class I Federal areas (CIAs) with visibility protection under the Clean Air Act. More information about the IMPROVE monitoring program, the 110 monitoring sites across the nation selected to represent the 156 CIAs, and the Steering Committee managing the monitoring program in support of regional haze plans required of all 50 states under the EPA Regional Haze Rule (RHR) can be found at: http://vista.cira.colostate.edu/improve/Overview/Overview.htm. EPA has also published a broader guidance document on Visibility Monitoring, see: http://www.epa.gov/ttn/amtic/files/ambient/visible/r-99-003.pdf.

Light extinction theory

Based on aerosol research, the technical method to determine visibility impairment is to calculate the light extinction coefficient (bext). This is defined as the loss of image-forming light per unit distance due to scattering and absorption by particles and gases in the atmosphere. The light extinction coefficient is the sum of the scattering coefficient (bscat) and absorption coefficient (babs), which are similarly defined as the loss of light per unit distance by scattering and absorption mechanisms respectively. The light extinction coefficient can be represented mathematically as:

$$b_{ext} = b_{sg} + b_{ag} + b_{sp} + b_{ap} = b_{scat} + b_{abs} \quad ;$$

where s, a, g, and p refer to scattering and absorption by gases and particles, respectively.

Speciated Monitoring Data

To determine visibility impairment under the RHR, filter sampling data from IMPROVE aerosol monitors are collected and analyzed following Standard Operating Procedures, see: (http://vista.cira.colostate.edu/improve/Publications/SOPs/UCDavis_SOPs/IMPROVE_SOPs.htm). These resulting mass concentration data are then converted to light extinction using an algorithm referred to as the IMPROVE equation; this equation has been reviewed and changed during the last 2 years, (see: http://vista.cira.colostate.edu/improve/Publications/GrayLit/019_RevisedIMPROVEeq/RevisedIMPROVEAlgorithm3.doc), creating a ripple effect for the monitoring metrics required for use in regional haze planning.

Haze Index- The Deciview (dv)

The RHR also requires that the light extinction data from the IMPROVE equation be analyzed and presented in terms of a "haze index" value called the deciview (dv); the dv index is related to total light extinction, described at: http://vista.cira.colostate.edu/improve/Publications/NewsLetters/apr_93.pdf. As such, light extinction for regional haze planning could be analyzed in terms of its component contributors to light extinction as defined in the old and revised IMPROVE equations, and/or as the associated deciview values.

IMPROVE Light Extinction Equation – Original vs. Revised

The original IMPROVE light extinction equation was adopted by the Steering Committee and used in their principle publications (see: http://vista.cira.colostate.edu/improve/Publications/Principle_pubs.htm) since the early 1990s. The equation has also been widely evaluated and used in peer-reviewed journal articles as well as urban visibility studies. For those reasons, the EPA adopted this equation in their 2003 guidance document on Tracking Progress Under the Regional Haze Rule. See: http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf.

The equation uses additive extinction by chemical species as measured by the IMPROVE aerosol monitor, combined with the effect of Relative Humidity (RH), to estimate the scattering of light by fine and coarse particles. The original IMPROVE equation, as adopted by EPA in their guidance document, is used to estimate total light extinction for the purposes of planning under the RHR:

$$
\begin{aligned}
b_{sp} = {} & (3) f_{SO4}(RH)[SULFATE] \\
& +(3) f_{NO3}(RH)[NITRATE] \\
& +(4) f_{org}(RH)[OMC] \\
& +(1)[SOIL] \\
& +(0.6)[CM]
\end{aligned}
$$

The brackets in this equation indicate the species concentration. The factors 3, 4, 1, and 0.6 are the m^2/g dry specific scattering efficiency for each of the respective species. Thus, a sulfate particle is three times more effective in scattering light than a particle of soil.

To account and control for relative humidity effects in the light extinction data to be used in regional haze planning, EPA sponsored a project to examine measured hourly relative humidity data over a 10-year period (1988-1997) within the United States to derive month-specific climatological mean humidity correction factors designed to represent each CIA. The hourly RH measurements from each site were converted to *f(RH)* values using a nonlinear weighting factor curve. Values above 95% RH were set equal to the *f(RH)* corresponding to 95% RH.

Appendix A of: http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf presents these values. Determination of the humidity factors is described in section 3.6 of that document. Using over 370 humidity monitoring locations across the country, monthly *f(RH)* values were calculated. In most regions there is a seasonal cycle of relative humidity, which is accounted for by generating the appropriate monthly *f (RH)* values, as in Appendix A. The 12 monthly averaged *f (RH)* values are listed for each IMPROVE or IMPROVE protocol site and their corresponding Class I areas. The site-specific values are listed for each CIA and are recommended to be used for all visibility and tracking progress calculations for that CIA. These values are provided in Table A-2. A table of 12 monthly-averaged *f(RH)* values for each CIA is also provided in Table A-3 for informational purposes.

Overview of revised IMPROVE equation

The IMPROVE light extinction equation was analyzed, revised, and approved by the Steering Committee during 2005. A detailed discussion of the revised equation and the reasons for changing it can be found at: http://vista.cira.colostate.edu/improve/Publications/NewsLetters/IMPNews4thQtr2005.pdf. A summary of the differences between the original and revised equations follows.

The original IMPROVE equation produces reasonable estimates of light scattering over a broad range of conditions. However, it tends to underestimate the highest extinction values and overestimate the lowest extinction values. Since EPA adopted the equation for use in RHR planning, the original IMPROVE equation has been scrutinized carefully to assess deficiencies that could bias the implementation of the RHR. With those concerns identified, the IMPROVE Steering Committee initiated an internal review resulting in recommendations for revisions of the light extinction equation. The review team of scientists from the National Park Service and the Cooperative Institute for Research in the Atmosphere developed a revised algorithm that reduces biases in light extinction estimates and is as consistent as possible with the current scientific literature. Review of the original equation and suggested revisions are presented at: http://vista.cira.colostate.edu/improve/Publications/NewsLetters/IMPNews2ndQtr2005.pdf.

In July 2005, the equation review results and proposed revisions were presented to the IMPROVE Steering Committee. A subcommittee was formed to further investigate the proposed equation. The subcommittee included scientists who worked on the initial review, as well as scientists who have been critical of the original IMPROVE equation. Their work resulted in the final version of the equation, which was again presented to the Steering Committee. In December 2005, the IMPROVE Steering Committee voted to adopt this revised equation for use by IMPROVE as an alternative to the current approach.

The revised equation splits ammonium sulfate, ammonium nitrate, and organic carbon compound concentrations into two size fractions: small and large. The revised equation for estimating the light extinction for the RHR is:

$$
\begin{aligned}
\text{Bext} = {} & 2.2 \times fs(RH) \times [\text{small sulfate}] + 4.8 \times fL(RH) \times [\text{large sulfate}] \\
& + 2.4 \times fs(RH) \times [\text{small nitrate}] + 5.1 \times fL(RH) \times [\text{large nitrate}] \\
& + 2.8 \times [\text{small organic mass}] + 6.1 \times [\text{large organic mass}] \\
& + 10 \times [\text{elemental carbon mass}] \\
& + 1 \times [\text{fine soil mass}] \\
& + 1.7 \times fss(RH) \times [\text{sea salt mass}] \\
& + 0.6 \times [\text{coarse mass}] \\
& + \text{Rayleigh scattering (site-specific)} \\
& + 0.33 \times [NO2\ (\text{ppb})]
\end{aligned}
$$

Though not explicitly shown, the organic mass concentration used is 1.8 times the organic carbon mass concentration, (changed from 1.4 times carbon mass the original equation uses). New terms have also been added for sea salt and for absorption by NO2. The apportionment of the total concentration of sulfate compounds into the concentrations of small and large size fractions is accomplished using the following equations:

$$[\textit{large sulfate}] = \frac{[\text{total sulfate}]}{20\ \mu g/m^3} \times [\text{total sulfate}], \text{ for } [\text{total sulfate}] < 20\ \mu g/m^3$$

$$[\textit{large sulfate}] = [\textit{total sulfate}], \textit{ for } [\textit{total sulfate}] \geq 20\ \mu g/m^3$$

$$[\textit{small sulfate}] = [\textit{total sulfate}] - [\textit{large sulfate}]$$

The same equations are used to apportion total nitrate and total organic mass into small and large size fractions. Sea salt is calculated as 1.8 x [*chloride*], or 1.8 x [*chlorine*] if the chloride measurement is below detection limits, missing, or invalid. The new equation contains three distinct water growth terms, designated fS, fL, and fSS for the small and large sulfate and nitrate fractions, and for sea salt, respectively.

Technical justification for revisions

The new IMPROVE equation for estimating light extinction for the RHR contains five major revisions from the original equation:

1) A sea salt term has been added. Sea salt is a particular concern for coastal locations where the sum of the major components of light extinction and mass has been deficient.
2) The assumed organic mass to organic carbon ratio has been changed from 1.4 to 1.8, to reflect more recent peer-reviewed literature on the subject.
3) The Rayleigh scattering factor has been changed from a network-wide constant to a site-specific value. This factor is based on the elevation and annual average temperature of individual monitoring sites.
4) A split component extinction efficiency model for sulfate, nitrate, and organic carbon components has been developed. The model includes new water growth terms for sulfate and nitrate to better estimate light extinction at the high and low extremes of the range of extinction.
5) An NO2 light absorption term has been added. This term can only be used at sites with available NO2 concentration data.

Comparison of original versus revised equation

One of the most compelling reasons for developing a revised equation was to reduce the biases in light scattering estimates at the extremes, when compared to nephelometer measurements a direct measure particle scattering. To assess the performance of the new equation, the fractional bias for each sample period was calculated as the difference in estimated aerosol light scattering divided by the measured light scattering using collocated nephelometers. These biases were then averaged into quintiles to indicate the bias in each of those five subsets of data. Analysis shows that the revised equation has lower fractional bias than the original equation, in all but the haziest conditions.

Scatter plots (Figures 2 and 3) of light scattering estimates from the original and revised equations versus nephelometer data for all available data at 21 monitoring sites were used to view the overall performance differences. These figures show bias at the extremes is reduced using the revised, compared to the original, equation (i.e., the points tend to be better centered on the one-to-one line). However, they also show the somewhat reduced precision of the revised equation compared to the original (i.e., points are more broadly scattered).

Figure 2. Scatter plot of the original IMPROVE equation-estimated particle light scattering versus measured particle light scattering.

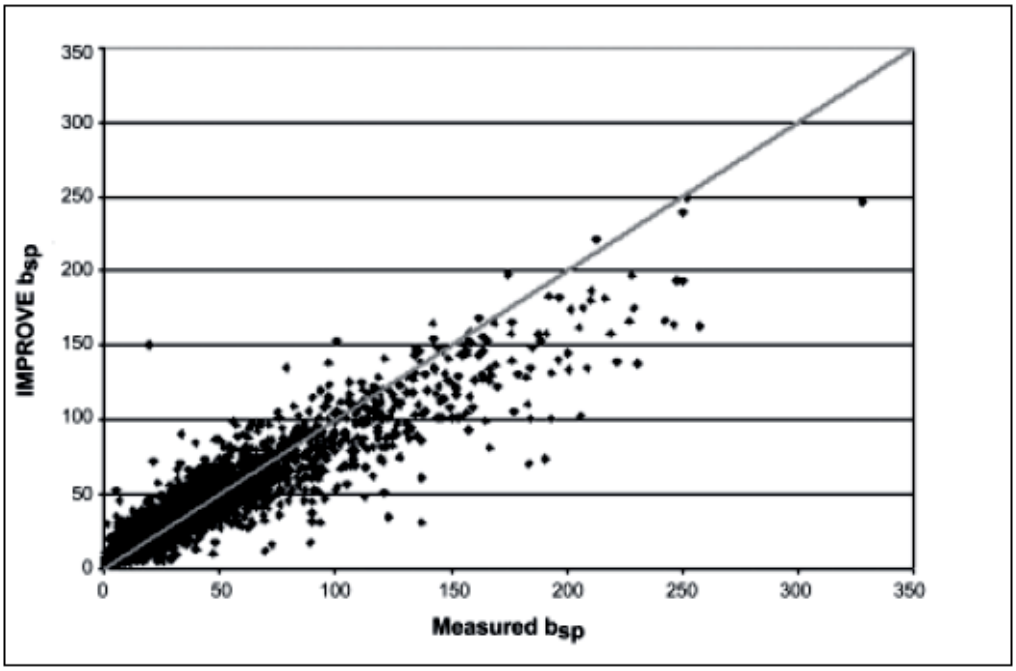
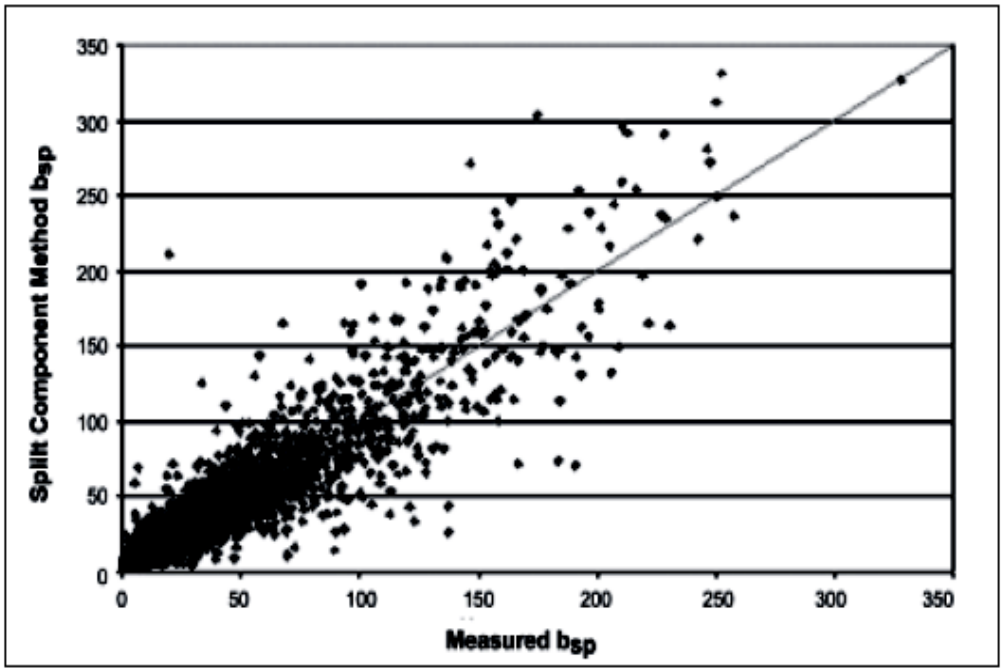


Figure 3. Scatter plot of the revised IMPROVE equation-estimated particle light scattering versus measured particle light scattering.



Directly measured light scattering data from collocated Optec NGN-2 nephelometers were used to evaluating the performance of the original IMPROVE equation, as well as for development and performance evaluation of several possible versions of the revised equation, leading to the final revised equation approved by the IMPROVE Steering Committee. The 21 nephelometer sites used in the evaluation were:

Acadia National Park, Maine
Big Bend National Park, Texas
Boundary Waters Canoe Area Wilderness, Minnesota
Columbia River Gorge National Scenic Area, Oregon
Dolly Sods Wilderness, West Virginia
Gila Wilderness, New Mexico
Grand Canyon National Park, Arizona
Great Gulf Wilderness, New Hampshire
Great Smoky Mountains National Park, Tennessee/North Carolina
Jarbidge Wilderness, Nevada
Lone Peak Wilderness, Utah
Lye Brook Wilderness, Vermont
Mammoth Cave National Park, Kentucky
Mount Rainier National Park, Washington
Mount Zirkel Wilderness, Colorado
Okefenokee National Wildlife Refuge, Georgia
Shenandoah National Park, Virginia
Shining Rock Wilderness, North Carolina
Snoqualmie Pass, Washington
Three Sisters Wilderness, Oregon
Upper Buffalo Wilderness, Arkansas

The revised IMPROVE equation reduces the biases compared to measurements at the high and low extremes, and is most apparent for the hazier eastern sites. The composition of "best and worst days" is very similar by the original and new equations. Most of the reduction of bias associated with the revised equation is attributed to the use of the split component extinction efficiency method for sulfate, nitrate, and organic components that permitted variable extinction efficiency depending on the component mass concentration. The revised equation also contains specific changes incorporating a better understanding of the atmosphere based on recent scientific literature. It reflects a more complete accounting for contributors to haze (e.g., sea salt and NO2 terms), and uses site-specific Rayleigh scattering terms to reduce elevation-related bias. EPA has prepared monthly average f(RH) terms for all IMPROVE monitoring sites for the revised equation. The revised equation has been added to the suite of data analysis tools on the Visibility Information Exchange (VIEWS - http://vista.cira.colostate.edu/views/) and the WRAP Technical Support System (TSS - http://vista.cira.colostate.edu/tss/Results/Monitoring.aspx) web sites. A complete discussion and report is available on the IMPROVE Web site at: http://vista.cira.colostate.edu/IMPROVE/Publications/GrayLit/019_RevisedIMPROVEeq/RevisedIMPROVEAlgorithm3.doc.

Effects on Regional Haze Planning in the WRAP Region: Original vs. Revised IMPROVE Equation

The effects of the revised IMPROVE equation on the data used for regional haze planning under the RHR have been evaluated by the AoH Workgroup on a December 9, 2005 call and in more detail at a Workgroup Meeting on January 24-25, 2006. The detailed presentation at: http://wrapair.org/forums/aoh/meetings/060124m/Review_of_New_IMPROVE_Equ_012406_ARS.pdf was the basis for the following observations from the AoH Workgroup. Analysis of the nature and causes of visibility impairment at the more than 100 CIAs in the WRAP region strongly suggests that control strategies for regional haze planning be evaluated using the revised IMPROVE equation, and that results be presented in units of both b_{ext} and dv.

