Appendix W

CENRAP Regional Haze Control Strategy Analysis Plan

Jeff Peltola

From: Gregory Stella [gms@alpinegeophysics.com]
Sent: Tuesday, May 09, 2006 3:53 PM
To: Jeff Peltola
Cc: 'Seltz, John'; mac@adeq.state.ar.us; 'T. W. Tesche'; 'Wilkinson, Jim'
Subject: Final CENRAP Regional Haze Control Strategy Analysis Plan

Attachments: Alpine Geophysics Final Report (9 May '06).pdf

Alpine Geophysics
Final Report...

VIA E-MAIL

9 May 2006

Mr. Jeff Peltola
CENRAP Technical Director
10005 S. Pennsylvania, Ste C
Oklahoma City, OK 73159

Dear Jeff:

The scientists at Alpine Geophysics are pleased to submit the attached document titled "Final CENRAP Regional Haze Control Strategy Analysis Plan" as outlined in Task 6 of our previously submitted quotation and work plan.

This document and associated materials are the product of our development and application of a quantitative procedure to identify and prioritize potential regional haze control strategies for Class I areas failing to meet visibility goal objectives. Additionally, we have addressed as many of the comments on the draft control strategy analysis plan as submitted to Alpine (April 25 and later) as we have determined to be within the scope of our original proposal to CENRAP.

To facilitate subsequent use of this methodology by CENRAP or others, this Final Report describes the various analytical steps and provides examples of this procedure (both in the body of the report and in supporting in appendixes). Document appendices and relevant technical support information have archived on the Alpine Geophysics project website facilitating easy access by interested parties. The login and password to access these data is provided below.

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ftp> ftp.alpinegeophysics.com
login> cenrap
pass> pass4ftp
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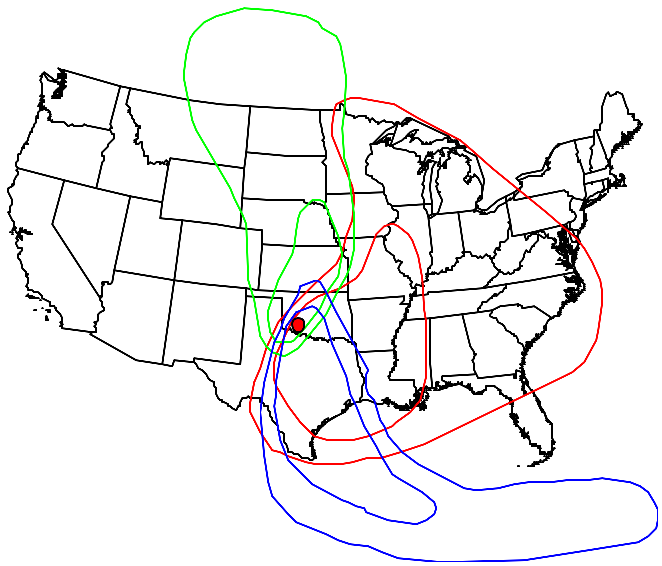
Should you have any questions or problems accessing these files and supporting materials, please contact me at your convenience.

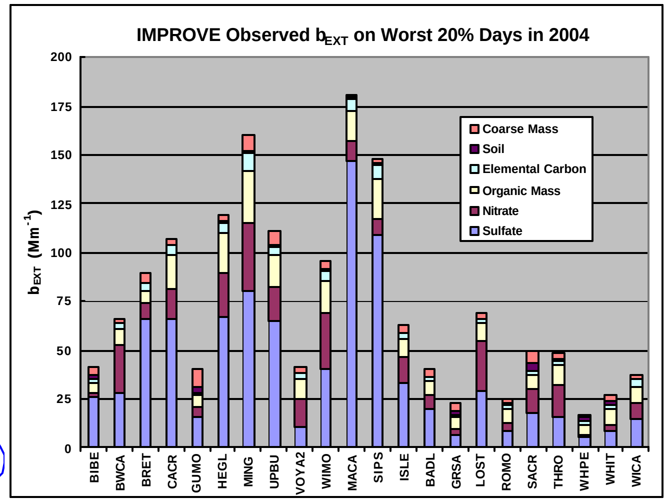
Respectfully yours,

Gregory Stella
Senior Scientist
Alpine Geophysics, LLC
Burnsville, NC 28714

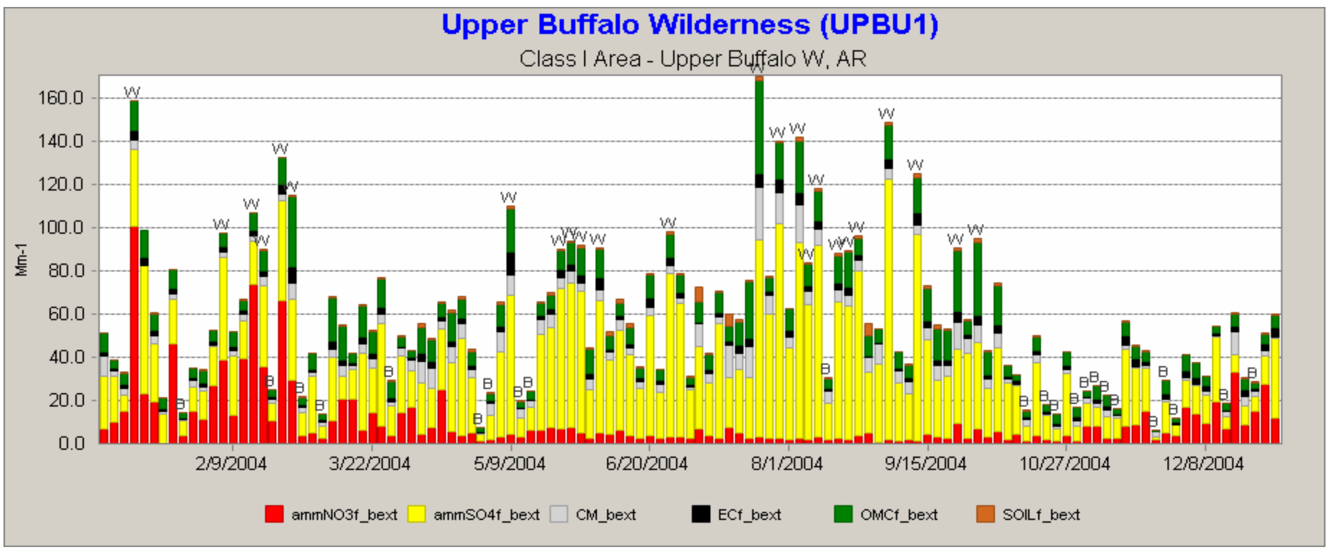
CENRAP REGIONAL HAZE CONTROL STRATEGY ANALYSIS PLAN



Wichita Mountains Areas of Influence (AOIs)



b_{ext} on CENRAP Worst 20% Days in 2004



Daily Variation in $PM_{2.5}$ Components at Upper Buffalo Wilderness

Prepared by

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9 May 2006

ALPINE GEOPHYSICS

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EXECUTIVE SUMMARY

The Implementation and Control Strategies (ICS) Workgroup of the Central Regional Air Planning Association (CENRAP), together with other workgroups and state, tribal and federal agencies, have been working for more than four years gathering information for developing regional haze (RH) control strategies for pertinent Class I areas within and adjacent to the CENRAP states and tribes. In late February 2006, under the direction of the CENRAP Technical Director, Alpine Geophysics, LLC was contracted to assist the ICS in this effort. Building upon information developed by the ICS and others, Alpine was charged with developing a quantitative procedure to identify and prioritize potential RH control strategies to be tested by CENRAP modelers. Alpine formulated a methodology for constructing control strategy recommendations based on presently available information and submitted a Work Plan detailing this approach to the ICS/CENRAP leadership for review and approval.