For the purposes of regional haze planning, the revised IMPROVE equation has benefits, as it:

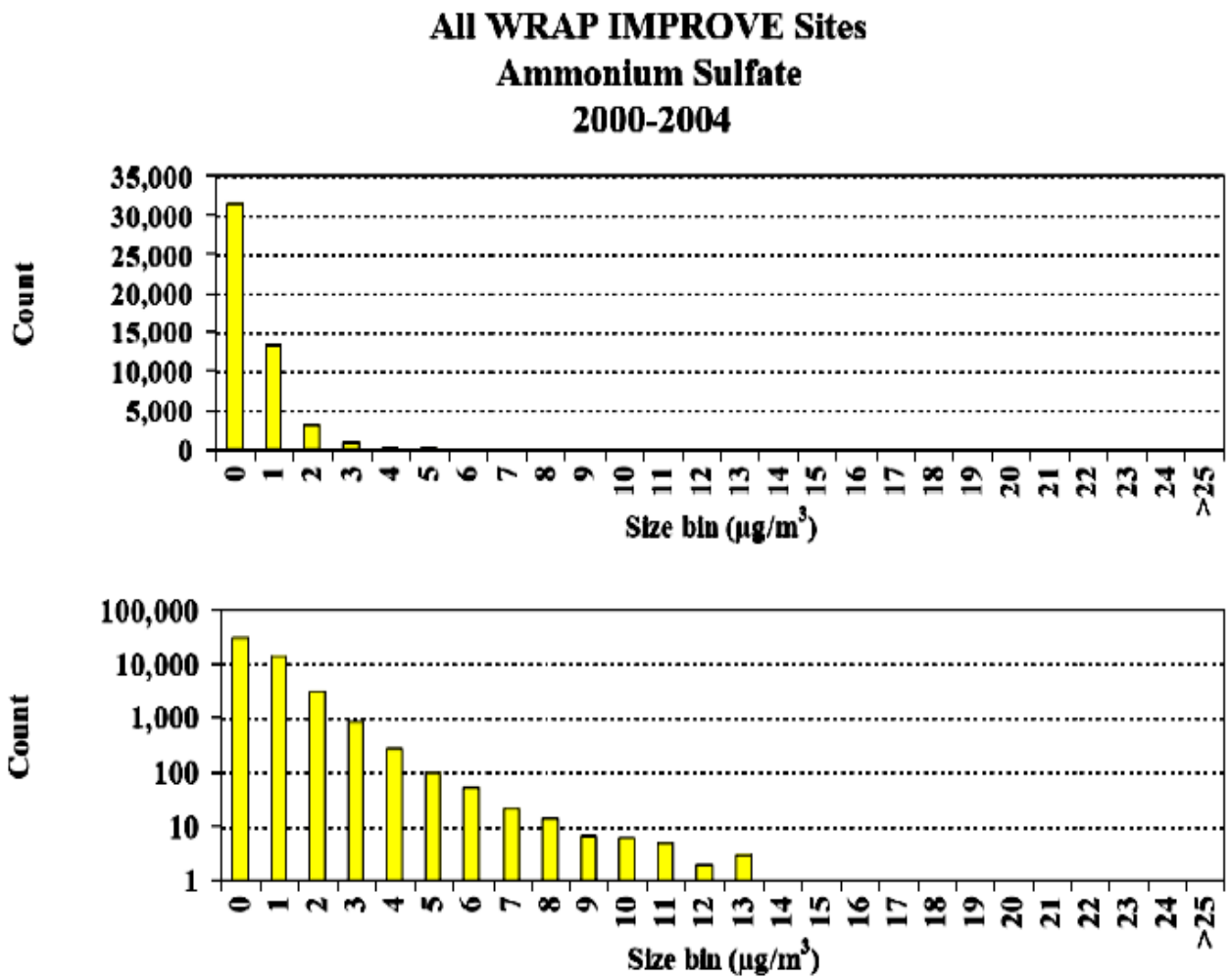
- incorporates new terms to more completely account for haze;
- uses updated research information;
- was developed by comparing to directly-measured optical light scattering data at collocated sites; and
- reduces known biases.

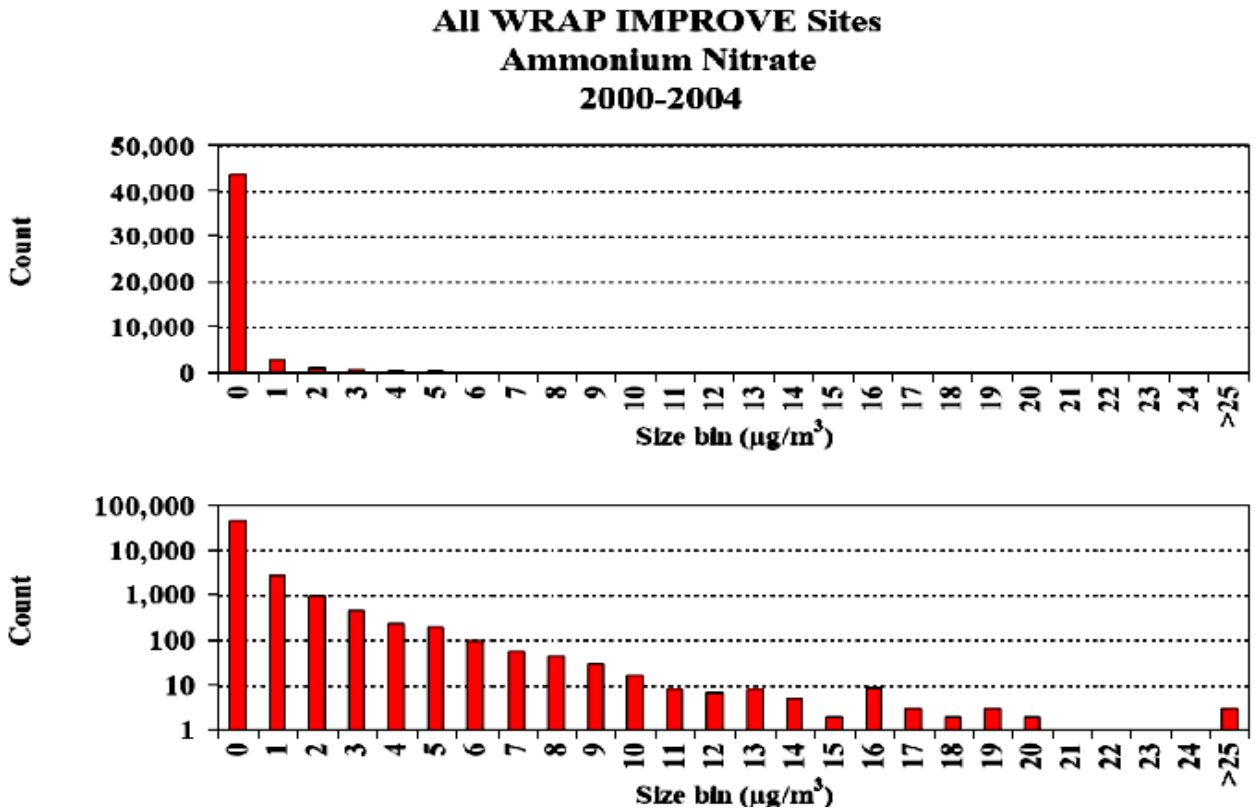
For regional haze planning purposes, using the revised IMPROVE equation has some tradeoffs, as it:

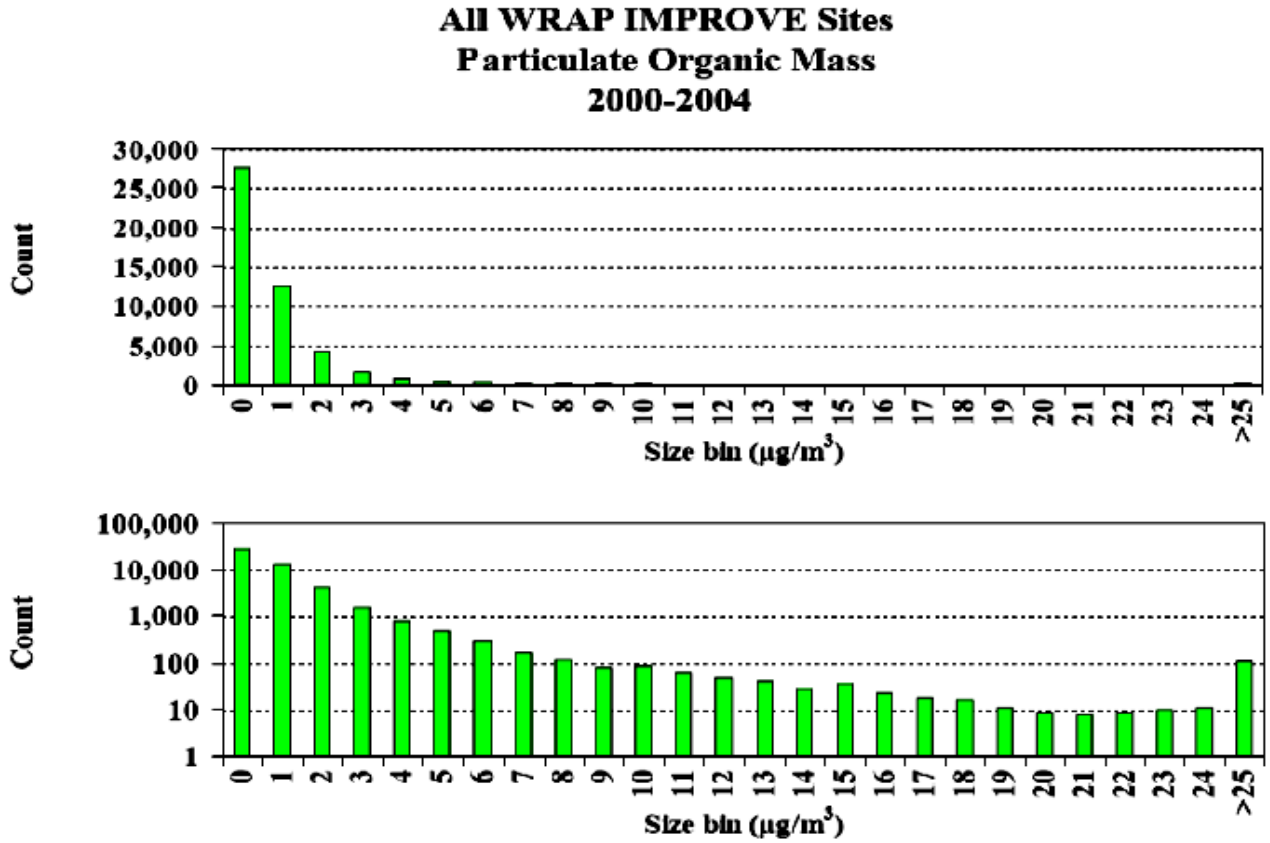
- is a national data analysis and addresses data distribution for the whole country, with the associated large sulfate impact dominating Eastern US visibility, and does not as directly address the mix of light extinction causes at Western Class I area monitoring sites;

- requires that in using the revised equation to the 2000-04 baseline monitoring period would also require that it be applied to as well to natural conditions estimates, to insure a consistent calculation of the glide path for each Class I area;
- has a somewhat greater uncertainty that causes it to mis-select the 20 % worst visibility days for the RHR a little more frequently, although little difference was observed with respect to the composition on those 20 % worst visibility days;
- chooses a "better fit" for all data across the distribution at the sites tested over the better precision of the original IMPROVE equation for individual data points in the middle of the distribution; and
- has less consequence for SO_4 and NO_3 light extinction in the WRAP region in terms of the revised IMPROVE "split component extinction efficiency method", as Figures 4 and 5 below show – Figure 6 shows that this new method for Organic Mass would have a more profound impact in the WRAP region, as expected from the episodic impacts of wildland fire emissions.

Figures 4, 5, 6. REWRITE Histograms of Sulfate, Nitrate, and Organic Mass concentration data from all IMPROVE sites for 2000-04 in the WRAP (same data in paired charts, lower charts logarithmic scale).




All WRAP IMPROVE Sites
Ammonium Nitrate
2000-2004
Count
50,000
40,000
30,000
20,000
10,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 >25
Size bin (µg/m3)
Count
100,000
10,000
1,000
100
10
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 >25
Size bin (µg/m3)


All WRAP IMPROVE Sites
Particulate Organic Mass
2000-2004
Count
30,000
25,000
20,000
15,000
10,000
5,000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 >25
Size bin (µg/m3)
Count
100,000
10,000
1,000
100
10
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 >25
Size bin (µg/m3)

2064 Natural Visibility Conditions Estimates

Default natural visibility conditions estimates and the associated methodology was published by EPA in 2003 at: http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_envcurhr_gd.pdf. This Estimating Natural Visibility Conditions Under the Regional Haze Rule guidance document was prepared prior to the review of the IMPROVE light extinction equation during 2005 and provided estimates of natural conditions in haze index units (deciviews) only. Numerous criticisms of these estimates have been noted, see the collection of documents at: http://www.wrapair.org/forums/aamrf/projects/NCB/index.html. These estimates are in terms of the original IMPROVE light extinction equation, and are not comparable to baseline period monitoring metrics calculated with the revised IMPROVE equation.

Regional haze planning in the WRAP region should separately assess reasonable progress toward the national visibility goal by IMPROVE light extinction species, due to the mixture of sulfate, nitrate, carbonaceous aerosols, and soil materials causing Western visibility impairment, along with the large amount of natural fire and dust emissions contributing to visibility impairment. For those reasons, Alternative Natural Conditions Estimates, in term of deciviews, total light extinction, and IMPROVE species light extinction have been developed, reviewed, and proposed for use in regional haze planning; see: http://vista.cira.colostate.edu/improve/Publications/NewsLetters/IMPNews2ndQtr2006.pdf.

Alternative Natural Visibility Conditions

EPA 2003 RHR guidance 2003 for tracking progress and estimating natural conditions were based on the original IMPROVE equation, providing a consistent set of instructions. see: http://vista.cira.colostate.edu/improve/Publications/GuidanceDocs/guidancedocs.htm. As noted earlier, a revised IMPROVE equation was developed and approved that mitigated some of the technical criticism of the original IMPROVE equation, especially as it applied to implementing the RHR through the regional haze implementation plans due in December 2007. Many of the regional planning organizations (RPOs) and states indicated their preference to use the revised equation, but to do so they need natural haze condition estimates for their CIAs determined in a consistent manner (i.e., by the new IMPROVE equation). The revised IMPROVE equation is described earlier in this document.

Estimates of natural haze levels using either equation involve applying the equation to estimates of natural species concentrations. The natural species concentration estimates used for this purpose come from the 1990 NAPAP State of Science Report 24 by John Trijonis, see: http://vista.cira.colostate.edu/improve/Publications/Principle/NAPAP_SOS/High%20Res/napap_(high).htm and are typical values for the eastern and western U.S. Some methodology is needed to adjust these typical values to estimate the 20% best and 20% worst values. A goal in developing the new values is to avoid problems identified in the EPA default approach. The Natural Haze Levels II Committee was established by the Inter-RPO Monitoring & Data Analysis Workgroup in Spring 2006 to review and refine, as appropriate, a methodology developed by Roger Ames (CIRA) for applying the new IMPROVE equation for estimating light extinction from aerosol concentrations to natural species concentration estimates. Ultimately this would provide natural haze estimates for the 20% best and 20% worst day for each of the CIAs covered by the RHR. The committee was composed of Marc Pitchford, NOAA; Bill Malm, NPS; Bruce Polkowsky, NPS; Pat Brewer, VISTAS; Tom Moore, WRAP; Ivar Tombach, consultant; John Vimont, NPS; Rich Poirot, Vermont; Roger Ames, CIRA; and Naresh Kumar, EPRI. The committee work has been summarized in an annotated presentation that is available at: http://vista.cira.colostate.edu/datawarehouse/improve/docs/naturalhazelevelsIIreport.ppt. This information was presented July 27, 2006 at the Attribution of Haze Workgroup meeting, see: http://wrapair.org/forums/aoh/meetings/060726den/NaturalHazeLevelsIIReport.ppt (the notes sections of each PPT slide contain additional information, if the PPT is downloaded on and displayed on your desktop) and on August 14 at the RPO Monitoring/Data Analysis Workgroup conference call. Comments received by August 25, 2006 were used to generate an approved approach that was forwarded to the individual RPOs for their consideration and use.

The alternative natural conditions estimates offer a number of advantages for regional haze planning, over the default estimates in EPA guidance. The alternative conditions are divided into the 6 measured IMPROVE light

extinction species, and can still be totaled to estimate total visibility in light extinction or deciviews, using the revised IMPROVE equation. The alternative estimates are based on analyzing and estimating the natural fraction of the 2000-04 baseline period monitoring data at each IMPROVE monitoring site. At more than a dozen sites, the natural fractions estimated by the alternative method for the 2000-04 data were compared to the period of record (>15 years) data for the same sites, and the alternative method for the 2000-04 period is quite similar to the long period of record since the late 1980s.

Tables 1 through 4 below show example data summaries for regional haze planning use in documenting differences between EPA default and alternative methods of estimating natural conditions at each CIA.

Both EPA default and alternative natural conditions estimates represent 2064 target values for regional haze planning purposes; the true values are not known at this time, and more analysis is needed to refine these estimates for future regional haze planning cycles, as anthropogenic emissions are reduced and natural visibility conditions are better measured.

Table 1 – *EXAMPLE DATA TABLE* - Comparison of Natural Visibility Conditions Estimates using EPA Default and New Alternative Methods, including the change in Regional Haze Rule Uniform Rate of Progress 2018 Target Values

Mandatory Federal Class I Area	**State**	**Monitoring Site Code**	20% Best Days 2064 Natural Conditions		20% Worst Days 2000-04 Baseline Period Monitoring Data		20% Worst Days 2064 Natural Conditions		Uniform Rate of Progress: 2018 Haze Planning Milestone for 20% Worst Days		Uniform Rate of Progress: 2018 Visibility Improvement Increment for 20% Worst Days	
			Default method (dv)	Alt. method (dv)	Default method (dv)	Alt. method (dv)	Default method (dv)	Alt. method (dv)	Default method (dv)	Alt. method (dv)	Default method (dv)	Alt. method (dv)
Agua Tibia Wild. Area	CA	AGTI1										
Arches NP	UT	ARCH1										

Table 2 – *EXAMPLE DATA TABLE* - Light Extinction Component s of 20% Worst Visibility Days for 2064 Natural Visibility Conditions Estimates (revised IMPROVE light extinction equation & alternative method for estimating Natural Visibility Conditions)

Mandatory Federal Class I Area	**State**	**Monitoring Site Code**	20% Worst Days 2064 Natural Conditions Estimates (dv) (from Table 1)	20% Worst Days 2064 Natural Conditions Estimates (1/Mm)	Light Extinction Components of 20% Worst Days 2064 Natural Visibility Conditions Estimates					
					Sulfate (1/Mm)	Nitrate (1/Mm)	Organic Material (1/Mm)	Elemental Carbon (1/Mm)	Fine Soil (1/Mm)	Coarse Material (1/Mm)
Agua Tibia Wild. Area	CA	AGTI1								
Arches NP	UT	ARCH1								

Table 3 – *EXAMPLE DATA TABLE* - Light Extinction Components of 20% Best Visibility Days for 2064 Natural Visibility Conditions Estimates (revised IMPROVE light extinction equation & alternative method for estimating Natural Visibility Conditions)

Mandatory Federal Class I Area	**State**	**Monitoring Site Code**	20% Best Days 2064 Natural Conditions Estimates (dv) (from Table 1)	20% Best Days 2064 Natural Conditions Estimates (1/Mm)	Light Extinction Components of 20% Best Days 2064 Natural Visibility Conditions Estimates					
					Sulfate (1/Mm)	Nitrate (1/Mm)	Organic Material (1/Mm)	Elemental Carbon (1/Mm)	Fine Soil (1/Mm)	Coarse Material (1/Mm)
Agua Tibia Wild. Area	CA	AGTI1								
Arches NP	UT	ARCH1								

Table 4 - *EXAMPLE DATA TABLE* - Uniform Rate of Progress: 2018 Haze Planning Milestone for 20% Worst Days and 2018 Visibility Improvement Increment for 20% Worst Days, by light extinction component, using Alternative Natural Conditions Estimates

Mandatory Federal Class I Area	**State**	**Monitoring Site Code**	Uniform Rate of Progress: 2018 Haze Planning Milestone: Light Extinction Components on 20% Worst Days (1/Mm)						Uniform Rate of Progress: 2018 Visibility Improvement Increment: Light Extinction Components on 20% Worst Days (1/Mm)					
			Sulfate	Nitrate	Organic Material	Elemental Carbon	Fine Soil	Coarse Material	Sulfate	Nitrate	Organic Material	Elemental Carbon	Fine Soil	Coarse Material
Agua Tibia Wilderness Area	CA	AGTI1												
Arches NP	UT	ARCH1												

These completed data tables will be available for use in reasonable progress analysis in the VIEWS and TSS websites.