Using the results of preliminary and more recent CENRAP visibility projection modeling together with current information on the composition of visibility-impairing fine particulate aerosols at 22 Class I monitors, Alpine identified residual visibility progress 'increments' that potentially require additional regional and/or subregional emission reductions to achieve visibility goals[1]. We synthesized pertinent 'attribution of haze' documents, CENRAP CAMx/CMAQ visibility modeling results, our own fine particulate modeling in the central U.S, and other technical reports, papers, and analyses bearing directly on the quantification of emissions-source/visibility-receptor impacts at the ten CENRAP Class I and twelve adjoining areas.

Complementing this task, we synthesized a number of recent regional modeling studies helpful in relating emissions reductions of visibility precursors (e.g. SO_2, NO_X) in upwind source regions (Areas of Influence or AOIs) to the improvement in visibility (in deciviews or Mm^{-1}) at downwind Class I areas. Figures ES-1 and ES-2 present 'level 1' AOI plots for sulfate and nitrate impacts at the Big Bend, Guadalupe, Wichita Mountains, Breton Island, Voyageurs, and Boundary Waters Class I Areas, respectively. Three distinct levels of AOI have been estimated for each visibility precursor and Class I areas, but the controls most likely to be considered for modeling will be drawn from the closest (i.e., AOI level 1 or AOI-1) area of influence for each Class I area/visibility precursor pair.

[1] We use the term 'increment' to denote the difference between the modeled visibility at a Class I area in 2018 compared to the value based on the Reasonable Progress Goal (RPG) glide path, evaluated at the same time period. A positive increment means that the modeled visibility at the Class I area is 'poorer' than the level associated with the linear FPG glide path. Accordingly, CENRAP may wish to consider recommending additional precursor controls to ameliorate such a positive visibility increment. In contrast, a negative increment suggests that the modeled growth and emissions controls by 2018 may produce better visibility conditions at the monitor when compared to the linear glide path.

We then deduced from available regional modeling studies 'rules of thumb' relating percentage or tonnage reductions in visibility reducing precursors (e.g., SO_2, NO_X, ammonia, and VOCs) on the expected impact on visibility downwind. These 'rules of thumb', i.e., source-receptor relationships, were essential in estimating the amounts of incremental precursor emissions reductions in regions upwind of each of the various Class I areas that CENRAP modelers should consider in the prescription of initial RH control strategy simulations.

Once an emissions reduction target was determined for each Class I area showing visibility projections above the uniform rate of progress line (i.e., a positive visibility increment), we applied a master list of controls on sources within the Class I AOIs to formulate the CENRAP Control Strategy plan, including cost-effectiveness as a key element.

Alpine's analysis of the most recent CENRAP visibility projection data identified six Class I areas within the CENRAP domain whose projected visibility falls above the uniform rate of progress line (i.e., a projected positive visibility increment). On this basis, we quantified their associated AOIs, emission reduction estimates for reaching 2018 reasonable progress objectives, and potential incremental emission reductions worthy of annual CMAQ/CAMx modeling. For each area, sulfate and to a lesser extent, nitrate reductions were shown to be most beneficial during the 20 percent worst visibility days in 2002.

As each of these areas (and all of the other Class I AOIs in the CENRAP domain) are dominated by EGU SO_2 and NO_X emissions and many of the Class I area AOIs intersect with States currently excluded by the EPA CAIR rule, a region-wide strategy for additional EGU emission reductions at CAIR levels for the non-CAIR EGUs may be beneficial to each Class I area in the CENRAP domain projected below the uniform rate of progress line. An alternate intra-state trading permutation of this regional approach is also recommended for review by CENRAP.

In lieu of a single regional control option applied consistently across the entire CENRAP domain, individual subregional control applications are proposed to reduce emissions within certain Class I area AOIs. Based on the single precursor emission reduction target calculations defined by the ICS, subregional control strategies can be defined for three of the Class I areas projected to be above the reasonable progress glide path[2]. In each case, the marginal cost curves (based on the application of all available control options on all controllable industries and source types) allow the selection of control technologies which attains the ICS defined, AOI-1 specific emission reduction targets.

However, the application of incremental control on all controllable point and area sources within certain AOIs still fails to meet the visibility objectives of three Class I areas modeled to be above the reasonable progress glide slope. In fact, as a result of the implementation of the exhaustive list of additional controls in each primary AOI, Alpine has determined that these three Class I areas[3] will be unable to achieve a level of emissions reduction necessary to bring these areas under the reasonable progress line. Influences such as incrementally uncontrollable source categories, cost-effectiveness limitations and international and inter-RPO emissions transport are barriers that prevent strategies from being configured for these Class I areas within the confines of the CENRAP domain.

[2] These areas include Boundary Waters, Wichita Mountains, and Voyageurs.
[3] These areas include Big Bend, Breton Island, and Guadalupe Mountains.

Although application of the exhaustive list of available control technologies to sources within the AOIs for each of the Class I areas failing to achieve ICS identified emission reduction targets, emission reductions beyond the base case should not be forsaken as a result. Indeed, *significant emission reductions may be warranted* in order to prepare impacted States and tribes for future attainment demonstrations where these measures may set the basis for defining and meeting future progress goals.

It should be noted that although this report and associated material includes controls for particular sources or source categories as options to consider for further photochemical modeling, it does not necessarily indicate that they will be modeled, and does not imply that these strategies ultimately will be implemented.

Finally, while the this methodology was developed and tested for regional haze control programs, with very minor adaptation, the same methods can be used effectively to aid in the design of regional 8-hr ozone and annual $PM_{2.5}$ NAAQS attainment strategies.

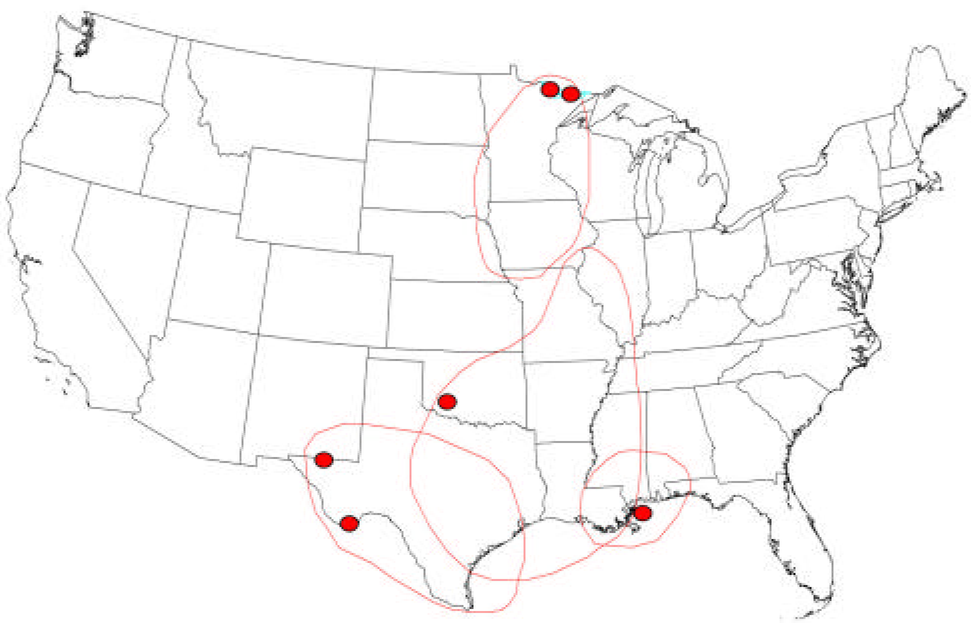


Figure ES-1. Level I Areas of Influence (AOI-1) for Sulfate associated with the Big Bend, Guadalupe, Wichita Mountains, Breton Island, Voyageur, and Boundary Waters Class I Areas.

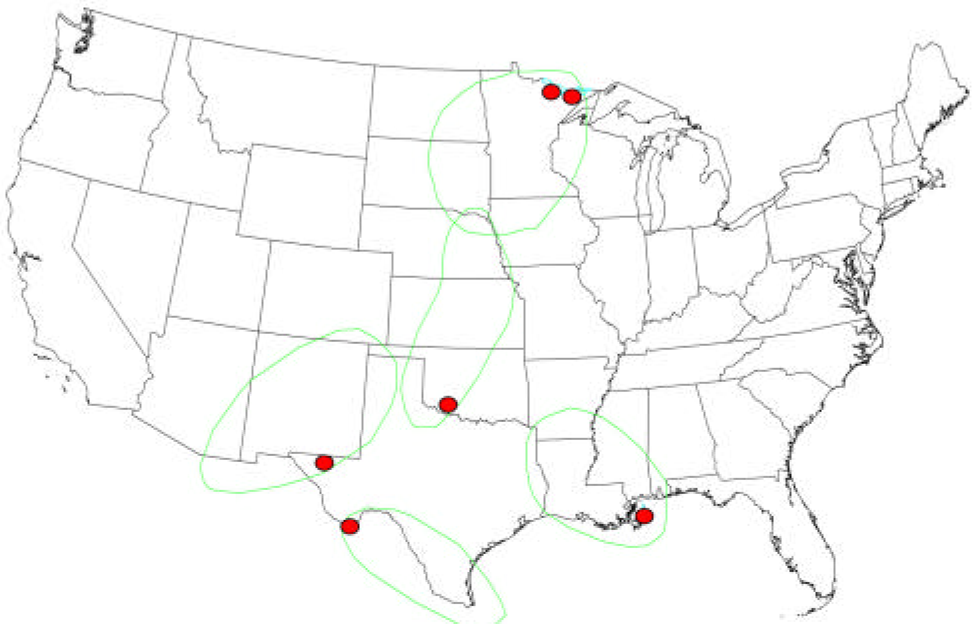


Figure ES-2. Level I Areas of Influence (AOI-1) for Nitrate Associated with the Big Bend, Guadalupe, Wichita Mountains, Breton Island, Voyageur, and Boundary Waters Class I Areas.

1.0 INTRODUCTION

The Implementation and Control Strategies (ICS) Workgroup of the Central Regional Air Planning Association (CENRAP), together with other workgroups and state, tribal and federal agencies, have worked for more than four years in developing the foundation for constructing regional haze (RH) control strategies for pertinent Class I areas (Table 1-1) within and adjacent to the CENRAP states and tribes (Seltz, 2006a,b; Anderson; 2005; Sharp and Anderson, 2005). In late February 2006, Alpine Geophysics, LLC (AG) was contracted to assist the ICS in these ongoing efforts. Specifically, using information developed by the ICS and others, AG was charged with developing a quantitative procedure to identify and prioritize potential RH control strategies to be tested by CENRAP modelers. Alpine formulated a methodology for constructing control strategy recommendations based on presently available information and submitted a Work Plan detailing this approach to the ICS/CENRAP leadership for review (Tesche and Stella, 2006).

Table 1-1. Class I Areas Addressed in this Study.

RPO	Class I Area	ST	Name
CENRAP	Big Bend Nat'l Park	TX	BIBE
CENRAP	Boundary Waters	MN	BWCA
CENRAP	Breton Island	LA	BRET
CENRAP	Caney Creek	AR	CACR
CENRAP	Guadalupe Mountains	TX	GUMO
CENRAP	Hercules-Glades	MO	HEGL
CENRAP	Mingo	MO	MING
CENRAP	Upper Buffalo	AR	UPBU
CENRAP	Voyageurs	MN	VOYA2
CENRAP	Wichita Mountains	OK	WIMO
VISTAS	Mammoth Cave	KY	MACA
VISTAS	Sipsey Wilderness	AL	SIPS
MRPO	Isle Royale	MI	ISLE
WRAP	Badlands	SD	BADL
WRAP	Great Sand Dunes	CO	GRSA
WRAP	Lostwood Wilderness	ND	LOST
WRAP	Rocky Mtn Nat'l Park	CO	ROMO
WRAP	Salt Creek	NM	SACR
WRAP	Theodore Roosevlt	ND	THRO
WRAP	Wheeler Peak	NM	WHPE
WRAP	White Mountain	NM	WHIT
WRAP	Wind Cave	SD	WICA

Based on comments received, the approved Work Plan was implemented, culminating in the quantitative methodology for identifying potentially viable regional haze control strategies for the CENRAP states and tribes. Using the most pertinent aerometric, emissions and air quality modeling data available, we implemented this methodology and, in this report, present a set of recommendations for regional haze precursor emissions reduction strategies. These recommendations, once reviewed and refined by the ICS and Modeling workgroup, will be passed on to the CENRAP Emissions and Air Quality Modeling contractors (ENVIRON International Corporation and the University of California, Riverside) for quantitative testing with the SMOKE/CMAQ/CAMx regional modeling systems.

To facilitate subsequent use of this methodology, this report describes the various analytical steps and provides examples (both in the body of the report and in supporting appendixes). In addition, relevant technical support information, data sets, and analysis software have been supplied to CENRAP for posting on their project website for access by interested parties.

1.1 Study Overview

Preliminary (Typ02a) and more recent (Typ02b) modeling projections from the CMAQ Base18b/Typ02 scenarios (Morris et al., 2006b) have indicated that some Class I areas within or near the CENRAP domain may achieve the 2018 Reasonable Progress Goals (RPG) under current 'on-the-books' and 'on-the-way' controls while others may not unless additional emissions reductions are implemented (see Figures 1-1 and 1-2). As shown in Figure 1-1, six CENRAP Class I Areas (Big Bend, Guadalupe, Wichita Mountains, Breton Island, Voyageur, and Boundary Waters) are projected, by the latest CMAQ modeling, to have somewhat higher visibility metrics (deciviews) when compared to the 2018 RPG glide paths. While Boundary Waters does not explicitly appear in Figure 1-1 due to data base insufficiencies, recent modeling by various RPOs suggests that Boundary Waters responds similarly to Voyageurs. Accordingly, it is thus included as one of the six projected Class I areas where additional precursor controls might be considered by CENRAP/ICS.