2000-04 Baseline Visibility Period Monitoring Data

The RHR requires that data from the IMPROVE monitoring sites representing CIAs for the 2000-04 baseline monitoring period is to be used to:

- Determine the current level of visibility impairment under the RHR;
- Quantify sources and pollutant species contributing to impairment;
- Assist in classifying natural and anthropogenic sources' contributions to impairment; and
- Develop regional haze implementation plans demonstrating reasonable progress across a 60-year timeline toward the Clean Air Act goal of no manmade visibility impairment in CIAs.

A short overview of the IMPROVE monitoring program operations is presented earlier in this document; additional information is at: http://vista.cira.colostate.edu/improve/.

Quality Assurance of IMPROVE Monitoring Data

The IMPROVE monitoring program has a Quality Assurance Project Plan (QAPP), see: http://vista.cira.colostate.edu/improve/Publications/QA_QC/IMPROVE_QAPP_R0.pdf, and a Quality Management Plan (QMP), see: http://vista.cira.colostate.edu/improve/Publications/QA_QC/IMPROVEAerosolQMP_May2002.PDF; both were published in 2002. The QMP and QAPP were prepared and the QA activities identified in that QMP and QAPP are executed by the laboratory and field operations contractor team for the IMPROVE aerosol sampler network, institutional members of the contractor team and locations are:

- Crocker Nuclear Laboratory – University of California, Davis, NC;
- Research Triangle Institute – Research Triangle Park, NC;
- Desert Research Institute – Reno, NV; and
- Environmental Protection Agency – coordinated by OAQPS, Research Triangle Park, NC.

Staff of the National Park Service, the U.S. Forest Service, and the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University all provide additional quality assurance checks for, and analyses of, the IMPROVE data from the contractor team. The continuity of contractor team members over time, the centralized QA efforts of the contractor team, as well as the additional QA and analytical efforts coordinated by CIRA all combine to provide a very high level of confidence in the IMPROVE data for regulatory planning purposes.

Quality Assurance of the 2000-04 Baseline Monitoring Period WRAP Region IMPROVE Data

Batches of IMPROVE aerosol sampler data are published through the VIEWS website, see: http://vista.cira.colostate.edu/views/. The publication goal for these data is quarterly, sometimes the data are published twice-yearly or an annual update is made depending when updated data are provided by Crocker Nuclear Laboratory. In October 2005, an update specific to the 2000-04 data was made, see: http://vista.cira.colostate.edu/improve/Publications/GrayLit/018_IMPROVEDataResubmission/DataRedeliverySummary2005.pdf.

Crocker Nuclear Laboratory resubmitted all of the IMPROVE aerosol data to VIEWS for the 2000-04 monitoring period in October 2005. The data were resubmitted to correct several errors and discrepancies in the data in order to provide the RHR analysts with the best available data set. There were four systematic changes that affected large blocks of data:

- New flow rate validation flags were assigned;

- Flow rates were recalculated to correct an error in the calculation that existed prior to January 2004;
- Spectral corrections were applied to sulfur and aluminum data collected beginning in December 2001, when Crocker changed the elemental analysis technique; and
- Carbon analysis data were resubmitted to correct a bias in the data.

In addition to these systematic changes, a number of site-specific data problems were resolved and the data were resubmitted as well. Examples included inadvertently swapped samples, backdated flow rate calibrations, samples requiring reanalysis, and equipment problems that were resolved after the original data had been submitted.

Attribution of Haze Workgroup Review of 2000-04 Baseline Period Monitoring Data

Data completeness was reviewed at the AoH Workgroup meeting of November 16-17, 2005, see: http://wrapair.org/forums/aoh/meetings/051116m/Summary_of_Regional_Haze_Baseline_Data_111605_ARS.pdf. This was a preliminary assessment, and the IMPROVE data have been updated since that time.

The RHR Tracking Progress guidance document published by EPA in 2003, see: http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf, prescribes the method for calculating the Worst 20% and Best 20% Visibility Days' metrics to determine the baseline period values to be used in regional haze planning. The following steps to calculate these metrics are already complete in VIEWS and the TSS, using both the original and revised IMPROVE light extinction equations; specific steps are:

- Assemble daily speciated data and monthly f(RH) values from each IMPROVE site for each CIA;
- Perform allowed data substitutions as prescribed in Tracking Progress guidance, if warranted;
- Sites must have at least 3 of 5 years of "complete" data;
- Calculate daily extinction, convert to Haze Index (deciviews);
- Determine the average Haze Index of the 20% worst and best visibility days for each complete year, average these annual values for baseline period statistic; and
- Determine Glide Path by comparing the 2000-04 baseline value with natural conditions.

Five (5) WRAP region IMPROVE sites did not meet the Regional Haze Rule (RHR) 2000-04 baseline monitoring period data completeness criteria of at least 3 years of complete data. In addition, thirteen (13) WRAP region IMPROVE sites did not meet data completeness requirements for 2002. In consultation with the individual states completing regional haze planning for these sites, the following procedures will be followed in completing data substitutions at these sites.
MERGE?????
In the Western Regional Air Partnership (WRAP) states, data substitution was performed for nine IMPROVE monitoring sites to achieve RHR data completeness, or to fully populate 2002, WRAP's selected modeling year. These data substitutions included estimating missing species from other on-site measurements and appropriately scaling data collected at selected donor sites which had favorable long-term comparisons. This document outlines the data substitution methods used at these sites.

Data Completeness Requirements

Regional Haze Rule (RHR) guidance outlines IMPROVE aerosol data completeness requirements including the following conditions:

- Individual samples must contain all species required for the calculation of light extinction (sulfate, nitrate, organic carbon, elemental carbon, soil, coarse mass, and, for the new IMPROVE algorithm, chloride or chlorine)
- Individual seasons must contain at least 50% of all possible daily samples
- Individual years must contain at least 75% of all possible daily samples

- Individual years must not contain more than 10 consecutive missing daily samples
- The baseline period (2000-04) must contain at least 3 complete years of data

Further details can be found in the RHR guidance document for tracking progress: http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf.

Routine Data Substitutions

RHR guidelines provide provisions to fill in missing data under specific circumstances. There are currently two methods routinely used in preparing the RHR data set to substitute data for missing samples:

- The use of a surrogate in the data set:
    - Total sulfate is generally determined as 3 times the sulfur measured on the A module filter. If sulfur is missing, the sulfur measurement from the B module filter is used to calculate sulfate.
    - For the new IMPROVE algorithm, sea salt is calculated from chloride measured on the B module filter. If chloride is missing or below detection limit, the chlorine measurement from the A module filter is used to calculate sea salt.

- The application of "patching" missing data described by the RHR guidance:
    - Missing samples not substituted using a surrogate as described above can be patched, or replaced, by a seasonal average if the patching exercise passes a series of tests outlined in the guidance document.

Once these methods have been applied to the data, the resulting complete years are eligible for use in calculation of baseline conditions and tracking progress under the Regional Haze Rule. These methods have been applied to all IMPROVE data.

Sites Not Meeting Data Completeness Requirements

After routine data substitutions were made, some WRAP sites still failed to meet data completeness requirements for the baseline period. These sites are listed in Table 1. Sites were candidates for substitution for two reasons:

- The sites had fewer than 3 complete years of data, thus RHR visibility metrics for the baseline period could not be calculated.

- The sites had at least 3 years of complete data, but were missing 2002, the year selected for regional modeling. If this year is missing, then the worst 20% visibility days from 2002 cannot be determined, and the relative response factors (RRFs), which are used to predict visibility metrics in 2018, cannot be calculated.

Sites that did not meet data completeness requirements were not necessary for submittal of State Implementation Plans (SIPs) are indicated with an asterisk (*) in Table 1. Additional data substitutions for these sites have not been applied.

Table 1
WRAP Sites Failing RHR Data Completeness Requirements

State	Site	<3 years	Missing 2002
AZ	BALD1	X	X

	INGA1*	X	X
	TONT1		X
CA	KAIS1	X	X
	RAFA1	X	X
	SEQU1		X
	TRIN1		X
MT	FLAT1*	X	X
	FOPE1*	X	X
	GLAC1		X
	NOCH1*	X	X
UT	CAPI1	X	X
WA	NOCA1	X	

* Indicates additional substitution is not required for a SIP.

Additional Data Substitutions

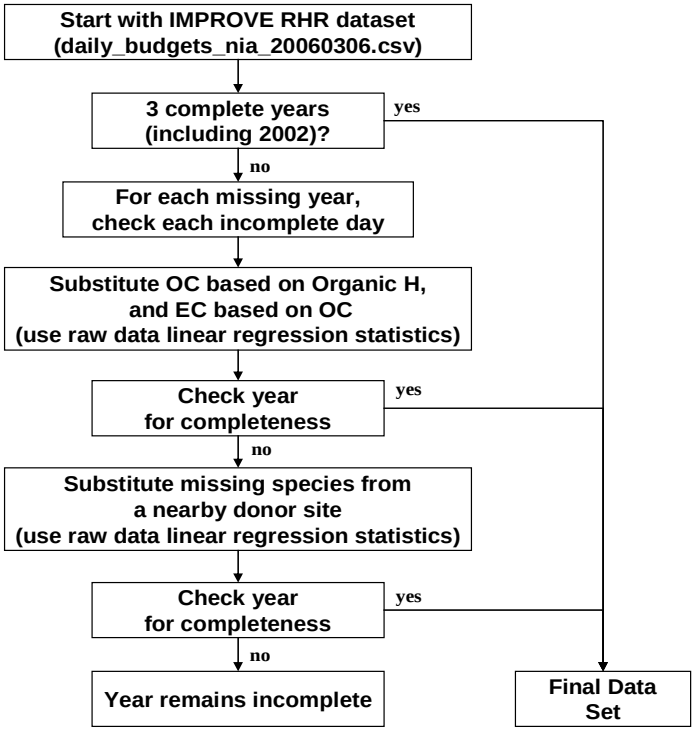
This section outlines WRAP methods for additional data substitutions designed to address problems at sites listed in Table 1. Similar methods were used at IMPROVE sites with incomplete data records in other RPOs.

Figure 1 presents a flow chart of the WRAP data substitution methods. The starting data set was the RHR IMPROVE data using the "New IMPROVE Algorithm," updated March 2006, (http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx). This data set includes the routine surrogate and patched data substitutions allowed by RHR guidance. Note that only years deemed incomplete under RHR guidance were candidates for additional data substitutions. Years deemed complete were not changed, even thought there may have been missing samples during those years.

The first of the additional substitution methods used organic hydrogen as a surrogate for organic carbon, and resultant organic carbon as a surrogate for elemental carbon. If the carbon data substitution was not sufficient to complete the required years, measured mass for individual species from nearby IMPROVE sites with favorable long-term comparisons were scaled appropriately and used as surrogates. IMPROVE donor sites were selected in consultation with individual states. These methods are described in detail below.

Figure 1

Flow Chart of Data Substitution Methods Used



All substitutions were made using quarterly specific Kendall-Theil linear regressions statistics. These statistics were chosen because they are more resistant to outliers than the standard linear least squares statistics. Kendall-Theil slopes and intercepts were used to calculate substituted values from surrogates.

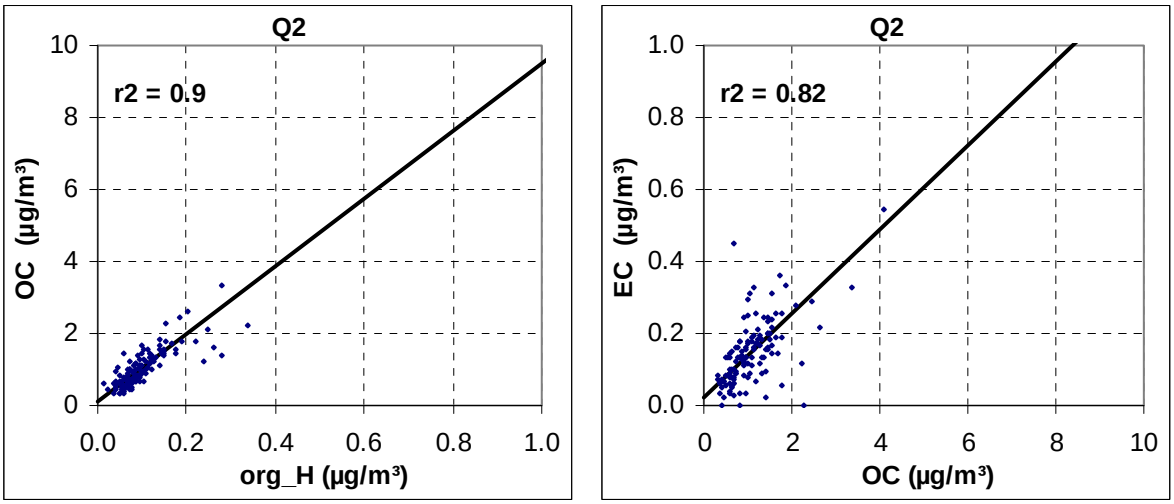
1. Carbon Substitutions

The first substitution method relied on using a surrogate for carbon mass measurements when the C module data is not available. Hydrogen (H) is measured on the A module filter, and is assumed to be primarily associated with organic carbon and inorganic compounds such as ammonium sulfate. Therefore, organic carbon (OC) can be estimated using the historical comparison between estimated organic H and OC. Organic H is estimated by subtracting the portion of H that is assumed to be associated with the inorganic compounds from the total H (Org_H = H – 0.24*S).

Figure 2 presents a sample comparison for data collected at the Tonto National Monument site in Arizona during the second quarter between 2000-04 for OC and organic H. Once OC has been estimated using this method, elemental carbon (EC) mass is determined using long-term comparisons between OC and EC at the site. Statistics were calculated and applied quarterly to account for seasonal variations.

Figure 2

Comparison of OC and Estimated Organic H, and EC and OC at Tonto National Monument, AZ
Using Second Quarter Raw OC and Organic H Data, 2000-04



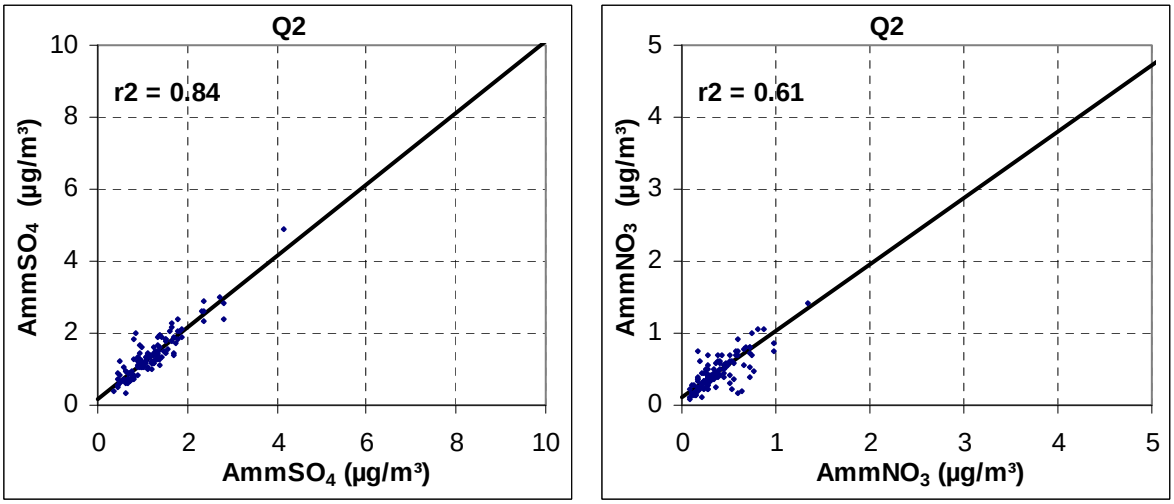
2. Donor Site Substitutions

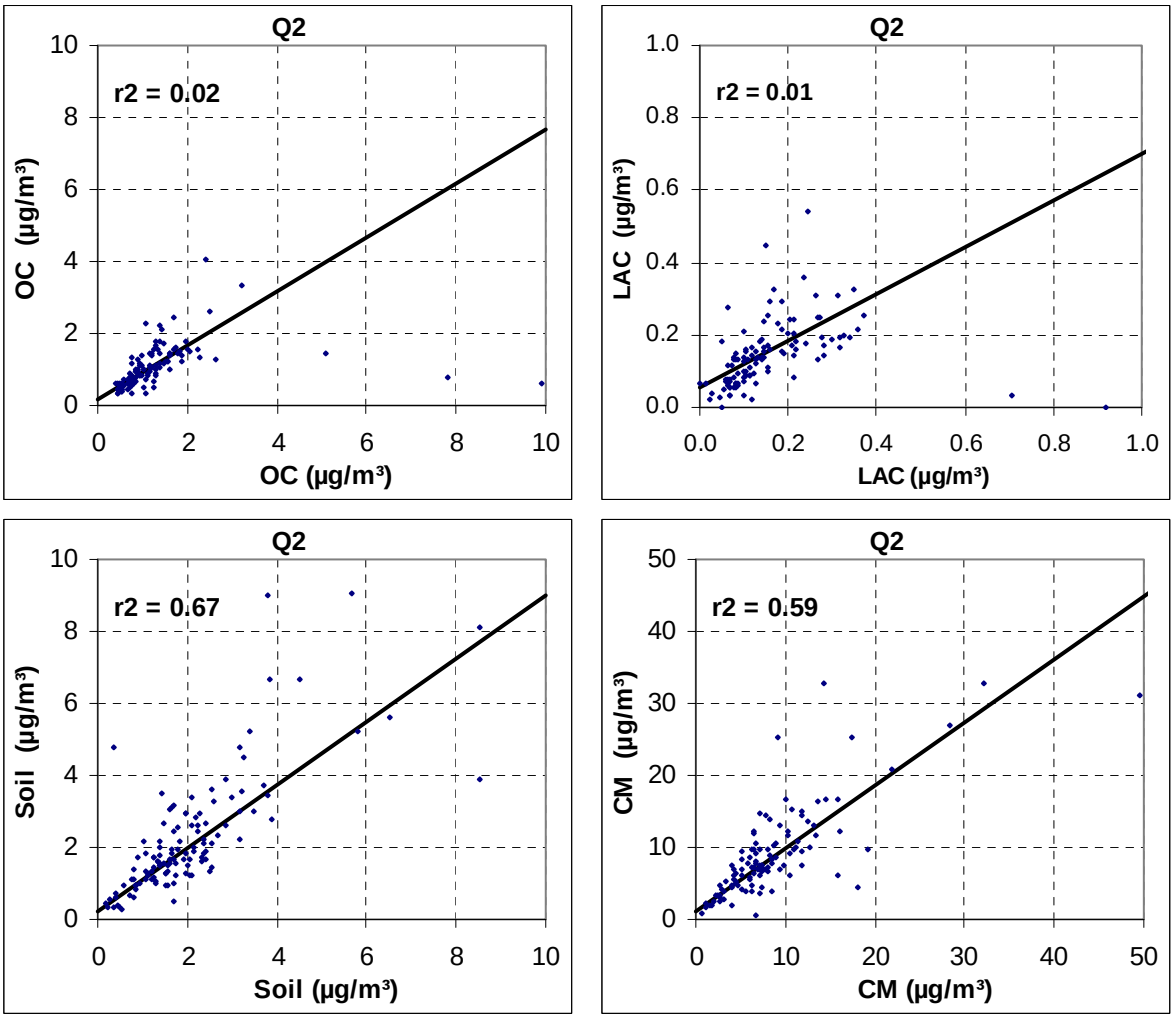
In the WRAP, the carbon data substitution methods were not sufficient to complete the required years. A second method involved identification of another nearby IMPROVE site which had favorable long-term comparisons and similar regional characteristics to be used as a donor site. Candidate sites were identified, and final donor sites for surrogate mass were selected in consultation with states.