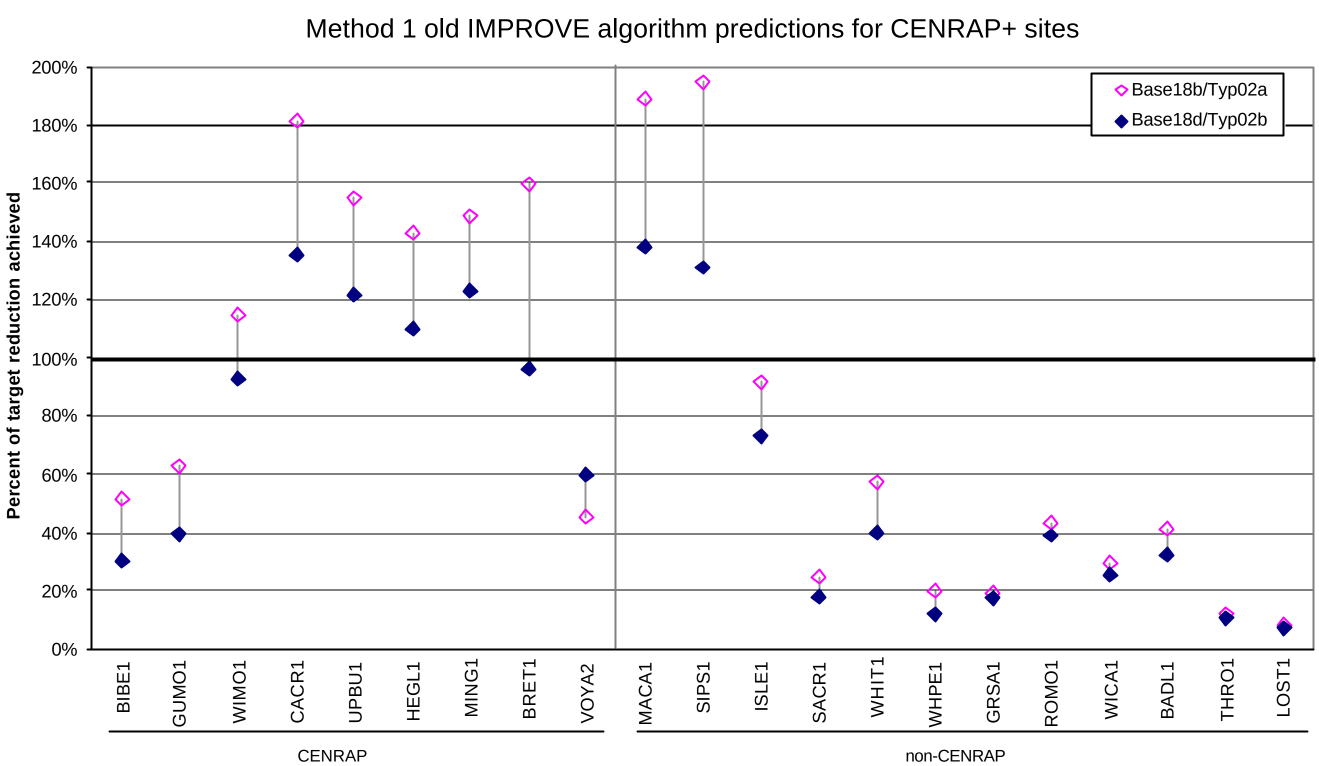


Figure 1-1. Current Visibility Projections (Base 18d/Typ02b) at CENRAP and Other Class I Sites (Source: Morris et al., 2006b).

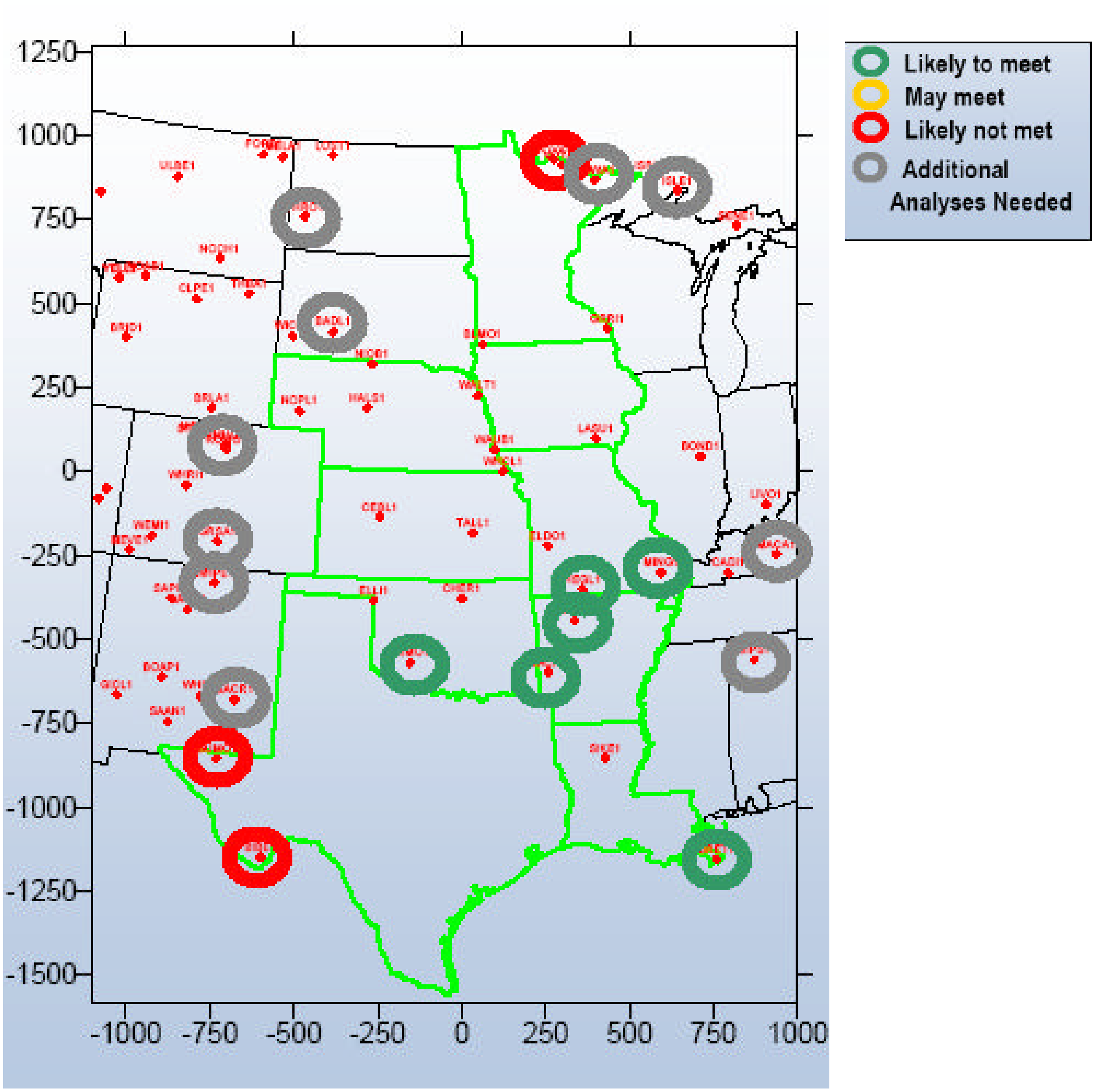


Figure 1-2. Preliminary Visibility Projections by State (Source: Morris et al., 2006b)

To prepare for the modeling of potential additional control strategies, an intensified effort has been undertaken by the ICS work group over the past two years to 'set the stage' for this activity (see for example ICS, 2005, Seltz, 2006). Consonant with these plans and on behalf of CENRAP, the ICS workgroup seeks to integrate focused contractor support with ongoing workgroup activities to accomplish the following objectives:

- Analyze existing regional haze modeling inventories developed by CENRAP, the States, tribes, and other RPOs;
- Synthesize available and pertinent air quality and meteorological data and recent 'attribution of haze studies' by CENRAP and the other RPOs;
- Review preliminary 2018 RPG modeling by CENRAP and other RPOs to identify the key Class I areas for which additional emissions reductions may be needed;
- Develop a prioritized set of regional and subregional precursor emissions control scenarios aimed at achieving the RPG at the CENRAP Class I areas; and
- Monitor the initial 2018 control strategy modeling performed by the CENRAP modeling team to ascertain whether subsequent strategies need to be refined or new strategies developed.

The project Work Plan (Tesche and Stella, 2006) describes in detail how these objectives have been addressed in cooperation with ICS and CENRAP.

1.2 Approach, Assumptions, and Constraints

Development of recommendations for potential CENRAP regional haze control strategy simulations was a three-step process. First, we assembled available information useful in quantifying the reductions in fine particulate aerosol concentrations needed to satisfy CENRAP's preliminary regional haze visibility projections. Naturally, the principal focus was on the Class I areas within the CENRAP region that were estimated to not meet the 2018 Reasonable Further Progress (RFP) glide paths. Based on preliminary and more recent modeling (Morris et al., 2006b), some Class I areas did meet the 2018 RFP glide paths while others did not. As new visibility projections for the Class I areas become available, the ICS may wish to re-examine this study's strategy recommendations in order to account for more up-to-date estimates.

The second step involved developing Areas of Influence (AOIs) upwind of each Class I area within which common 'visibility precursor-Class I receptor' impacts could be aggregated into similar groupings. We used results of numerous statistical and pattern recognition studies, as well as pertinent regional photochemical aerosol modeling by Alpine and ENVIRON scientists as well as other groups (including the RPOs). These analyses culminated in quantitative 'rules of thumb' relating emissions reductions of visibility-impairing precursors (in tons/day) to ambient aerosol concentrations at each of the ten (10) CENRAP Class I monitors. We also developed these quantitative source-receptor relationships for a dozen Class I areas in adjoining RPOs to the extent possible give available data, project resources and schedule. As of this writing, CENRAP Modeling contractors are still performing focused particulate source apportionment modeling (CAMx PSAT) over the region. Once this work is completed, the ICS may wish to re-examine our methodology and strategy recommendations to determine if refined source-receptor relationships alter in any way our present findings and conclusions.