Figure 3 presents a sample inter-site mass comparison by species for data collected during the second quarter, 2000-04, between the Tonto National Monument site and the Sierra Ancha site in Arizona. Component specific correlations were calculated and applied quarterly. Note that only species missing in a given sample were substituted based on donor site data. Species collected at the site under investigation were never replaced with data from a donor site.

Figure 3

Comparison of Aerosol Species Mass Between
Tonto National Monument, AZ (y-axis) and Sierra Ancha, AZ (x-axis)
Using Second Quarter Raw Data, 2000-04





2. Data Completeness Following Substitutions

Table 2 indicates which years required some degree of substitution, where a 2 indicates a substituted year, a 1 indicates the year was already complete under RHR guidelines, and dashes indicate the year did not meet RHR guidelines and no additional substitutions were made. The table also lists sites that were selected as donor sites.

The minimum data requirement of 3 complete years (including 2002) was met for each site, and additional substitutions beyond these requirements were made on a case by case basis in consultation with individual states. For example, at the KAIS1 site, substitutions were made only for the 2002 year even though substituted data (from the YOSE1 donor site) was available for other years. In this case, the years 2000 and 2001 had less than 50% of the original RHR data. In contrast, additional substitutions were applied for all incomplete years (2000-2002) at the RAFA1 site. For the RAFA1 site, the original RHR data was more substantial (73-86% available) and substitutions had less of an impact on the worst days' distributions.

Table 2
Data Completeness at WRAP Sites Following Data Substitution

State	Site	<3 years	Missing 2002	Donor	2000	2001	2002	2003	2004
AZ	BALD1	X	X	TONT1	--	2	2	1	1
	TONT1		X	SIAN1	--	1	2	1	1

CA	KAIS1	X	X	YOSE1	--	--	2	1	1
	RAFA1	X	X	PINN1	2	2	2	1	1
	SEQU1		X	DOME1	1	1	2	2	1
	TRIN1		X	LAVO1	--	1	2	1	1
MT	GLAC1		X	FLAT1	1	1	2	2	1
UT	CAPI1	X	X	CANY1	2	2	2	1	1
WA	NOCA1	X		SNPA1	--	1	1	2	2

-- indicates an incomplete year with no substitutions made
1 indicates a complete RHR year
2 indicates a year is considered complete with some substituted values

Availability and Archival of Data Sets

A dedicated page on the VIEWS database will act as the repository of all site-specific substitute data sets: http://vista.cira.colostate.edu/views/web/documents/substitutedata.aspx. Table 3 presents a key to the substituted data files. All materials prepared in the data substitution work (descriptive narrative, tables of regression statistics, graphics, etc.) will be posted on this site for review by states, tribes, and other data users. This information will also be made accessible through the TSS.

Table 3
Key to Substituted Data Files

Column Header	Description
site	IMPROVE site code
year	
month	
day	
QUARTER	1 = Jan. – Mar., 2 = Apr.-Jun., 3 = Jul. – Sept., 4 = Oct. – Dec.
date	
Group	10 = One of the 20% best visibility days; 90 = One of the 20% worst visibility days
good_year	0 = incomplete year, 1 = complete RHR year, 2 = complete year with substitutions
ss_rayleigh	Site specific Rayleigh value (clean air extinction)
fsrh	f(RH) value for small sulfate, nitrate and organic mass
flrh	f(RH) value for large sulfate, nitrate and organic mass
fssrh	f(RH) value for sea salt mass
Sea_Salt	Sea salt mass (µg/m3)
Soil	Soil Mass (µg/m3)
Amm_NO3	Ammonium nitrate mass (µg/m3)
OMC	Organic mass by carbon (µg/m3)
LAC	Light absorbing carbon (aka EC/Elemental Carbon) (µg/m3)
CM	Coarse mass (µg/m3)
Amm_SO4	Ammonium sulfate mass (µg/m3)
Large_OMC	Large organic mass (µg/m3)
Small_OMC	Small organic mass (µg/m3)
Large_Amm_SO4	Large ammonium sulfate mass (µg/m3)
Small_Amm_SO4	Small ammonium sulfate mass (µg/m3)
Large_Amm_NO3	Large ammonium nitrate mass (µg/m3)
Small_Amm_NO3	Small ammonium nitrate mass (µg/m3)
EAmm_SO4	Extinction due to ammonium sulfate (Mm-1)
EAmm_NO3	Extinction due to ammonium nitrate (Mm-1)
EOMC	Extinction due to organic carbon mass (Mm-1)
ELAC	Extinction due to light absorbing carbon mass (Mm-1)
ESoil	Extinction due to soil mass (Mm-1)
ECM	Extinction due to coarse mass (Mm-1)
ESea_Salt	Extinction due to sea salt mass (Mm-1)
RBext	Reconstructed aerosol extinction (Mm-1)
TBext	Reconstructed total extinction (Mm-1)
OC_SUB1	OC substituted using OC vs. organic H correlations

EC_SUB1	EC substituted using EC vs. OC correlations
(NH4)2SO4_SUB2	Ammonium sulfate substituted using site donor correlations
(NH4)NO3_SUB2	Ammonium nitrate substituted using site donor correlations
OM_SUB2	Organic mass substituted using site donor correlations
EC_SUB2	Elemental carbon (aka light absorbing carbon) substituted using site donor correlations
Soil_SUB2	Soil substituted using site donor correlations
CM_SUB2	Coarse mass substituted using site donor correlations
SeaSalt_SUB2	Sea salt substituted using site donor correlations

2018 Planning Milestone Visibility Projection Values

2018 visibility projections at Class I areas are used to assess visibility improvements and assist in the Reasonable Progress determination for the December 2007 Regional Haze Rule (RHR) Implementation Plans prepared by states, EPA, and possibly tribes. The model projected 2018 visibility is compared against a 2018 Uniform Rate of Progress (URP) goal that is obtained through construction of a linear Glide Path from the observed 2000-2004 Baseline Period to Natural Conditions in 2064 using the Haze Index metric in deciviews.

Difficult to Meet 2018 URP Goal at Western U.S. Class I Areas

2018 visibility projections at western Class I areas fail to achieve the URP goal for several reasons:

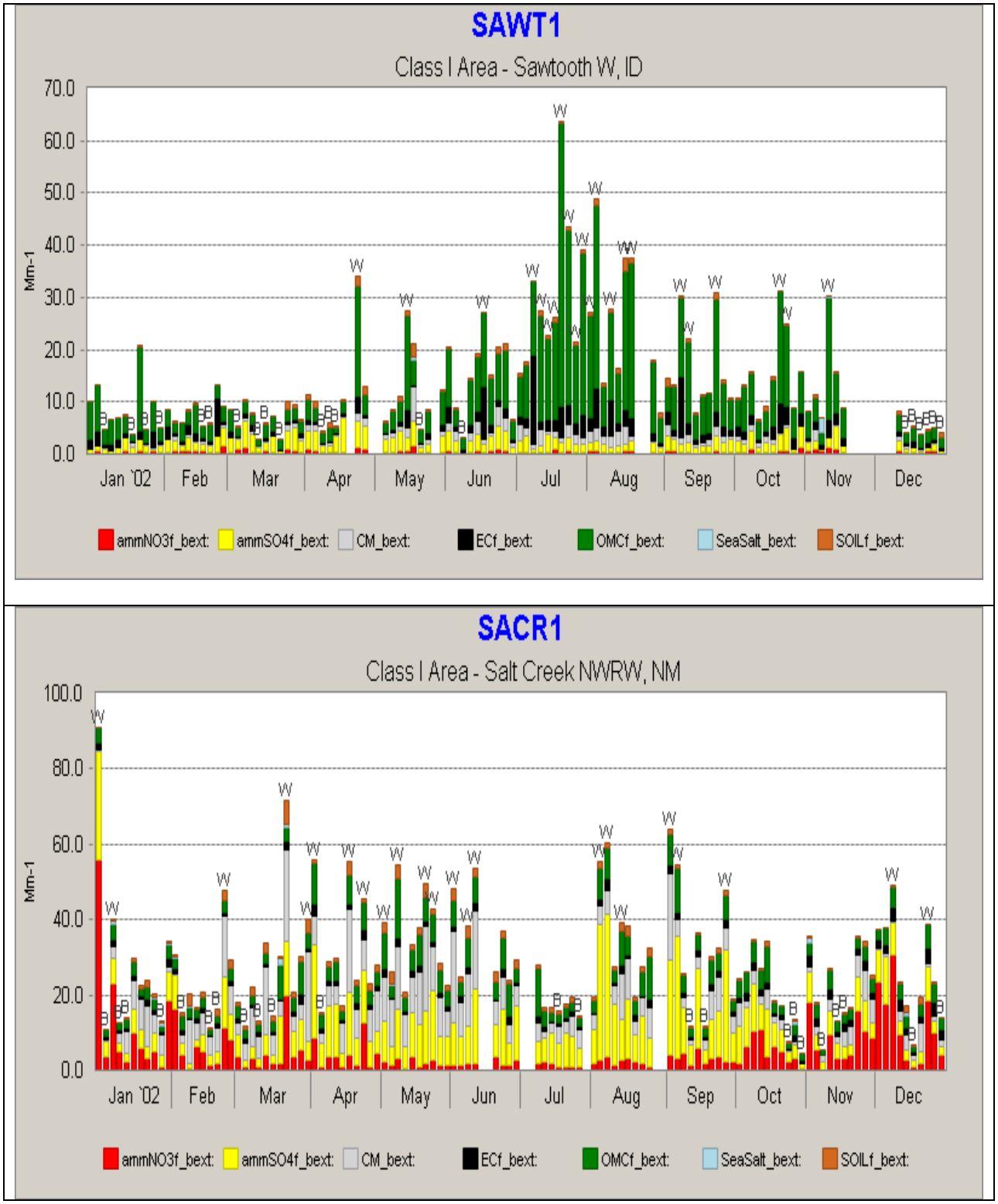
- High contributions from fires (EC and OC) at some Class I areas that are assumed to remain unchanged from 2002 to 2018.
- High contributions from dust (Soil and CM) at some Class I areas, especially in the Desert Southwest, much of which is natural and remains unchanged from 2002 to 2018 (e.g., wind blown dust).
- High contributions of International Transport (e.g., Canada, Mexico and Global) and Offshore Marine Vessels that are assumed unchanged.
- Relatively clean visibility conditions at many Class I areas where the contribution of United States anthropogenic sources is small.

Most of these sources are uncontrollable, unpredictable and difficult to forecast. For example, Figure 10 displays the 2002 daily extinction at the Sawtooth, Idaho and Salt Creek, New Mexico Class I areas where the Worst 20% monitored visibility days are dominated by fires and dust, respectively. Because it is impossible to accurately forecast future-year emissions for these source categories, many of them were held constant from 2000-04 Baseline period to 2018 Base Case conditions:

- Biogenics;
- Natural Fires (wildfire, wildland fire use, and non-federal rangeland fire in the WRAP region);
- Wind blown dust (from WRAP model);
- Ammonia (from WRAP model);
- Mexico and Canada;
- Boundary Conditions (global transport from 2002 simulation of GEOS-CHEM global model); and
- Offshore Marine Vessels.

Thus, modeled visibility reductions would come from reductions in on-road and non-road mobile sources (NOx, EC, OC and SO2), controlled large stationary point sources (SO2 and NOx), potentially other sources in nonattainment areas (mainly NOx and VOC in California), and applying Emissions Reduction Techniques to anthropogenic prescribed and agricultural fire sources' 2000-04 activity patterns in the WRAP region (mainly OC and EC). Other source categories are assumed to remain relatively unchanged, or even increase in some cases due to increased activity between 2002 and 2018 (e.g., road dust, oil and gas, etc.).

Figure 10. Daily observed extinction at the Sawtooth (top) and Salt Creek (bottom) Class I area IMPROVE monitors for 2002 showing Worst 20% days that are dominated by fires (EC and OC) and dust (Soil and CM), respectively.



EPA Guidance for Projecting Visibility

EPA released revised guidance for using models to project future-year visibility as part of the RP determination in September 2006 (EPA, 2006). The EPA default guidance method is to use "2002 worst monitored days" (Worst 20 %) to develop scaling factors to project future visibility conditions in 2018. The RHR requires monitoring data from the 2000-04 Baseline period to be used as the basis of the regional haze implementation plans. The modeling results for the 2002 Base Case and 2018 emissions scenarios using the 2002 meteorology are used to project PM concentrations for each of the Worst 20 % days from the 2000-2004 5-year Baseline to obtain estimates of PM concentrations for the Worst 20 % days in 2018 from which visibility is estimated using the revised IMPROVE equation. The ratio of the 2018 to 2002 modeling results that are used to scale the observed PM concentrations for the Worst 20 % days from the 2000-04 Baseline are called Relative Response Factors (RRFs). EPA's default guidance for projecting future-year visibility is in the same document and is closely linked to guidance for interpreting the modeling results for $PM_{2.5}$ and 8-hour ozone National Ambient Air Quality Standard (NAAQS) attainment demonstrations is found at: http://www.epa.gov/scram001/guidance/guide/draft_pm.pdf. The purpose of applying the EPA guidance to develop the RRFs for future visibility conditions is based on the assumption that the air quality model is better at predicting relative changes in concentration than absolute concentrations.

Basic steps for applying the EPA RRF guidance to project visibility conditions in 2018 at each CIA (i.e., IMPROVE monitoring site associated with a CIA) are:

- Model species concentrations for a 2000-04 Baseline case;
- Model species concentrations for a 2018 emissions scenario;
- Determine a species-specific and CIA-specific RRF for the average of the Worst 20 % monitored days (selected from 2002 IMPROVE data), where, for example:
  - RRF sulfate = 2018 sulfate/2002 sulfate
- Using the RRFs based on the 2002/2018 modeling results for Worst 20 % days from 2002, apply the RRFs to the observed PM concentrations from the Worst 20 % days in the 2000-04 5-year Baseline to obtain the 2018 projected PM concentrations:
  - [2018 concentrations] = RRF x [2000-04 Baseline Worst 20 % days concentrations]
- Calculate projected 2018 visibility values for Worst 20 % days from the 5 years and for each Class I area using deciviews and compare the 2018 projected deciviews with the 2018 URP goal to assess how closely the URP goal is achieved.

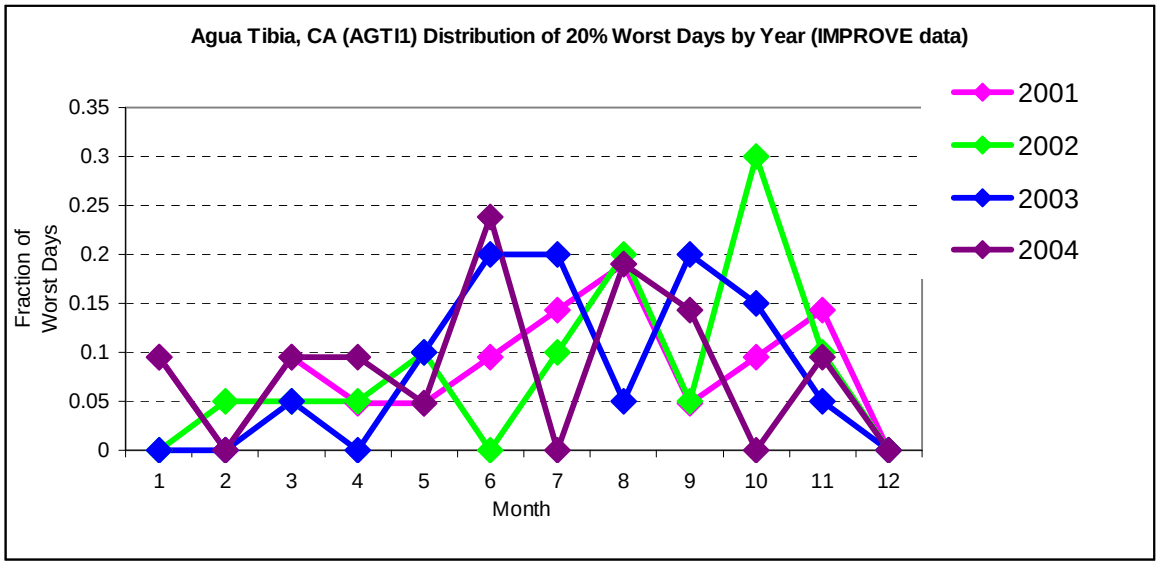
The 20% best visibility days are projected in the same manner, selecting the 20% best monitored days from 2002 IMPROVE data. Several issues with this approach are evident when analyzing the regional haze monitoring data and modeling results.

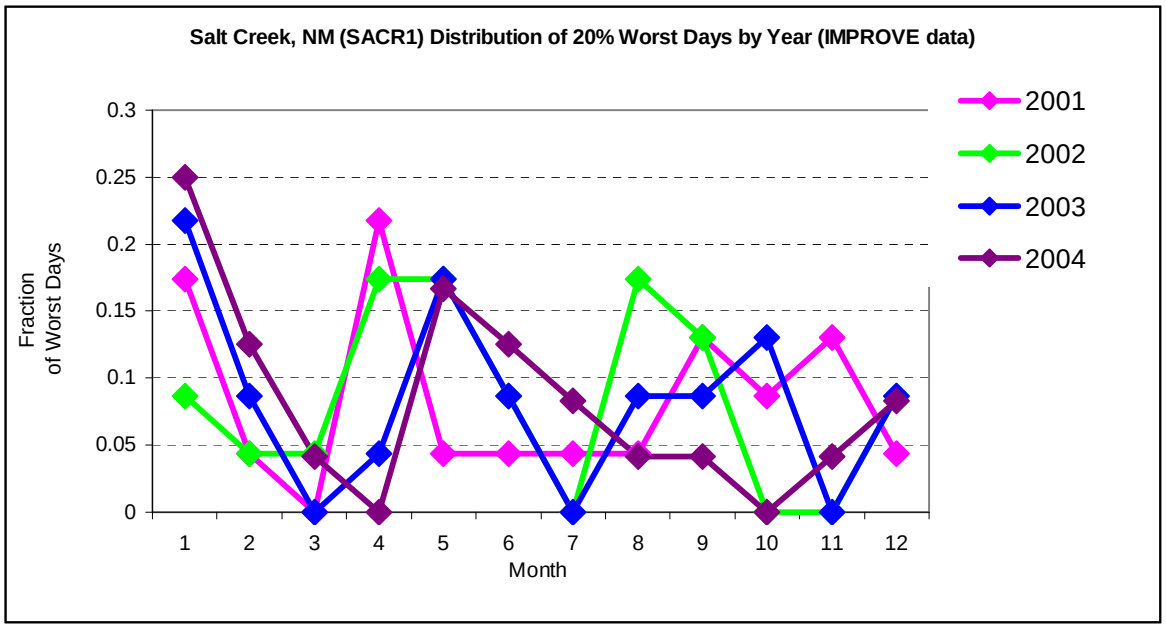
Representativeness of 2002 Worst 20 % Days for W20% Days for Other Years in the 2000-04 Baseline: The RRFs based on 2002 Worst 20% days may not be representative of Worst 20% days from other years in the 2000-04 Baseline period. For example, they may occur at different times of the year and represent different conditions and/or chemical constituents. For example, Figures 11 through 15 display the distribution of Worst 20 % days for the 2000-2004 Baseline at 5 CIAs. At Agua Tibia (Figure 11, top) we see that 30% of the Worst 20 % days in 2002 occur in October, but none did in 2004 and 10-15% did in 2001 and 2003. On the other hand, in June there are no Worst 20 % days in 2002 at Agua Tibia, yet there are 10% (2001) and 20% (2003 and 2004) of the Worst 20 % days in other years of the Baseline period. Similar seasonal variations in the Worst 20 % days for 2002 versus the other years in the Baseline are seen at Salt Creek, Badlands, Sawtooth, and Mount Rainier CIAs. Accounting for the differences of monthly and seasonal variations in the Worst 20 % days between 2002 and all 5 years in the Baseline period may be important in projecting 2018 visibility conditions.

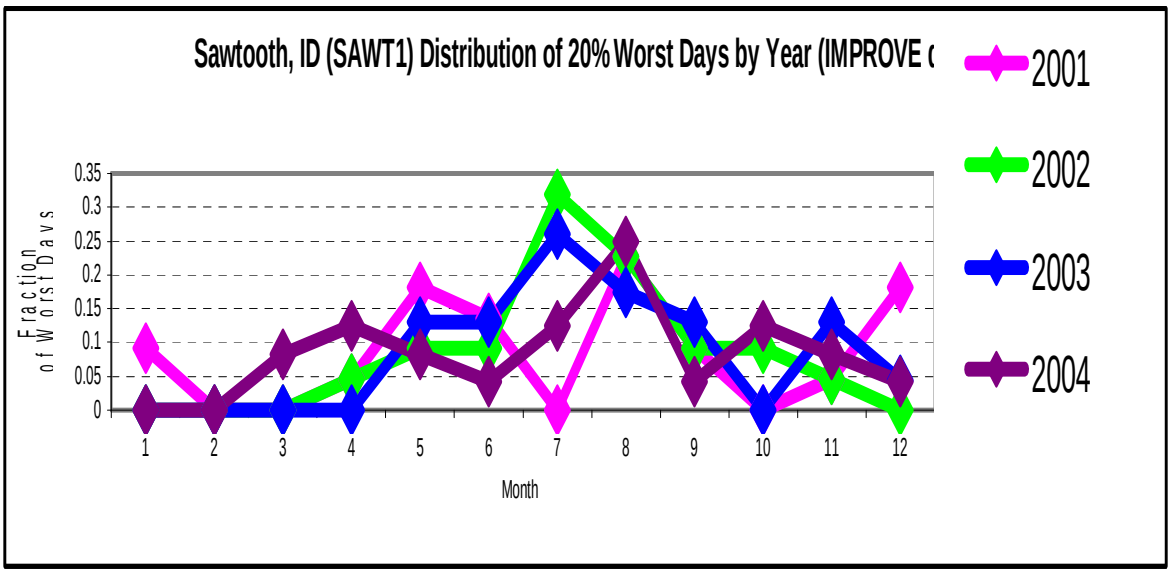
Episodic Events: Another issue associated with the representativeness of the RRFs derived from the 2002 Worst 20 % days is the occurrence of episodic events that may dominate the Worst 20 %. For example, if fires

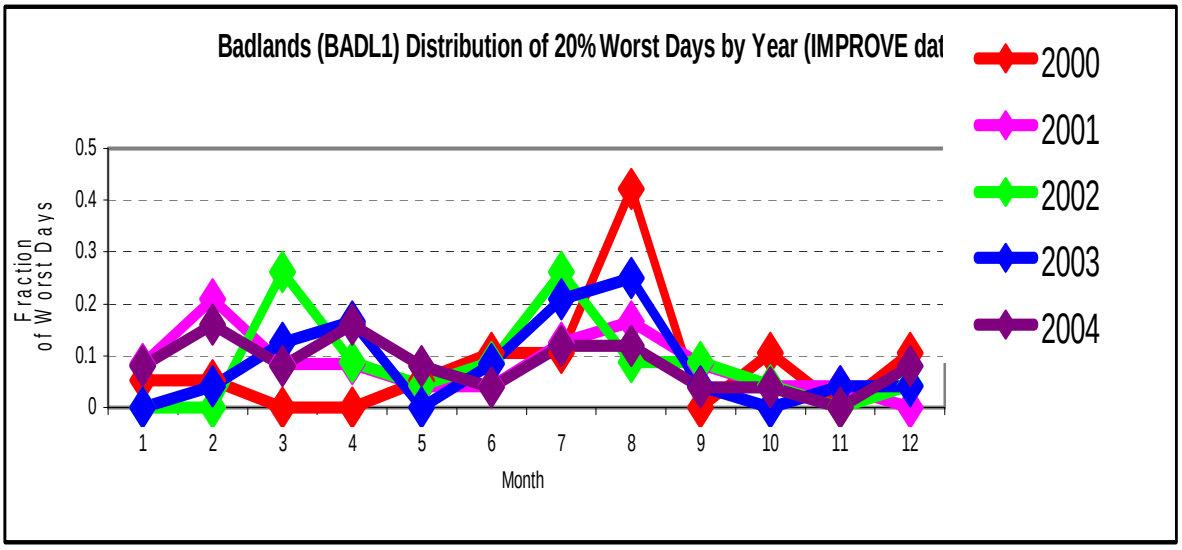
dominate the Worst 20 % days in 2002 and they are kept constant in 2018 the resultant RRFs will be very stiff and project little change in future-year PM concentrations for all W20% days in the Baseline even though fires may not have dominated the Worst 20 % days in other years of the Baseline. Conversely, if fires occur in other years of the Baseline and not in 2002, then the RRFs will reflect changes in anthropogenic emissions that are applied to PM concentrations due to fires which is also not appropriate. Again, accounting for monthly or seasonal variations in the RRFs may help alleviate this issue since prescribed burns, agricultural burning and wild fires each generally occur during the same time periods of the year.

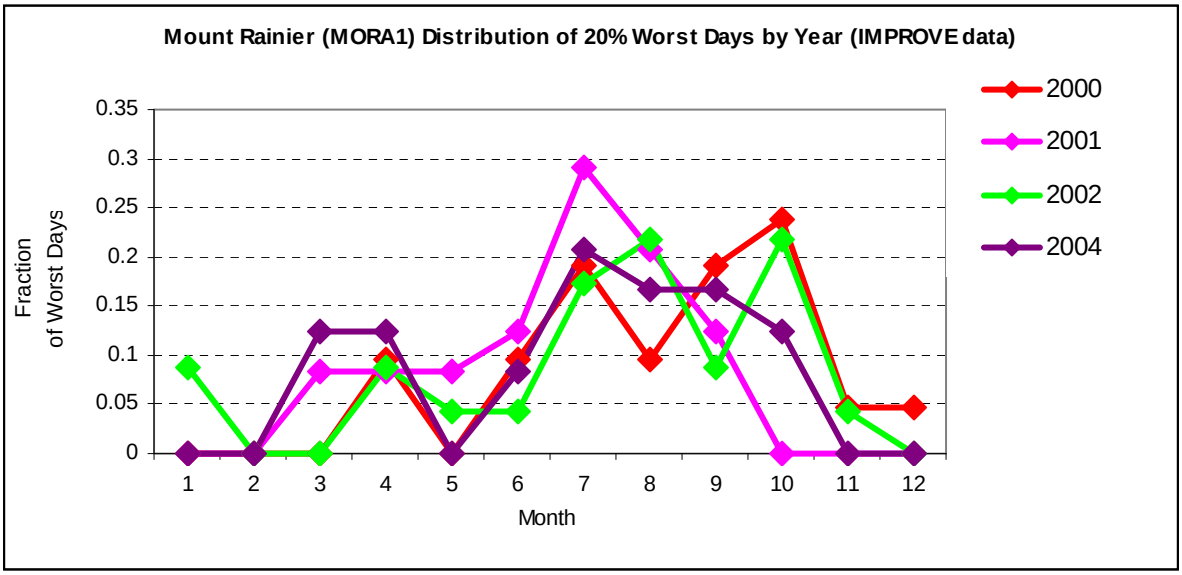
Figures 11, 12, 13, 14, 15. Time Series of Monthly Variation in the Fraction Variation of the 20% Worst Monitored Days at randomly-selected WRAP region Class I areas.






Sawtooth, ID (SAWT1) Distribution of 20% Worst Days by Year (IMPROVE d
Fraction of Worst Days
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
2001
2002
2003
2004


Badlands (BADL1) Distribution of 20% Worst Days by Year (IMPROVE dat
Fraction of Worst Days
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
2000
2001
2002
2003
2004

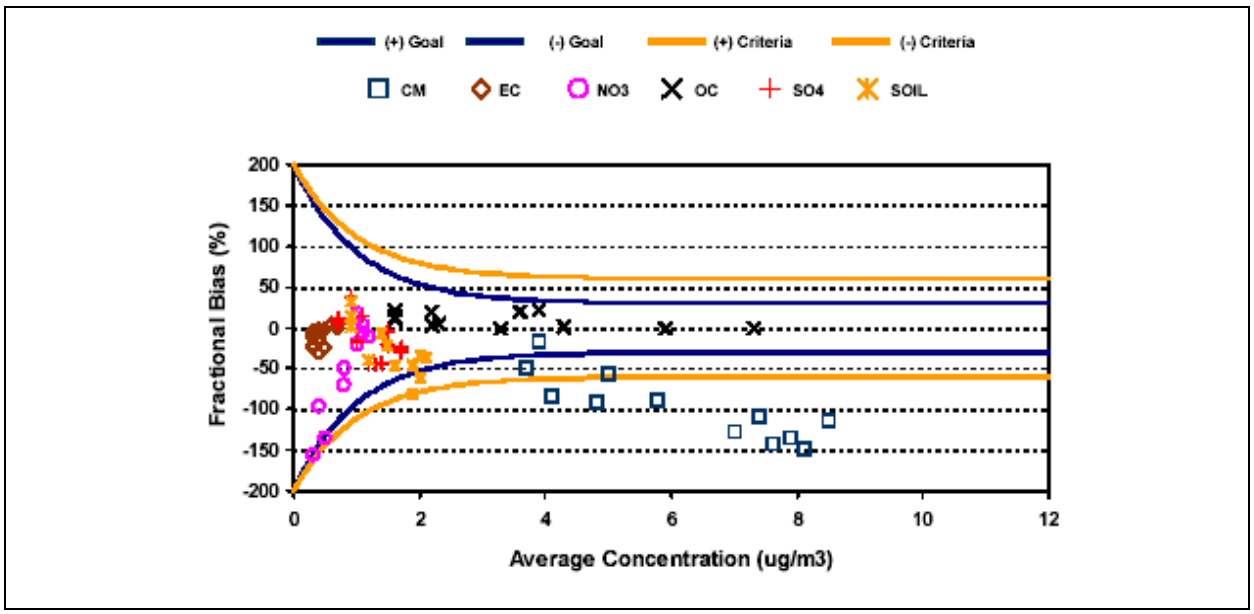

Mount Rainier (MORA1) Distribution of 20% Worst Days by Year (IMPROVE data)
Fraction of Worst Days
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
2000
2001
2002
2004

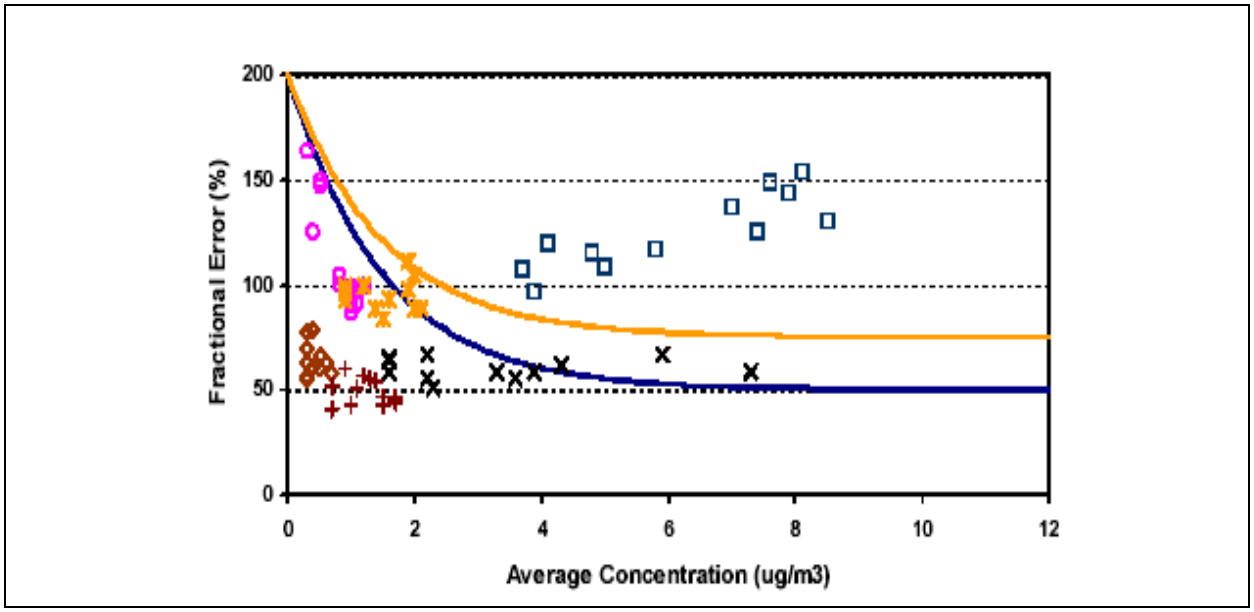
Missing IMPROVE Data: To date, 2018 visibility projections have not been made at 14 western Class I areas due to insufficient valid IMPROVE observations to satisfy the RHR data completeness criteria. Five sites did not have enough data to have at least 3 complete years from the 2000-2004 Baseline period, which is the minimal requirement in EPA guidance. 14 sites did not have sufficient data from 2002 to define the WORST 20 % days from which the RRFs are based (of these 14 sites with insufficient data in 2002, 4 were also included as the 5 sites without 3-years of complete data). This issue is being addressed using data substitution as described earlier in this document, and visibility projections will then be made using the substituted data in the projection algorithm.

Model Performance Issues: Air quality modeling in support of regional haze implementation planning is conducted by the WRAP Regional Modeling Center (RMC), see: http://pah.cert.ucr.edu/aqm/308/. The RMC uses state of the art, regional gridded photochemical models for aerosol modeling called CMAQ and CAMx. Extensive and numerous air quality modeling studies have been performed by the RMC over the past 6 years to support regional haze planning in the WRAP region.

The RMC has evaluated the CMAQ Actual Base02b model performance against available data (see: http://pah.cert.ucr.edu/aqm/308/cmaq.shtml#base02bvsbase02a36k). One of the conclusions of the RMC 2005 final report on the 2002 base case model performance of the CMAQ and CAMx models that they were performing sufficient well for most species to produce meaningful RRFs, with the exceptions of Coarse Matter (CM). Figure 16 displays "Bugle Plots" of PM species model performance in terms of fractional bias and error across IMPROVE sites in the western U.S. and compares them with model performance goals and criteria that are a function of average concentrations that allow for larger bias and error performance measures as the concentrations of the PM species approach zero under the assumption that model performance is not as important as the PM contribution becomes an insignificant component of the PM mass and extinction. As shown in Figure 16, the model performance goals and criteria are met for all PM species except CM, which is greatly underestimated by the model. This is believed to be in part for the inability of the regional model, using a 36 km grid, to capture the contributions of local CM sources on the monitored concentrations. To account for this CM model performance issue, the model derived RRFs for CM is not used and instead the CM RRFs are set to 1.0, which assumes that the CM measurements that occur in the 2000-2004 Baseline period will also occur in 2018.

Figure 16. CMAQ PM species model performance "Bugle Plots" across IMPROVE sites in the WRAP region and comparison with model performance goals and criteria.





Fire and dust air quality modeling results, and their projection using RRFs was considered at a WRAP workshop in May 2006, see: http://www.wrapair.org/forums/ioc/meetings/060523m/. Aerosol sampling at IMPROVE sites is 24 hours in duration, midnight to midnight, conducted every-3rd-day, and the hourly modeling results are summed and matched in time. The RMC models provide hourly estimates of visibility and aerosol species concentrations. The modeled gaseous and aerosol species are "mapped" to the IMPROVE and other networks' observational species, to calculate mass and aerosol light extinction in comparable terms. More information on RMC species mapping is shown in Tables 6 and 7 below.

Table 6. Mapping of Gaseous RMC Model Species to Gaseous Observational Species

Table 4-3a. Mapping of gaseous model species to gaseous observation species.

Compound	Observation Species			Model Species	
	IMPROVE	CASTNet	AQS	CMAQ	CAMx
Gaseous Species					
O_3			O3	O3	O3
CO			CO	CO	CO
NO			NO	NO	NO
SO_2			SO2	SO2	SO2
SO_2 ($\mu g/m^3$)		TOTAL_SO2		2617.6*SO2	2617.6*SO2
HNO_3				HNO3	HNO3
HNO_3 ($\mu g/m^3$)		NHNO3 (nylon filter)		2576.7*HNO3	2576.7*HNO3
NO_y				NO + NO2 + HONO + NO3 + 2*N2O5 + HNO3 + PAN + XNO2 + TPAN + HNO4	NO + NO2 + HONO + NXOY + HNO3 + PAN + NTR

Table 7. Mapping of Particulate RMC Model Species to Particulate Observational Species

Table 4-3b. Mapping of particulate model species to particulate observation species.