The third step synthesized the results of the first two, together with information on the estimated 2018 CENRAP emissions inventory and the cost-effectiveness of various controls, to deduce a prioritized set of RH control strategies containing elements of both regional emissions reductions and targeted reductions within the AOIs closest to those six CENRAP Class I areas for which positive visibility increments were estimated (Morris et al., 2006b). We used the most up-to-date modeling inventory supplied by the CENRAP Modeling contractor; however, the current round of inventory corrections and refinements will undoubtedly lead to refined emissions data sets in coming months. Thus, another constraint limiting the 'shelf-life' of this study's recommendations is the accuracy and representativeness of the draft 2018 emissions data used in developing this plan's precursor emissions control recommendations.

While project work scope precluded re-running the strategy development process described in this report with updated CAMx/PSAT and CMAQ visibility projections expected in late May or early June 2006, the methodological tools are cataloged and archived should the ICS wish to undertake this activity at a later time.

1.3 Structure of Report

This report is organized as follows. Section 2 provides a brief background on the Regional Haze Rule (RHR) and the role that CENRAP and the other RPOs are playing in developing strategies that will show progress in meeting Reasonable Progress Goals by 2018. We also discuss key considerations that influence the design of regional and subregional control strategies in the context of the RHR. Our technical approach is summarized in Section 3. Details of our methodology are given in the Work Plan (Tesche and Stella, 2006a). In Section 4 we describe the information available to characterize the daily and annul composition of $PM_{2.5}$ constituents (sulfate, nitrate, elemental carbon, etc) at the various IMPROVE monitors in the CENRAP and adjoining Class I Areas. We also describe the method to relate the modeled deciview (dv) or extinction coefficient (Mm^{-1}) – derived from the most recent CENRAP visibility projection modeling – to the fine particulate component concentrations at each Class I area expressed in units of mass per unit volume (i.e., $\mu g/m^3$).

Section 5 presents the quantitative methods for converting these concentration increments (whose reductions will likely achieve the individual Class I areas visibility goals by 2108) to mass emissions rate reductions for the primary particulate aerosol precursors, NO_X and SO_2. In addition, the section describes the methods used to construct Area of Influence (AOI) domains surrounding each Class I area based on historical data analysis, statistical pattern recognition studies, and various photochemical and aerosol modeling studies performed throughout the eastern U.S. by Alpine, ENVIRON, state, tribal and federal regulatory agencies, the Southern

Appalachian Mountains Initiative (SAMI), the RPOs, and university scientists[4]. In Section 6, the information developed in the two preceding chapters is used, together with original analyses of the 2018 regional haze inventories and control technology cost-effectiveness information, to construct a series of curves from which quantitative estimates of suggested precursor emissions controls (within specific AOIs) are developed for each Class I Area in CENRAP projected above the reasonable progress glide path in 2018. Our summary and recommendations are presented in Section 7.

1.4 Technical Support Resources

Several technical appendixes and support documents are provided to accommodate the extensive tabular and graphical information underpinning our methodology. Some appendixes constitute simple tabular data or emissions summaries (in Excel format) while other appendixes contain information in PowerPoint or Adobe Acrobat formats. Finally, the study's Work Plan, Final Report, Technical Support Documents (i.e., the appendixes and other materials), and a compilation of science reports, professional papers and journal articles have been transferred to CENRAP for uploading to their project ftp site.

[4] The AOI methodology was carried out by Dr. Jim Wilkinson of Alpine whose recent Ph.D. original research and Dissertation from Georgia Tech focused on the development of the AOI methodology for regional haze, ozone, and $PM_{2.5}$ control strategy modeling in the eastern U.S.

2.0 CONTEXT FOR REGIONAL HAZE STRATEGY DEVELOPMENT

Section 169A of the Clean Air Act (CCA) sets forth a national goal for visibility which is the "prevention of any future, and the remedying of any existing, impairment of visibility in Class I areas which impairment results from manmade air pollution." In 1999, EPA published a final rule to address a type of visibility impairment known as regional haze (64 FR 35714). The Regional Haze Rule (RHR) requires States to submit implementation plans (SIPs) to address regional haze visibility impairment in federally-protected parks and wilderness areas (i.e., the Class I scenic areas identified in the Clean Air Act). The 1999 rule was issued to fulfill a long-standing EPA commitment to address regional haze under the authority and requirements of sections 169A and 169B of the CAA. In essence, the RHR prescribes that states are to make efforts to improve visibility in 156 Class I areas at such rates that "natural conditions" would be achieved in each area by 2064. A 'reasonable rate of progress' corresponds to linear improvement in visibility, as characterized in units of deciview (dv), between current conditions during the base period of 2000-2004 and natural conditions at the end point of 2064. It is important to note that a modeled 2018 visibility condition at a Class I monitor – numerically equaling the monitor's RPG goal – is not meant to imply 'attainment' of any standard nor is lesser modeled progress in reaching a particular RPG indicative of 'nonattainment'. Indeed, as will be discussed later, progress in attaining visibility improvements at some CENRAP monitors (in Texas and Minnesota) may be thwarted by substantial contributions of visibility precursors from Mexico and Canada over which the States and Tribes have no direct control.

2.1 Role of CENRAP and the Other Regional Planning Organizations (RPOs)

CENRAP is one of five Regional Planning Organizations (RPOs) that have responsibility for coordinating development of State Implementation Plans (SIPs) and Tribal Implementation Plans (TIPs) in selected areas of the U.S. to address the requirements of the Regional Haze Rule (RHR). The RHR visibility SIPs/TIPs are due in 2007/2008. CENRAP modeling results may also form the regional component for 8-hour ozone and fine particulate ($PM_{2.5}$) SIPs/TIPs that are also expected to be due in 2007/2008. CENRAP is a regional partnership of states, tribes, federal agencies, stakeholders and citizen groups established to initiate and coordinate activities associated with the management of regional haze and other air quality issues within the CENRAP states. The CENRAP region includes states and tribal lands located within the boundaries of Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, Oklahoma and Texas.

The regional emissions and fine particulate/visibility modeling for CENRAP is being performed by the Emissions and Air Quality Modeling Contractor that is comprised of staff from ENVIRON International Corporation (ENVIRON) and the University of California, Riverside (UCR). The ENVIRON/UCR team performs the emissions and air quality modeling simulations for states and tribes within the CENRAP region, providing analytical results used in developing implementation plans under the EPA Regional Haze Rule. Alpine Geophysics serves as the Technical Advisor to CENRAP, working interactively with the emissions and air quality modelers at ENVIRON and UCR.

2.2 Considerations in Designing Regional Haze Control Strategies

Where the year 2018 base case modeling does not show an acceptable regional haze or visibility glide slope for a Class I area within or adjacent to the CENRAP domain, additional (and possibly substantial) emission reductions will most likely be required to show reasonable progress in meeting 2108 visibility goals. Due to the unique location, meteorology, and emission sources within an area of influence to each Class I area, individualized control strategies reducing emissions from the remaining residual sources or source types are most likely to achieve required results. It is highly unlikely that a single cost effective "across-the-board" reduction strategy will achieve the visibility goals for every Class I area.

Although emissions located within areas of direct proximity to Class I area monitors will generally have the greatest influence on attaining visibility goals, these sources may not be the only ones with significant impact on the air quality. Using methods such as localized geography analysis (e.g., within 200km of Class I area boundaries) to initially identify source types and pollutants with the greatest influence will only provide part of the picture. In reality, other methods will also provide information related to transport sources impacting a Class I area. These other methods can include back trajectory analysis, residence time probability, source apportionment modeling (PSAT, OSAT, TSSA), and the cause of haze (COH) studies performed in the past two years by the various RPOs including CENRAP. Other geographic studies, such as identifying sources that have an impact on more than one Class I area are also warranted. These methods can also help to limit or refine geography, pollutants, or source categories of interest for additional reduction potential in each Class I area.

Using these techniques in addition to review of the future year base case emissions inventories and assigned control strategies will allow CENRAP and the ICS Workgroup to further define incremental reduction allowing for the attainment of Class I area air quality or visibility objectives.