Compound	Observation Species				Model Species	
	IMPROVE	CASTNet	STN	NADP/ NTN	CMAQ	CAMx
Particulate Species						
SO_4	3*S	TSO4 (Teflon filter)	SO4	wSO4	ASO4J + ASO4I	PSO4
NO_3	NO3	TNO3 (Teflon filter)	NO3	wNO3	ANO3J + ANO3I	PNO3
Particulate NO_3+SO_4		0.29*TNO_3 + 0.375*TSO_4			0.29*(ANO3I + ANO3J) + 0.375*(ASO4I + ASO4J)	0.29*PNO3 + 0.375*PSO4
Total NO_3 (gas+particle)		TOTAL_NO_3			ANO3I + ANO3J + 0.9841*2576.7*HNO3	PNO3 + 0.9841*2576.7*HNO3
NH_4	0.375*SO4 + 0.29*NO3	TNH4 (Teflon filter)	NH4	wNH4	ANH4J + ANH4I	PNH4
OC	1.4*(OC1+ OC2 + OC3 + OC4 + OP)		OC		AORGAJ + AORGAI + AORGPAJ + AORGPAI + AORGBJ + AORGBI	POA + SOA1 + SOA2 + SOA3 + SOA4
EC	EC1 + EC2 + EC3 - OP		EC		AECJ + AECI	PEC
TCM			OC+EC			
SOIL	2.2*Al + 2.49*Si + 1.63*Ca + 2.42*Fe + 1.94*Ti				A25I +A25J	FCRS + FPRM
CM	MT - FM				ACORS + ASEAS + ASOIL	CCRS + CPRM
$PM_{2.5}$	FM		PM25		ASO4J + ASO4I + ANO3J + ANO3I + ANH4J + ANH4I+ AORGAJ + AORGAI + AORGPAJ + AORGPAI + AORGBJ + AORGBI + AECJ + AECI + A25J + A25I	PSO4 + PNO3 + PNH4 + POA + SOA1 + SOA2 + SOA3 + SOA4 + PEC + FCRS + FPRM
RCFM	1.375*SO4 + 1.29*NO3 + EC + OC + SOIL				1.375*(ASO4J + ASO4I) + 1.29*(ANO3J + ANO3I) + AORGAJ + AORGAI + AORGPAJ + AORGPAI + AORGBJ + AORGBI + AECJ + AECI + A25J + A25I	1.375*PSO4 + 1.29*PNO3 + POA + SOA1 + SOA2 + SOA3 + SOA4 + PEC + FCRS + FPRM
PM_{10}	MT				PM25 + CM	PM25 + CM

2018 URP Goal - One Element of Reasonable Progress

Section 169A of the Clean Air Act states that "Congress declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade pollution." States are required to "make reasonable progress toward meeting the national goal" in each of the 10-year planning periods identified in the RHR. In determining whether a given regional

haze implementation plan provides for reasonable progress, the following four factors shall be considered when evaluating controls on an existing facility:

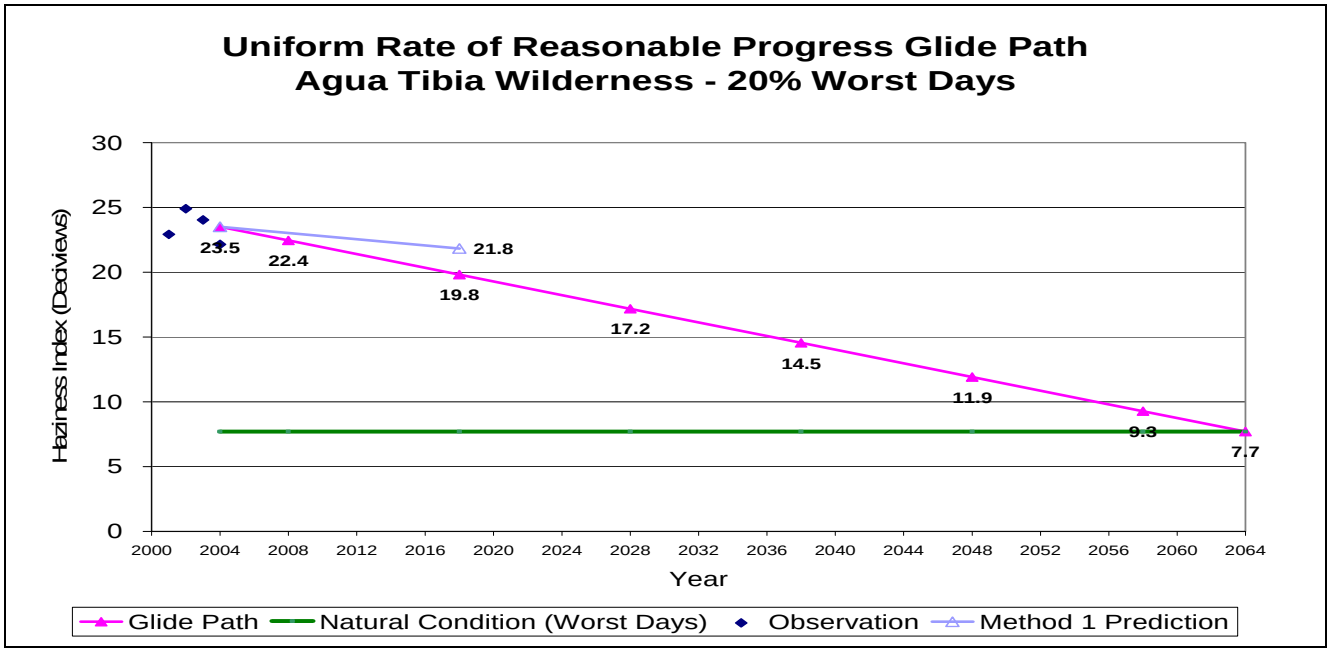
1. costs of compliance;
2. time necessary for compliance;
3. energy and non-air quality environmental impacts of compliance; and
4. remaining useful life of any existing source subject to such requirements.

In addition, EPA's 1999 visibility rule EPA required consideration of a fifth factor of whether visibility projections at a CIA achieves a uniform rate of progress (URP) toward natural conditions in 2064. Thus, the modeled achievement of the 2018 URP goal is just one element of Reasonable Progress and meeting it or not meeting it does not preclude the requirement for performing the four factor analysis to determine whether reasonable emissions controls are available for reducing visibility impairment at CIAs.

EPA Default 2018 URP Goal Calculations

Using the EPA default approach for RRFs (average modeling results across observed Worst 20 % days in 2002), no WRAP Class I area is projected to achieve the 2018 URP goal. Figure 17 shows examples of a linear Glide Path from the 2000-2004 Baseline to Natural Conditions in 2064 that defines the 2018 URP goal and the model projected visibility in 2018 for the Agua Tibia and Sawtooth CIAs. In both cases, the model projected 2018 visibility is substantially above 2018 URP goal derived from the Glide Path. For Agua Tibia, a 3.7 dv reduction (23.5-19.8) is needed from the 2000-2004 Baseline in order to achieve the 2018 URP goal yet only a 1.7 dv reduction (23.5-21.8) is modeled, thus Agua Tibia is projected to only achieve 46% of the 2018 URP goal. Similarly, for Sawtooth a 1.7 dv reduction from the Baseline is needed to achieve the 2018 URP goal and only a 0.5 dv reduction is projected in 2018, thus the Sawtooth CIA only achieves 29% of the 2018 URP goal. Expressing the 2018 projected visibility as a percent of achieving the 2018 URP goal is a useful metric for analyzing visibility projections across many CIAs or for different methods and is used in "DotPlot" displays in Figure 21 below.

Figure 17. Haze Index linear Glide Path toward Natural Conditions in 2064 to define 2018 URP goal and model projected 2018 base case visibility using EPA default average Worst 20 % RRF approach for the Agua Tibia, CA (top) and Sawtooth, ID (bottom) CIAs.



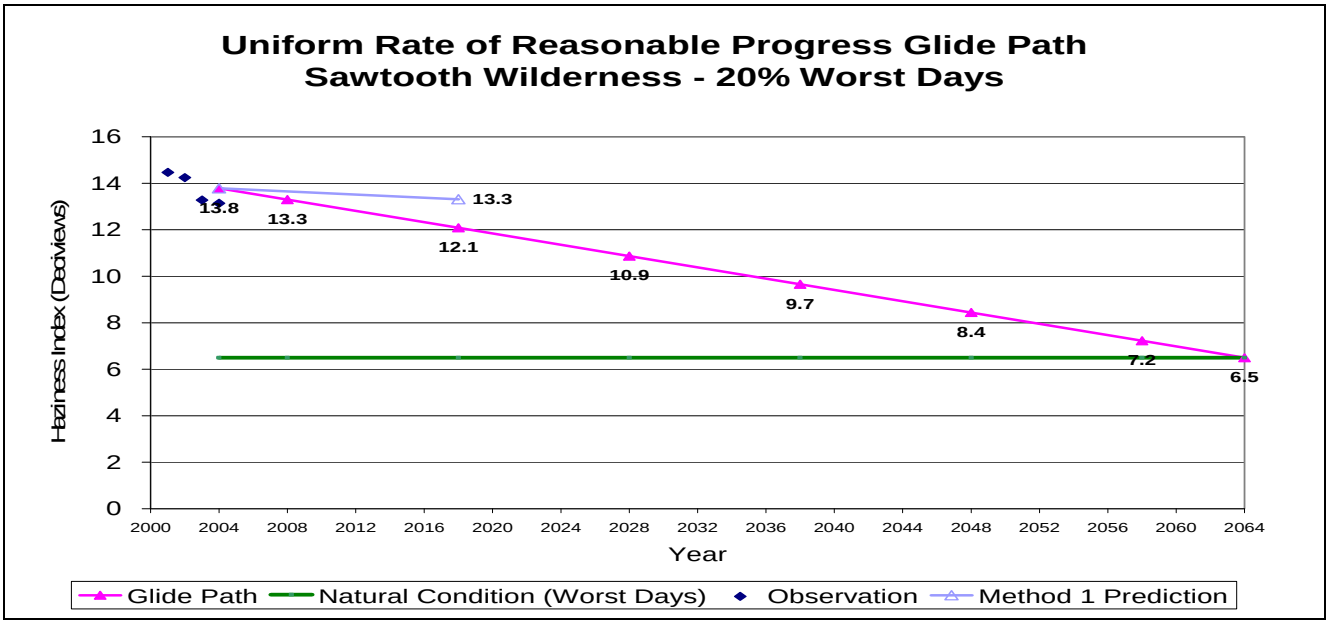


Figure 18 and 19 display the observed extinction and the model estimated reduction in extinction for the 2002 Worst 20 % days and their average for the Agua Tibia and Sawtooth CIAs, with the percent values for the average of the Worst 20 % days provided in Table 8. Most of the 2018 visibility benefits at Agua Tibia are due to reductions in NO3, there are also relatively large reductions in EC (-34%) but it is a smaller component of the extinction budget (6%). SO4 is a larger component of the extinction budget (31%) but exhibits little reduction (-4%). Figure 20 displays the CAMx PM Source Apportionment Technology (PSAT) results for Agua Tibia that shows most of the SO4 is due to off-shore marine vessels and boundary conditions (international transport) that are assumed to remain unchanged from 2002 to 2018. The largest estimated contributor to NO3 extinction at Agua Tibia for the Worst 20 % days in 2002 is California mobile sources that have large emission reductions. Since California does not have jurisdiction over controlling off-shore marine vessels or international transport it is not reasonable to expect them to achieve the 2018 URP goal with such a large component of the extinction budget remaining unchanged. At Sawtooth, OCM mainly from fires dominates the extinction budget for the average of the Worst 20 % days (70%), but there is very little reduction in OCM between 2002 and 2018 (-5%). Thus not meeting the 2018 URP goal is not unexpected given the large contribution of an uncontrollable source that has remained unchanged.

Figure 18. Observed extinction for the Worst 20 % days in 2002 and average for the Agua Tibia (top) and Sawtooth (bottom) CIAs (observed values from the entire 2000-2004 Baseline will be included on the TSS website)

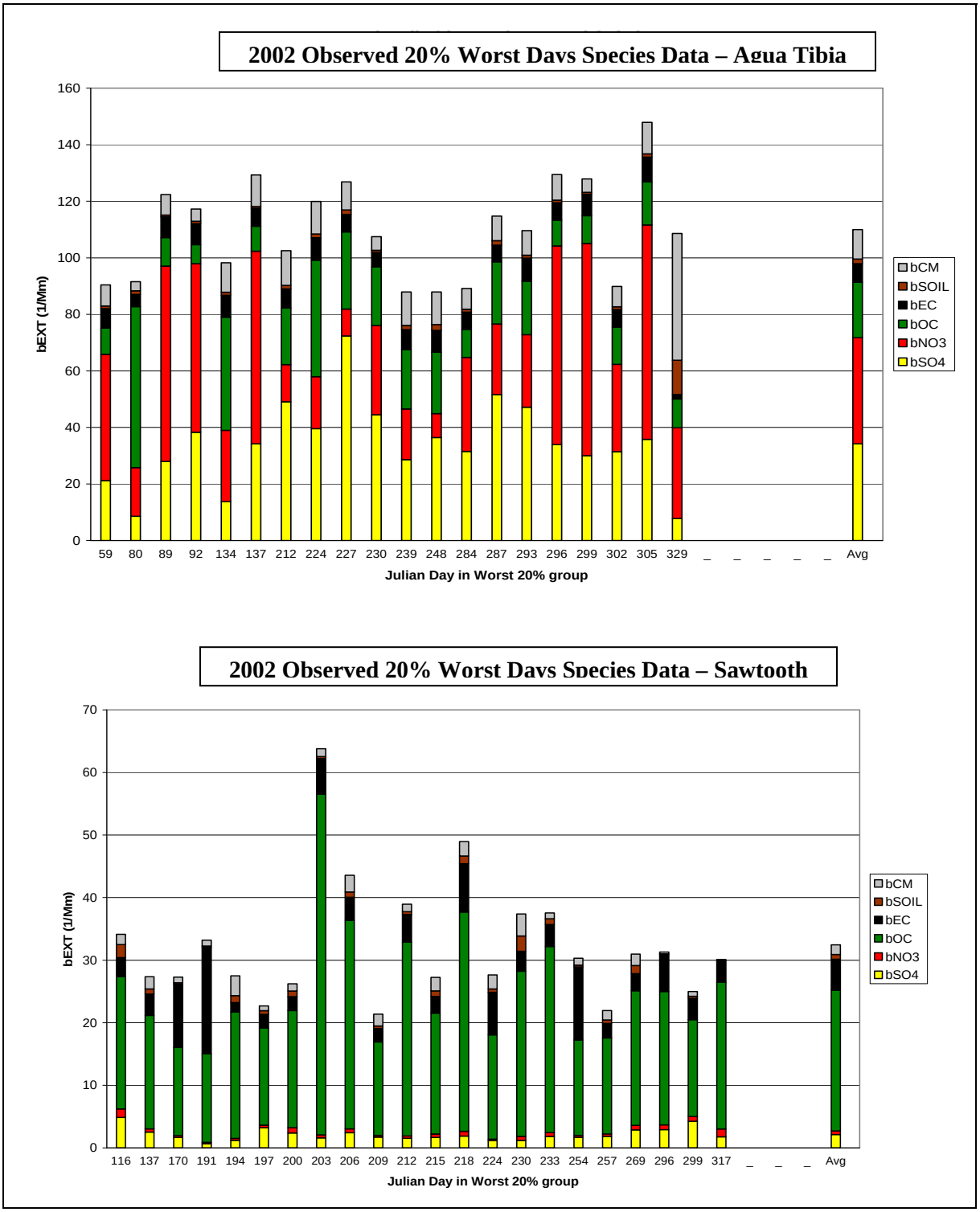


Figure 19. Modeled reduction in extinction (Plan02c to Base18b scenarios) for the 2002 Worst 20 % days and their average estimated by CMAQ between 2002 and 2018 for the Agua Tibia (top) and Sawtooth (bottom) CIAs.