2.3 Resources Available to this Study

The reference section of this report and the technical discussions in Sections 4 through 6 identify the major data bases, reports, modeling output files and other resources used in this study. Certain regional modeling and data analysis studies performed by the RPOs and their contractors were particularly useful in developing source-receptor relationships for the various Class I areas. These include: (a) the recent (25 April 2006) visibility projections for the CENRAP and adjoining RPOs recently described by Morris et al. (2006b), (b) monitoring information for the various Class I areas of interest, summarized on the IMPROVE website, and (c) the most recent 2018 SMOKE emissions inventory developed for CENRAP by various state, tribal and federal agencies and contractors.

3.0 TECHNICAL APPROACH

As described in the Work Plan (Tesche and Stella, 2006b), our technical approach consisted of six (6) tasks which are summarized briefly here to provide background for the more detailed technical discussions given in subsequent chapters.

Task 1: Synthesize Relevant Regional Haze Aerometric Analyses: The objective of Task 1 was to synthesize pertinent 'attribution of haze' documents, CENRAP CAMx/CMAQ visibility modeling results, and other technical reports, papers, and analyses bearing directly on the quantification of emissions-source/visibility-receptor impacts at the 10 CENRAP Class I areas and adjoining areas. This Task was aimed at quantifying what is known about source-receptor relationships at the 10 CENRAP Class I areas on the basis of emissions, air chemistry and meteorological statistical analyses and receptor modeling studies.

Task 2: Review Existing Inventories and Control Scenario Strategy Options: This involved a concise summarization of existing regional haze modeling inventories and associated local, State, Tribal and Federal control programs to determine available incremental controls on sources or source types affecting visibility increments (i.e., differences between the modeled 2018 visibility level and the RFP glide slope for the particular Class I Area). In addition, we attempted to confirm future year control plans and reduction scenarios necessary to accomplish incremental reduction analysis. The product of this effort was a set of suggestions for alternate incremental control strategies based on analysis of available emissions, monitoring, and modeled data.

The Task 2 review was conducted in a top down fashion starting with an analysis of the major source categories in the domains of interest (based on results from Tasks 1 and 3) to determine which major categories have the highest residual contribution to the area. Once the highest source types were identified, subcategories within those source types were reviewed. In addition to reviewing the residual emission categories in the future year base, we also identified reductions that have already occurred within each category or at specific units. This allows CENRAP to determine if certain source categories that have yet to be controlled under the base case have the potential for reduction or if source types already reduced have reached the full cost-effective potential. Finally, unit level tables of emission comparisons from 2002 to 2018 were developed that facilitate ICS's review of existing emission reductions and the assignment of new cost-effective controls to units using the best control for the scenario.

Once the list of potential sources available for reduction were identified, we used relevant control strategy information extracted from EPA's AirControlNET (Pechan, 2005) and other sources to further define the most cost-effective strategies for these sources. Since AirConrolNET does not allow for the interactive processing of new inventories (it comes preconfigured with inventories and control strategies applied), this extract was performed outside of the AirConrolNET model to assign incremental control programs. Finally, we ran every accessible control strategy against the identified source list to develop incremental cost curves necessary to design command and control or cost-effectiveness based control strategies by source or domain. This master list of controls was then used in the development of our final control strategy recommendations.

Task 3: Synthesize Relevant Regional Haze Source Attribution Modeling: Complementing Task 1, work under Task 3 was aimed at synthesizing key results from recent regional modeling studies helpful relating emissions reductions of visibility precursors (e.g. SO_2, NO_X) in upwind source regions to the improvement in visibility (in deciviews or, alternatively, in Mm^{-1}) at downwind Class I. More specifically, we attempted to extract from available regional modeling studies useful 'rules of thumb' relating percentage or tonnage reductions in visibility reducing precursors (e.g., SO_2, NO_X, ammonia, and VOCs) on the expected impact on visibility downwind. These 'rules of thumb' or source-receptor relationships were essential in estimating the amounts of precursor emissions to be reduced in regions upwind of each of the various Class I areas.

Task 4: Develop CENRAP Control Strategy Plan: The objective of Task 4 was to assemble the findings and technical work products from Tasks 1 through 3, supplemented with any additional information provided by the ICS Workgroup or CENRAP Modeling contractors, and construct the CENRAP Control Strategy Plan. As described in subsequent chapters, this plan addresses feasible regional haze control strategies with each one including both regional and sub-regional elements.

More specifically, using the results of the most recent CENRAP visibility projection modeling (Morris et al., 2006b), we identified six Class I areas that potentially require additional regional and/or subregional incremental emission reductions to achieve reasonable progress visibility goals. Once an emissions reduction target was determined for each Class I area, we used the master list of controls developed in Task 2 to formulate the CENRAP Control Strategy plan, including cost-effectiveness as a key element. This plan identifies specific source categories (e.g., SIC, SCC, plant ID), and emissions reductions to be implemented. The specificity of the prescribed control scenarios recommended in the plan is sufficient to allow the CENRAP modeling contractors to readily implement the suggested changes through the SMOKE model input stream.

The CENRAP Control Strategy Plan is intended to identify the specific sources and/or source categories where additional control is available with emphasis on known incremental reductions first (e.g., BART). Using this plan as a starting point, CENRAP is equipped to assess the present strategy recommendations and identify any new assumptions (recent or new facility configurations, updated control strategy information from the states and tribes), emergent data sets (e.g., CAMx PSAT modeling; updated 2018 CMAQ visibility projections), corrected modeling inventories, and so on that were unavailable during the three-week time period when this plan was developed.

Task 5: Review Control Strategy Plan With ICS: The project team participated in a teleconference call on 13 April 2006 with the CENRAP ICS Workgroup to discuss the study methodology, findings, and recommendations.

Task 6: Final Report: To the maximum extend feasible within this project's work scope, we incorporated written responses from CENRAP on the 10 April draft report, culminating in this final document.

4.0 ESTIMATION OF RESIDUAL VISIBILITY IMPROVEMENT NEEDS

The estimation of residual visibility improvement needs (i.e., the aerosol species concentration reductions [mass per unit volume] at each Class I monitor) was performed through three activities: (a) literature review and synthesis, (b) analysis of current CMAQ visibility projections and IMPROVE measurements at the Class I sites, and (c) integration of this information into a computational scheme for use in later tasks.

4.1 Literature Review and Synthesis of Pertinent Source-Receptor Information

Our synthesis of *existing* source-receptor information for the CENRAP and adjacent Class I area was guided by the following set of questions for which specific answers were sought in recent reports, papers, RPO and science meeting presentations, as well as recent one-atmosphere modeling studies. These core questions include:

> **What aerosol components are responsible for haze?**

- What are the major components for best, worst and average days visibility days across the CENRAP domain and how do they compare?
- How variable are they episodically, seasonally, inter-annually?
- What site characteristics best group sites with similar patterns of major components?
- How do the relative concentrations of the major components compare with the relative emission rates nearby and regionally?

> **What is meteorology's role in the causes of haze?**

- How do meteorological conditions influencing the CENRAP Class I areas differ for best, worst and typical haze conditions?
- What empirical relationships are their between meteorological conditions and haziness?
- How well can haze conditions be predicted solely using meteorological factors?
- What characteristics best group CENRAP Class I sites with similar relationships between meteorological conditions and haze?
- How well can inter-annual variations in haze be accounted for by variations in meteorological conditions at the CENRAP Class I areas?

> **What are the emission sources responsible for haze?**

- What geographic areas are associated with transported air that arrives at sites on best, typical and worst haze days in the CENRAP region?
- Are the emission characteristics of the transport areas consistent with the aerosol components responsible for haze?
- What do the aerosol characteristics on best, typical and worst days indicate about CENERAP or upwind emissions sources?
- What does the spatial and temporal pattern analysis indicate about the locations and time periods associated with sources responsible for haze?
- What evidence is there for urban impacts on haze at the CENRAP Class I areas and what is the magnitude and frequency when evident?