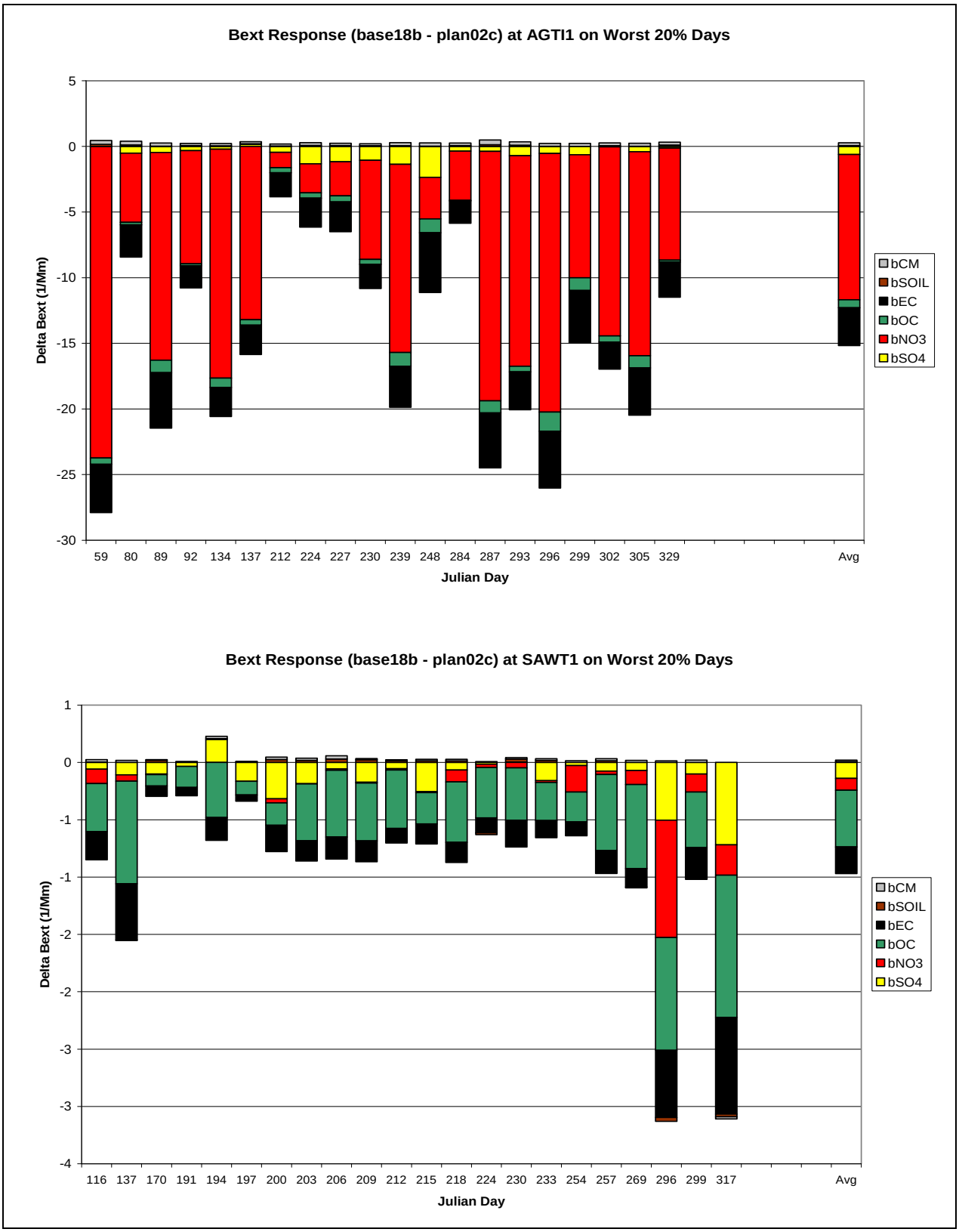
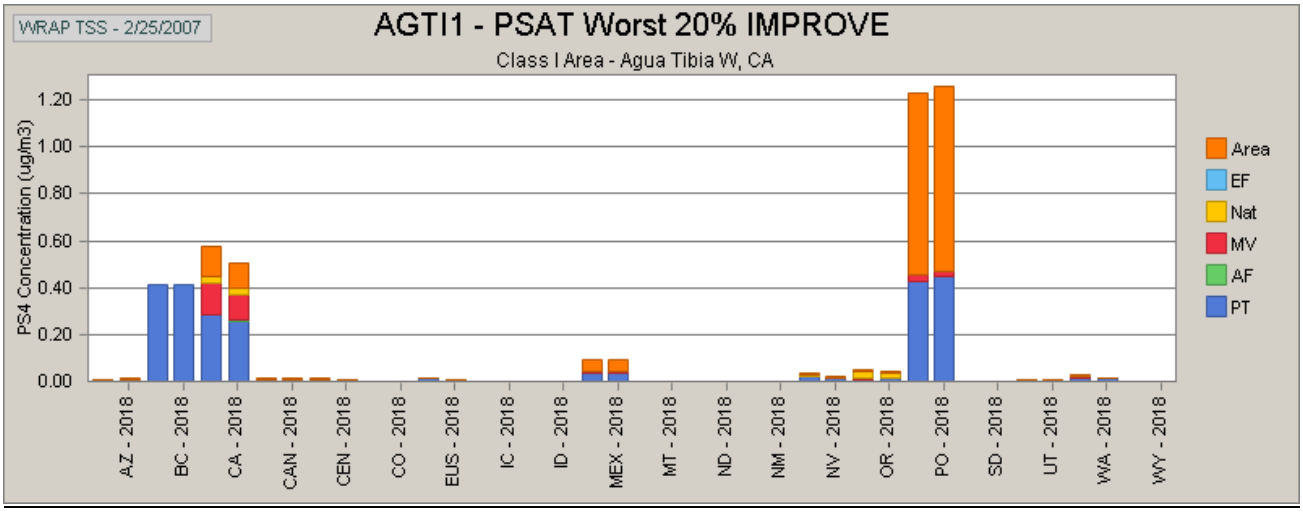
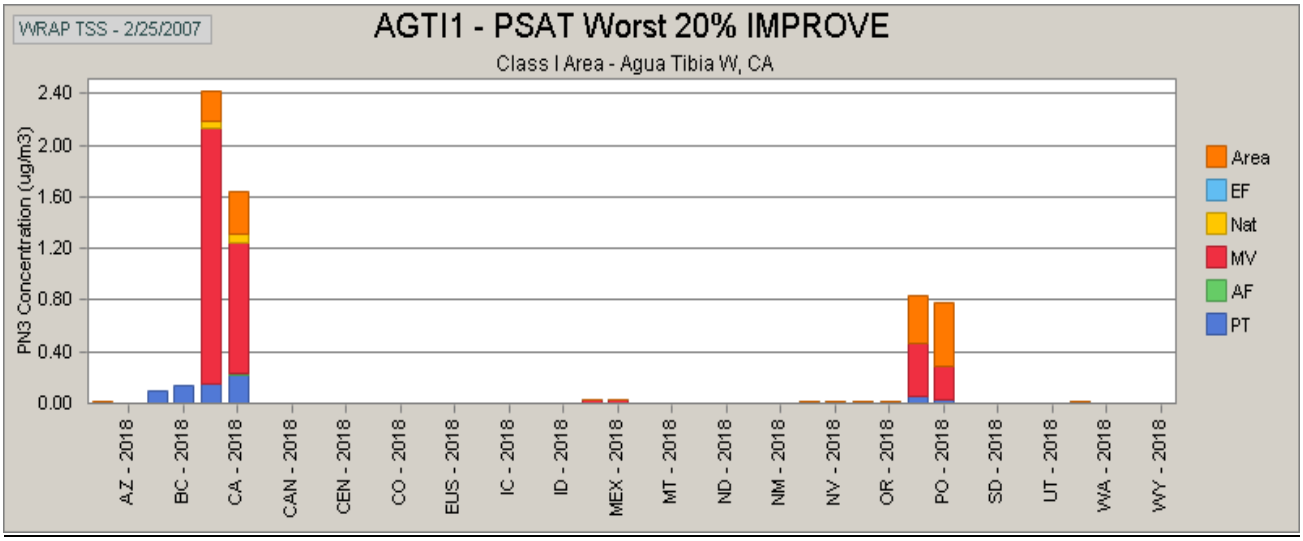


Table 8. Percent contribution to the observed average extinction for the Worst 20 % days in 2002 and model estimated percent reduction in the average extinction for the 2002 Worst 20 % days between 2002 and 2018.

	Agua Tibia CIA		Sawtooth CIA	
Light Extinction Species	**Average 20 % Worst Visibility Days (Measured % Contribution)**	**2002 to 2018 (Modeled 20 % Worst Days' Reduction)**	**Average 20 % Worst Visibility Days (Measured % Contribution)**	**2002 to 2018 (Modeled 20 % Worst Days' Reduction)**
bSO4	31%	-4%	6%	-6%
bNO3	34%	-38%	0%	-14%
BOCM	18%	-7%	70%	-5%
BEC	6%	-34%	15%	-10%
BSOIL	2%	+8%	2%	0%
BCM	9%	+15%	5%	0%

Figure 20. CAMx PM Source Apportionment Technology (PSAT) results for average Worst 20 % days measured in 2002 and the same days in 2018 at Agua Tibia for SO4 (top) and NO3 (bottom).





Alternative Model Projection Techniques

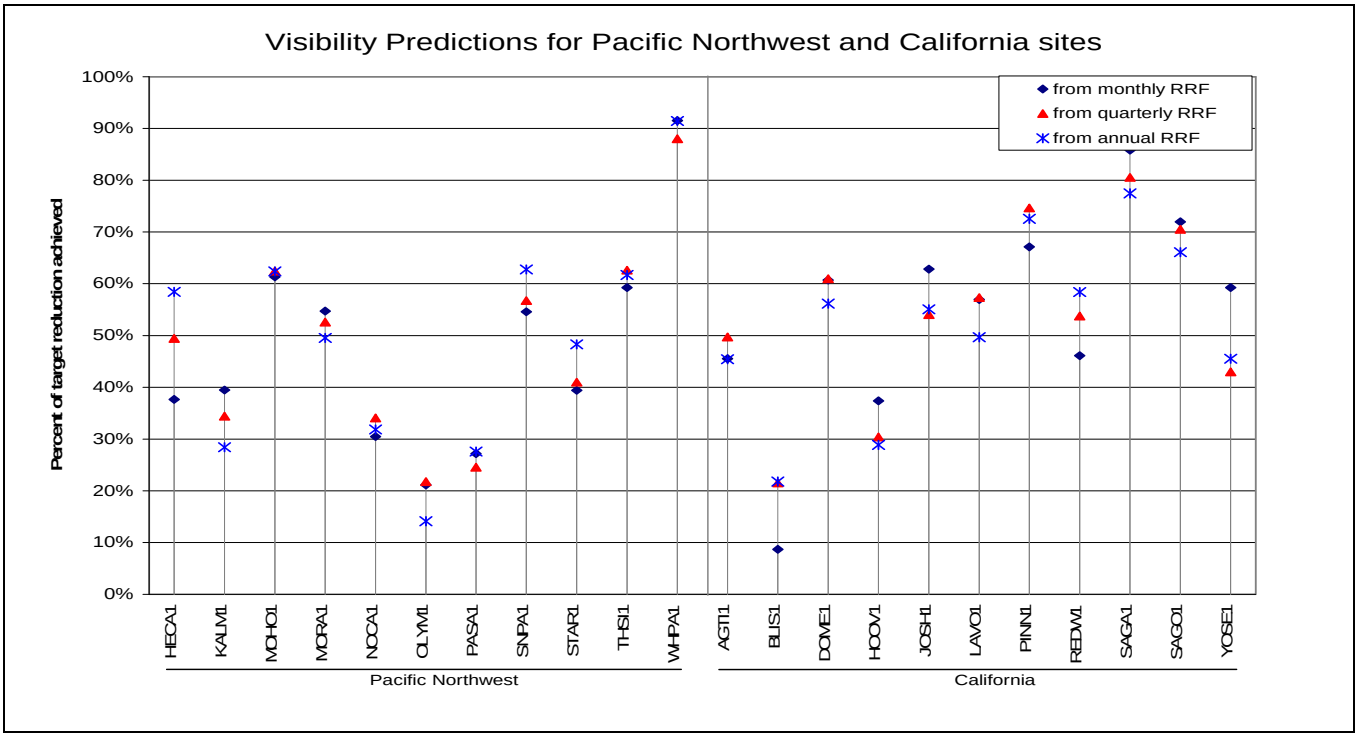
To address concerns that the EPA default modeled derived RRFs based on the average estimates from the site-specific Worst 20 % days for only 2002 (annual average Worst 20 %) may not represent the Worst 20 % days in other years of the 2000-2004 5-year Baseline period and may not represent seasonal variations, two alternative visibility projection techniques were analyzed:

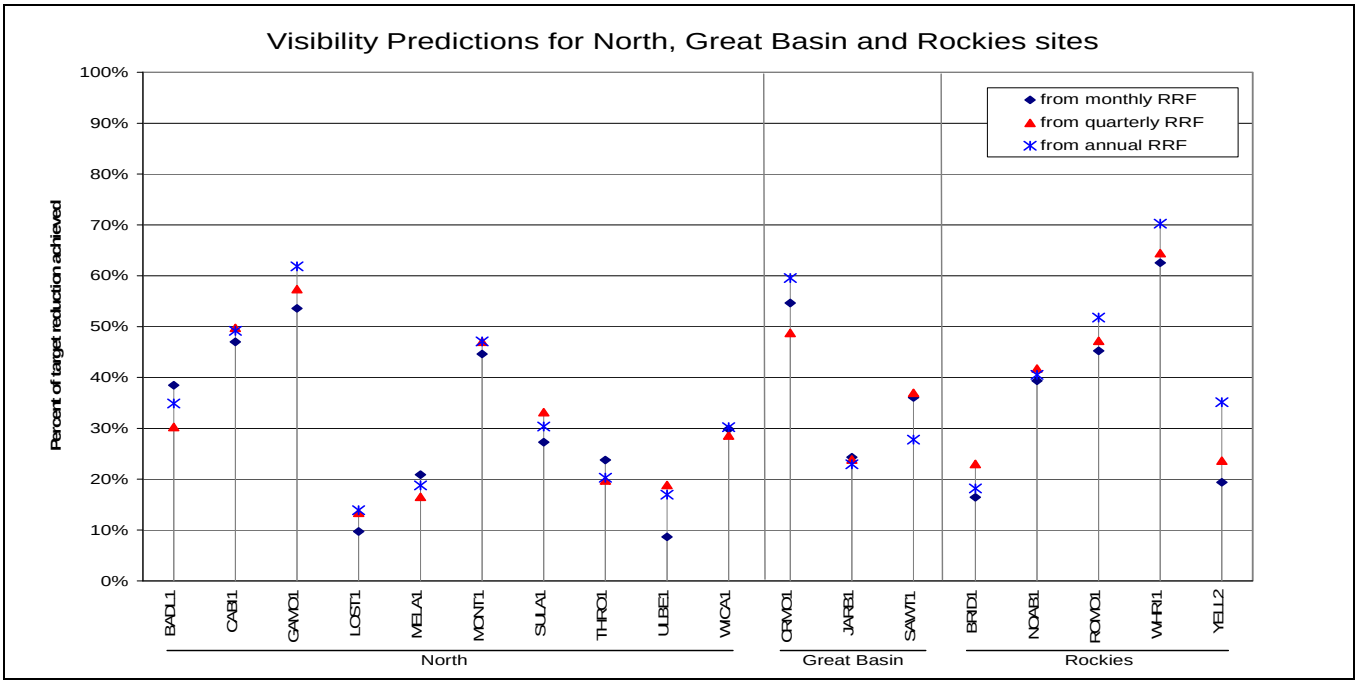
Quarterly Worst 20 %: RRFs are derived using the observed worst 20% visibility days from each quarter of 2002 and these quarterly RRFs are then applied to PM concentrations in the Worst 20 % days in the same quarter and the 2000-2004 Baseline.

Monthly Worst 20 %: Use RRFs based on the worst 20% days from each month in 2002 that are applied to the 2000-2004 Baseline Worst 20 % days in the same month.

The 2018 visibility projections at several WRAP CIAs using the three projection approaches (EPA default annual RRFs, quarterly RRFs and monthly RRFs) are shown in "DotPlots" in Figure 21. DotPlots display the 2018 visibility projections at a CIA as a percentage of achieving the 2018 URP goal with a value of 100% exactly achieving the URP goal and values below 100% not achieving the URP goal (above the Glide Slope). For example, using the EPA default annual RRFs for the Agua Tibia (AGTI) and Sawtooth (SAWT) CIAs, the DotPlots display values of 46% and 29%, respectively. Although there are some differences in the 2018 visibility projections using the alternative methods, the differences are generally small and do not change the fundamental conclusion that the 2018 URP goal is not achieved at western CIAs because of the large contribution to visibility impairment of unchanged emissions and transport from 2002 to 2018, many of which are uncontrollable.

Figure 21. "DotPlots" displaying percent of achieving 2018 URP goal reduction at Class I areas in the Pacific Northwest/California (top) and Northern/Great Basin/Rockies (bottom) CIAs projected using the EPA default annual average Worst 20 % days and alternative monthly and quarterly worst 20% days RRFs.





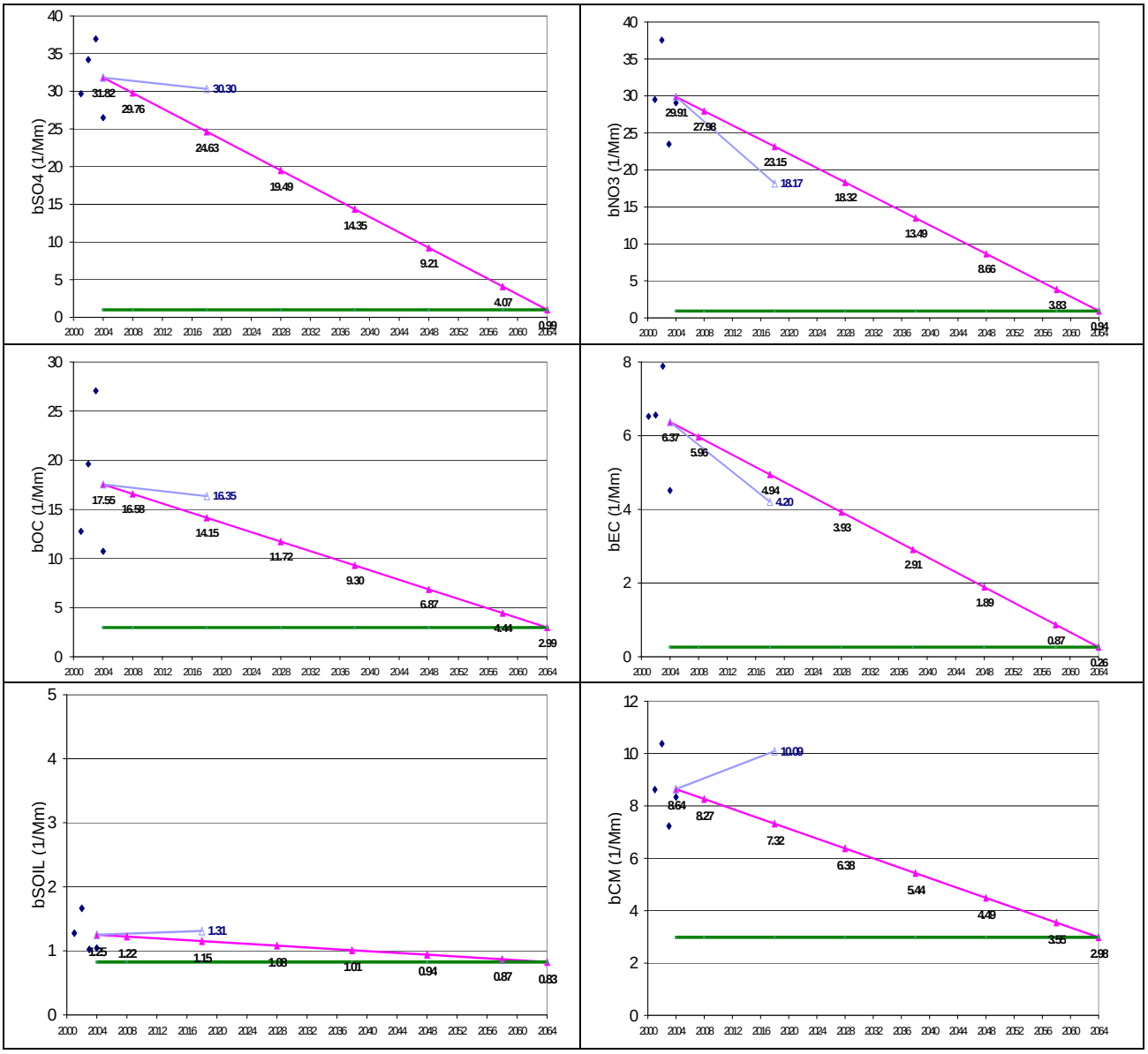
Alternative Model Reasonable Progress Metrics

There is a large contribution to visibility impairment for the Worst 20 % days at CIAs in the WRAP region due to emissions that are assumed to remain unchanged between 2002 and 2018. This has resulted in WRAP looking at alternative modeling metrics to the RHR Worst 20 % days Haze Index to evaluate reasonable progress. A RHR plan needs to demonstrate reasonable reductions of controllable emissions, at a reasonable rate toward the "zero controllable United States anthropogenic emission contribution to visibility impairment at CIAs in 2064" national visibility goal. The WRAP is suggesting that these alternative modeling metrics would be important information to include in a reasonable progress determination. Thus, as an alternative modeled URP test, species-specific visibility extinction Glide Paths toward Natural Conditions in 2064 have been developed, to compare the model projected 2018 species-specific extinction in 2018 with the species-specific 2018 URP goal.

Figure 22 displays example species-specific Glide Paths and model projected 2018 extinction due to the individual PM components for the Agua Tibia CIA discussed previously. In Figure 22 the Glide Paths are presented as linear extinction from the 2000-2004 Baseline to 2064 Natural Conditions; in reality these Glide Paths should be slightly curved reflecting the Haze Index logarithm of extinction using the total extinction that is the RHR metric. Such curvature will be included to these species-specific Glide Paths when implemented on the WRAP Technical Support System (TSS) website. SO4 extinction shows little reduction in 2018 reflecting the dominance of this component at Agua Tibia to sources that have been assumed to remain unchanged between 2002 and 2018 (off shore marine vessels and international transport, see above).

Visibility impairment due to NO3, on the other hand, shows large reductions that are below the linear extinction Glide Path owing to the large contribution of this component of light extinction due to controllable U.S. sources (California mobile sources, see above). Like NO3, the 2018 projected extinction due to EC is below the Glide Path reflecting large contributions from controllable U.S. sources (presumably California mobile sources), whereas extinction due to OC is above the Glide Path presumably due to contributions from unchanged sources (e.g., secondary organic aerosol from biogenics, international transport, etc.). The visibility extinction due to Soil and CM are projected to increase from 2000-2004 to 2018 due to growth and little or no controls in primary PM anthropogenic emissions and unchanged natural PM emissions (wind blown dust).

Figure 22. Example PM extinction (Mm-1) species-specific Glide Paths for SO4 (top left), NO3 (top right), OC (middle left), EC (middle right), Soil (bottom left) and CM (bottom left) at the Agua Tibia CIA (note: Glide Paths should be curved according to Haze Index logarithms of total extinction that will be done when implemented on the TSS website).



Modeling Metric Conclusions

WRAP recommends the use of both the EPA default and the WRAP-developed alternative projection techniques for assessing reasonable progress toward the national visibility goal at each Class I area. Analysis and assessment of the results from all 3 overall visibility projection techniques will assist haze planners in bounding and understanding reasonable progress analysis results. Specifically, the recommendations for projecting the overall visibility metric projections are as follows:

- Use the EPA default visibility projection method as the starting point - the default approach of annual average Worst 20 % visibility days' RRFs will enable all haze plans to assess progress in the same manner; AND
- Employ as desired the alternative projection techniques developed by WRAP in the Class I area-specific reasonable progress demonstration - the quarterly and monthly average Worst 20 % visibility days' RRFs.

The tools containing the necessary input data and results displays for these 3 methods are found at: http://vista.cira.colostate.edu/TSS/Tools/ModelingResults.aspx, select the "Model Projections (Scaled by RRFs)" tab.

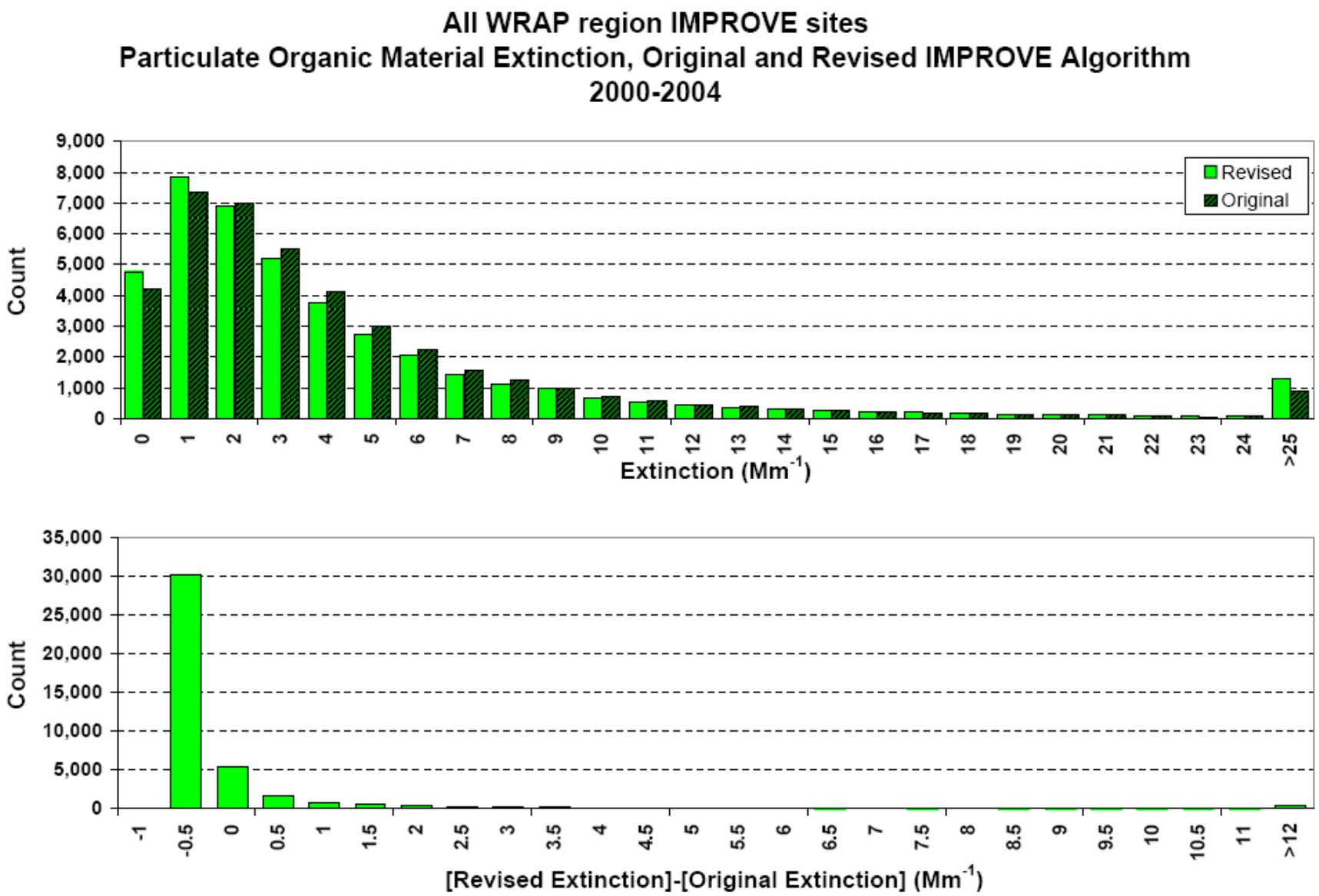
In addition to evaluating all 3 overall visibility projections metrics as described above, the WRAP recommends the assessment, analysis, and use of WRAP-developed alternative IMPROVE species-specific visibility projection metrics and "glide paths" for the Worst 20 % visibility days identified in the 3 overall visibility metric projections above. Specifically, the separate projection of each IMPROVE species is recommended to better understand the amount of visibility change expected in the overall reasonable progress demonstration, to be done as follows:

- Go to http://vista.cira.colostate.edu/TSS/Tools/ModelingResults.aspx, again select the "Model Projections (Scaled by RRFs)" tab, and isolate the individual IMPROVE light extinction species by selecting the species of interest using the Control key.

Assessment, analysis, and use of multiple overall visibility projection metrics and the IMPROVE species-specific projections and glide paths will provide haze planners with additional information and insight into the amount of reasonable progress that can be achieved by 2018. These alternative projections techniques and metrics have been implemented on the TSS website as further information to assist in regional haze planning. Beyond the "Model Projections (Scaled by RRFs)" tool, TSS users will be able to query additional modeling, emissions, and monitoring results for a given CIA to help understand the causes of and options for improving visibility impairment at a CIA.

The fractional monthly variation of the 20% Worst visibility days over the 2000-04 Baseline period is substantial and is likely to continue. For the following reasons, a variety of alternative projection techniques should be analyzed and used in preparing regional haze plans in the West.

- Missing data and/or incomplete data for worst and best days' monitored distributions from historic datasets, and operational limitations of these monitors, the future data completeness from year-to-year is likely to continue to affect many WRAP region sites;
- The 24-hour average data and systematic bias of the 1 in 3-day sampling frequency of the monitored observations;
- The episodic and/or substantial nature of dust, international, and fire impacts on individual IMPROVE samplers and CIAs from year-to-year; and
- These characteristics are likely to continue during the nominal 60-year implementation period of the RHR.



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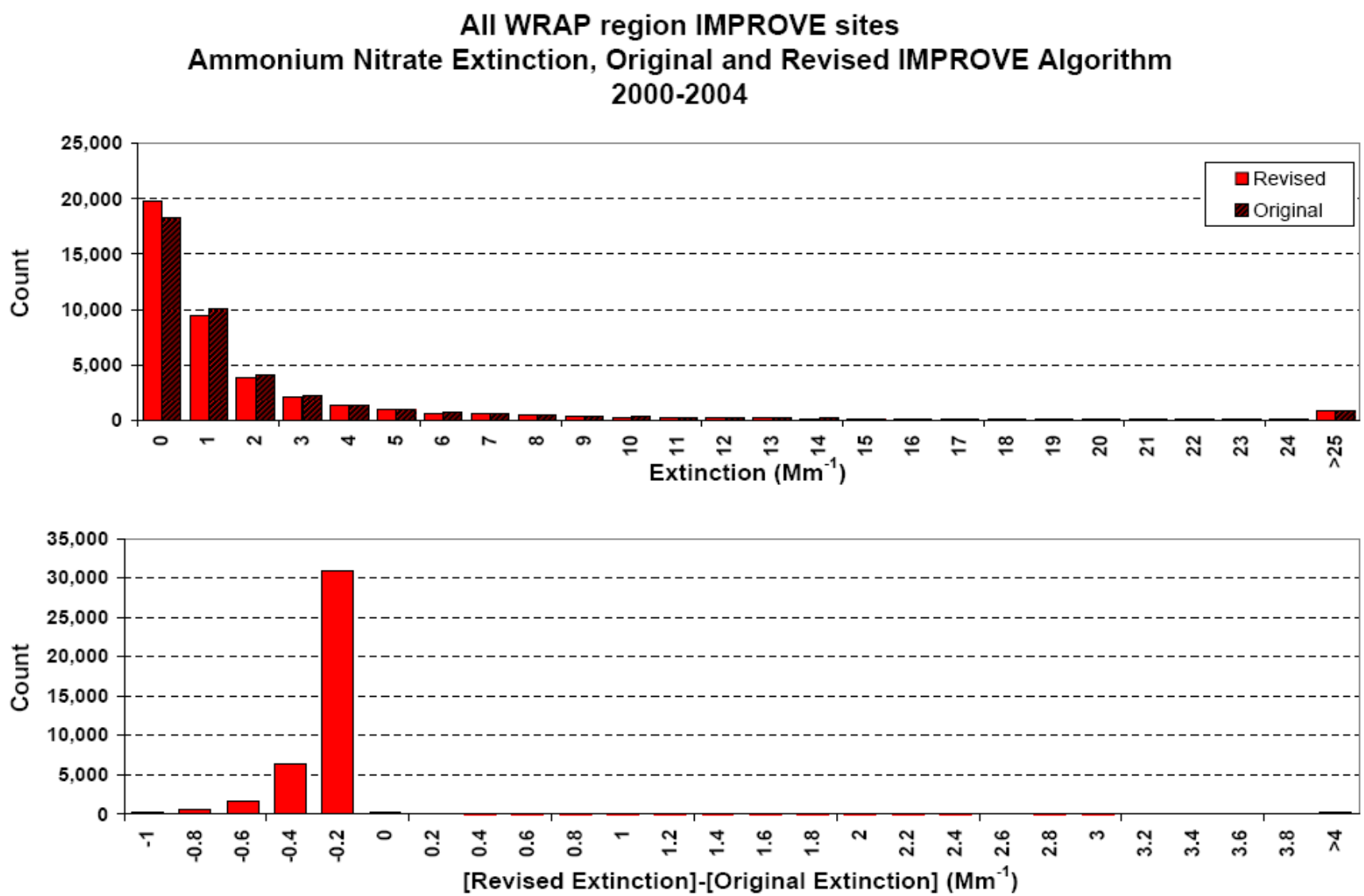

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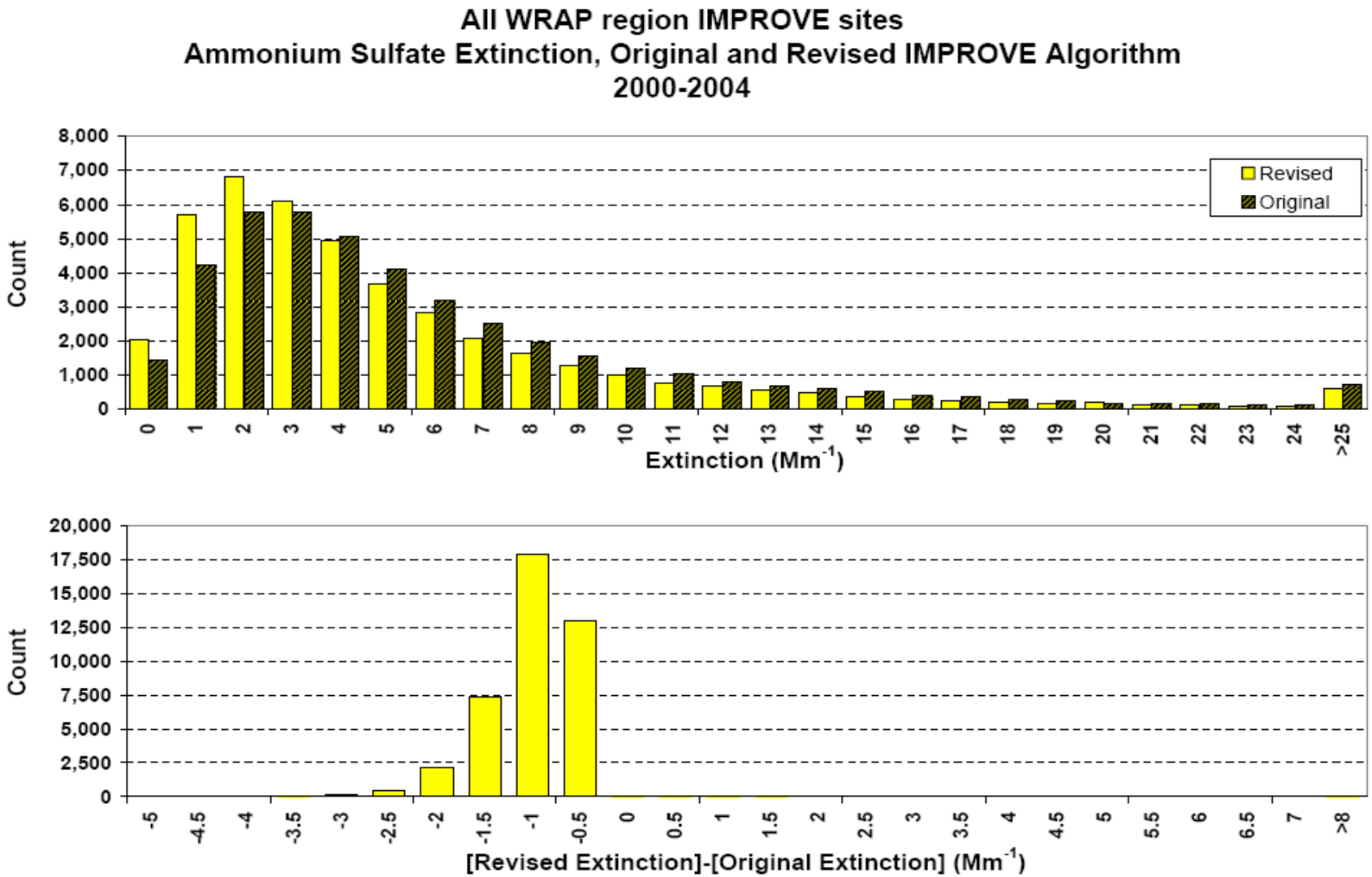

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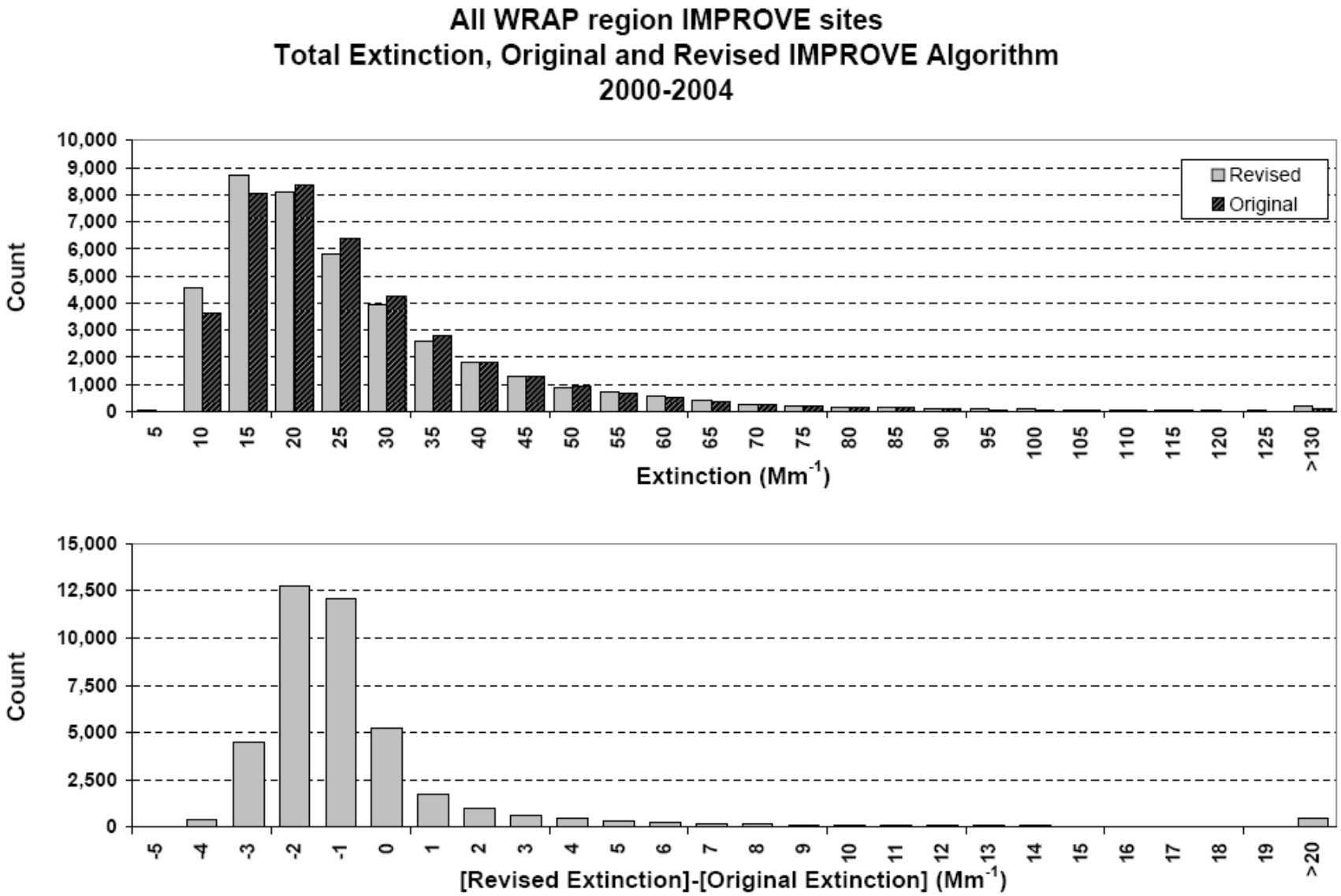

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