- What connections can be made between sample periods with unusual species concentrations and activity of highly sporadic sources (e.g. major fires, dust storms)?
- What can be inferred about impacts from sources in other states, other RPOs and other countries, particularly Mexico and Canada?
- What refinements to default natural haze levels can be made using ambient monitoring and emission data?

> **Are there detectable and/or statistically significant multi-year trends in the causes of haze?**
- Are the aerosol components responsible for haze changing?
  Where changes are seen, are they the result of meteorological or emissions changes?
- Where emissions are known to have changed, are there corresponding changes in haze levels?

With these questions in mind, we surveyed the literature relevant to the CENRAP Class I areas in order *to summarize*:

> **Characteristics of Each CENRAP Monitoring Site**
- Their representation of the Class I area and nearby Class I areas;
- Relationship to terrain features, bodies of water, etc;
- Proximity to major point sources, cities, etc.

> **Meteorological Characteristics of Each CENRAP Monitoring Site**
- Expected mesoscale flow patterns of interest (sea/land breeze, mountain/valley winds, convergence zones, nocturnal jets, etc.);
- Orographic precipitation patterns (i.e. favored for precipitation, or in rain-shadow);
- Inversion layers;
- Potential for transport from cities and other significant sources/source areas.

> **Visibility-Aerosol Related Data Analyses**
- Descriptive statistics and interpretation for aerosol data- individual components and reconstructed extinction
- Key aerosol species component spatial and seasonal patterns (e.g., Best 20%, middle 60%, worst 20% reconstructed extinction days and seasonal patterns by site)
- Spatial and seasonal patterns of aerosol components frequency distributions.
- Aerosol component data in light of emissions sources, monitoring site settings, back trajectories
- Results of cluster, CART, and other pattern-recognition analyses to group sites with similar patterns in aerosol component contributions to haze

> **Back Trajectory Analyses**
- Results of back trajectory end point data for each CENRAP Class I area;
- Back trajectory summary statistics residence time by season, best 20% and worst 20% reconstructed extinction and aerosol components for all CENRAP Class I areas;
- Conditional probability maps for high and low extinction and aerosol components.
- Results of emissions density maps giving location information, site setting information, etc., and
- Mesoscale meteorological analyses complementing back trajectories.

Of course, complete answers to all these questions could not be developed in the course of this three week study; however, sufficient information was available that, when distilled into key tabular and graphical summaries, provided a solid foundation for continued efforts in Task 1 and especially Task 2 (discussed in Section 5). Key reports and modeling summaries synthesized during this initial review were supplied to CENRAP for uploading onto the CENSARA project website for easy access by interested CENRAP workgroup members or stakeholders.

4.2 Preliminary Visibility Estimates for Class I Areas

The visibility projection estimates for 2018 available at the time this study was performed (Typ02a) were developed in early 2006 by ENVIRON/UCR and presented at the February CENRAP meetings in Baton Rouge, LA. Appendix B presents these <u>preliminary</u> visibility projections for the ten (10) CENRAP Class I areas and the twelve (12) outlying Class I areas in the WRAP, MRPO, and VISTAS domains. After the draft report had been prepared, Morris et al., (2006b) published an updated set of visibility projections (Typ02b). Given the importance of using the most up to date projections possible, where feasible we repeated our technical work using the <u>updated projections</u> (See Table 1-1 for a visual comparison of the differences). Table 4-1 lists the following information derived from these more recent CENRAP projections of Morris et al., (2006b).

> Visibility (in dv) on the 20% worst days in 2002;

> The 2000-2004 visibility baseline (in dv);

> The 2018 visibility goal (in dv) based on the requirements of the Regional Haze Rule;

> The CMAQ-forecasted 2018 visibility levels on the 20% worst days;

> The 'increment' in visibility, expressed in dv (calculated as the difference between the 2018 goal and the 2018 forecast. Negative values (presented in red in Table 2) denote that additional visibility improvement needed to achieve the desired 2018 progress goal; and

> The 'increment' in visibility, expressed in units of inverse mega-meters (Mm^{-1}).

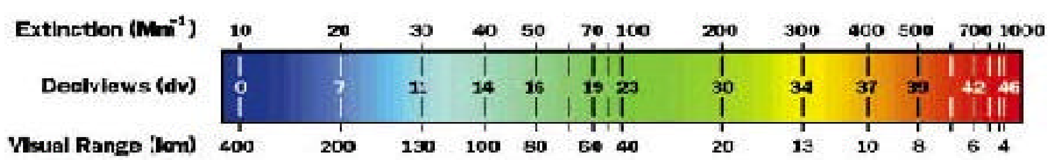
Table 4-1. Reasonable Progress Goal Estimates and 'Increments'.

RPO	Class I Area	ST	Name	W20% Bkgrnd DV	2000/2004 Baseline DV	2018 Goal DV	2018 Forecast DV	Deciview Incre DV	Ext Incre Mm-1	Annual f(RH)
CENRAP	Big Bend Nat'l Park	TX	BIBE	6.93	17.10	14.73	16.39	1.66	7.9	2.1
CENRAP	Boundary Waters	MN	BWCA	11.21	18.30	16.62	17.54	0.92	5.1	3.3
CENRAP	Breton Island	LA	BRET	11.53	25.59	22.31	22.45	0.14	1.3	3.8
CENRAP	Caney Creek	AR	CACR	11.33	25.34	22.07	20.91	-1.16	-10.0	3.2
CENRAP	Guadalupe Mountains	TX	GUMO	7.02	17.48	15.04	16.53	1.49	7.2	1.8
CENRAP	Hercules-Glades	MO	HEGL	11.27	25.63	22.28	21.94	-0.34	-3.1	3.1
CENRAP	Mingo	MO	MING	11.27	26.49	22.94	22.13	-0.81	-7.7	3.2
CENRAP	Upper Buffalo	AR	UPBU	11.28	25.31	22.03	21.33	-0.70	-6.1	3.1
CENRAP	Voyageurs	MN	VOYA2	11.09	18.46	16.74	17.43	0.69	3.8	3.4
CENRAP	Wichita Mountains	OK	WIMO	11.07	23.06	20.26	20.47	0.21	1.6	2.6
VISTAS	Mammoth Cave	KY	MACA	11.53	29.94	25.65	24.01	-1.64	-19.7	3.2
VISTAS	Sipsey Wilderness	AL	SIPS	11.39	27.71	23.91	22.72	-1.19	-12.3	3.3
MRPO	Isle Royale	MI	ISLE	11.22	20.28	18.16	18.74	0.58	3.7	3.5
WRAP	Badlands	SD	BADL	7.30	17.00	14.74	16.37	1.63	7.7	2.6
WRAP	Great Sand Dunes	CO	GRSA	7.10	13.20	11.78	12.96	1.18	4.1	2.0
WRAP	Lostwood Wilderness	ND	LOST	7.33	19.49	16.66	19.28	2.62	15.8	2.9
WRAP	Rocky Mtn Nat'l Park	CO	ROMO	7.05	14.15	12.49	13.51	1.02	3.7	2.1
WRAP	Salt Creek	NM	SACR	6.99	18.05	15.47	17.59	2.12	11.1	1.8
WRAP	Theodore Roosevlt	ND	THRO	7.31	17.66	15.24	17.40	2.16	11.1	3.7
WRAP	Wheeler Peak	NM	WHPE	7.04	11.26	10.27	11.14	0.87	2.5	1.9
WRAP	White Mountain	NM	WHIT	6.98	14.06	12.41	13.40	0.99	3.6	1.8
WRAP	Wind Cave	SD	WICA	7.24	15.81	13.81	15.30	1.49	6.4	2.5

The relationship between deciviews (dv) and inverse megameters (Mm^{-1}) is described in detail by Malm, (1999). Equation 4-1 defines the Haze Index (HI):

$$HI = 10 \ln(b_{ext}/10) \qquad (4\text{-}1)$$

where *HI* is the haze index (deciviews [dv]) and b_{ext} is the light extinction coefficient (Mm^{-1}). Thus, one deciview is approximately equal to 11.05 Mm^{-1} and a change of one dv represents a change of approximately ten percent in b_{ext}, "which is a small but perceptible scenic change under many circumstances". Malm (1999) provides the following graphical representation between the extinction (Mm^{-1}), deciviews, and visual range (km):



The measured light extinction at the Class I areas for the 20% worst days each year are available at http://vista.cira.colostate.edu/views/web/AnnualSummaryDev/Composition.aspx, the IMPROVE site. The most recent measured extinction values (in Mm^{-1}) for the various Class I monitors are listed in Table 4-2, presented in Figure 4-1, and also given in Appendix B. For the most part, IMPROVE extinction measurements for the 20% worst days are available for 2004, the most recent year analyzed. These data are presented as extinction totals for the individual visibility-impairing chemical species: sulfate; nitrate; organic mass; elemental carbon; soil; and coarse mass. Table 4-3 lists the fractional extinction for each chemical species. Finally, the IMPROVE data for each species at the 22 Class I monitors are presented as a function of time in the appendices to this document. These time series plots reveal the seasonal and daily variation in the visibility-impairing components throughout the year at teach site. Figures 4-2 and 4-3 present the absolute and fractional extinction values listed in Tables 4-2 and 4-3 in the form of stacked bar charts for ease of comparison.

Table 4-2. Measured Extinction at Class I Areas.

				Measured Extinction (Mm^{-1}) on 20% Worst Days in 2004						
					Amm	Organic	Elem	Soil	Coarse	
RPO	Class I Area	ST	Name	Sulfate	Nitrate	Mass	Carbon	Mass	Mass	Total
CENRAP	Big Bend Nat'l Park	TX	BIBE	25.86	1.57	5.85	1.80	2.21	4.55	41.84
CENRAP	Boundary Waters	MN	BWCA	28.09	24.78	7.76	2.94	0.44	2.10	66.11
CENRAP	Breton Island	LA	BRET	65.60	8.49	6.13	4.26	0.40	4.45	89.33
CENRAP	Caney Creek	AR	CACR	65.68	15.43	17.95	4.27	0.79	2.66	106.78
CENRAP	Guadalupe Mountains	TX	GUMO	15.92	4.98	5.51	1.30	2.83	9.99	40.53
CENRAP	Hercules-Glades	MO	HEGL	67.23	21.92	21.14	5.12	0.88	2.85	119.14
CENRAP	Mingo	MO	MING	80.44	35.11	26.10	8.95	1.55	8.40	160.55
CENRAP	Upper Buffalo	AR	UPBU	64.43	17.39	16.47	4.48	0.90	7.23	110.90
CENRAP	Voyageurs	MN	VOYA2	10.16	15.14	9.94	2.68	0.46	2.84	41.22
CENRAP	Wichita Mountains	OK	WIMO	40.78	28.25	16.64	4.67	0.70	4.06	95.10
VISTAS	Mammoth Cave	KY	MACA	146.48	10.78	15.58	5.33	1.04	1.76	180.97
VISTAS	Sipsey Wilderness	AL	SIPS	109.27	8.09	20.22	7.06	0.95	2.66	148.25
MRPO	Isle Royale	MI	ISLE	33.33	12.64	9.71	2.93	0.48	3.51	62.60
WRAP	Badlands	SD	BADL	20.05	6.58	7.53	1.55	0.75	3.60	40.06
WRAP	Great Sand Dunes	CO	GRSA	6.20	2.78	6.44	1.30	2.11	3.78	22.61
WRAP	Lostwood Wilderness	ND	LOST	28.44	26.00	9.02	2.22	0.41	2.73	68.82
WRAP	Rocky Mtn Nat'l Park	CO	ROMO	8.19	4.73	6.37	2.00	1.11	2.78	25.18
WRAP	Salt Creek	NM	SACR	17.74	12.42	7.04	2.24	4.18	6.08	49.70
WRAP	Theodore Roosevlt	ND	THRO	15.68	16.28	9.95	2.52	0.55	2.99	47.97
WRAP	Wheeler Peak	NM	WHPE	5.69	1.26	4.98	2.05	1.59	1.29	16.86
WRAP	White Mountain	NM	WHIT	8.77	2.49	8.52	2.11	1.58	3.81	27.28
WRAP	Wind Cave	SD	WICA	14.27	8.91	8.35	3.17	0.79	2.08	37.57

4.3 Estimation of Visibility-Impairing Concentration Increments

The information in Tables 4-1 through 4-3 as well as other data provided in the appendices of this document was used to estimate the extent to which additional visibility-impairing precursor emissions reductions might be needed on the basis of current estimates of the projected positive increments and the chemical composition of fine particulate aerosol at the six CENRAP Class I monitors on the worst 20% days. The next step was to transform the visibility increment estimates into concentration increment estimates based on current IMPROVE algorithms. Using the modeled visibility increment (Mm^{-1}) estimates and annual f(RH) values (Table 4-1) together with the measured sulfate, nitrate, OC, EC, soil, and course mass fractions from the IMPROVE Class I monitors (Tables 4-2 and 4-3), we deduced the atmospheric concentrations of the six species groups ($\mu g/m^3$) using the standard IMPROVE equation (EPA, 2003). These concentrations were calculated assuming: (a) the required concentration reductions would be met by each precursor in proportion to the most recent IMPROVE distribution at each Class I monitor (Table 4-4); and (b) the concentration reductions would be met by each precursor individually (Table 4-5).

Table 4-3. Extinction Fraction for 20% Worst Days by Class I Area.

				Extinction Fraction for 20% Worst Days by Class I Area					
				Amm	Amm	Organic	Elem	Soil	Coarse
RPO	Class I Area	ST	Name	Sulfate	Nitrate	Mass	Carbon	Mass	Mass
CENRAP	Big Bend Nat'l Park	TX	BIBE	0.62	0.04	0.14	0.04	0.05	0.11
CENRAP	Boundary Waters	MN	BWCA	0.42	0.37	0.12	0.04	0.01	0.03
CENRAP	Breton Island	LA	BRET	0.73	0.10	0.07	0.05	0.00	0.05
CENRAP	Caney Creek	AR	CACR	0.62	0.14	0.17	0.04	0.01	0.02
CENRAP	Guadalupe Mountains	TX	GUMO	0.39	0.12	0.14	0.03	0.07	0.25
CENRAP	Hercules-Glades	MO	HEGL	0.56	0.18	0.18	0.04	0.01	0.02
CENRAP	Mingo	MO	MING	0.50	0.22	0.16	0.06	0.01	0.05
CENRAP	Upper Buffalo	AR	UPBU	0.58	0.16	0.15	0.04	0.01	0.07
CENRAP	Voyageurs	MN	VOYA2	0.25	0.37	0.24	0.07	0.01	0.07
CENRAP	Wichita Mountains	OK	WIMO	0.43	0.30	0.17	0.05	0.01	0.04
VISTAS	Mammoth Cave	KY	MACA	0.81	0.06	0.09	0.03	0.01	0.01
VISTAS	Sipsey Wilderness	AL	SIPS	0.74	0.05	0.14	0.05	0.01	0.02
MRPO	Isle Royale	MI	ISLE	0.53	0.20	0.16	0.05	0.01	0.06
WRAP	Badlands	SD	BADL	0.50	0.16	0.19	0.04	0.02	0.09
WRAP	Great Sand Dunes	CO	GRSA	0.27	0.12	0.28	0.06	0.09	0.17
WRAP	Lostwood Wilderness	ND	LOST	0.41	0.38	0.13	0.03	0.01	0.04
WRAP	Rocky Mtn Nat'l Park	CO	ROMO	0.33	0.19	0.25	0.08	0.04	0.11
WRAP	Salt Creek	NM	SACR	0.36	0.25	0.14	0.05	0.08	0.12
WRAP	Theodore Roosevlt	ND	THRO	0.33	0.34	0.21	0.05	0.01	0.06
WRAP	Wheeler Peak	NM	WHPE	0.34	0.07	0.30	0.12	0.09	0.08
WRAP	White Mountain	NM	WHIT	0.32	0.09	0.31	0.08	0.06	0.14
WRAP	Wind Cave	SD	WICA	0.38	0.24	0.22	0.08	0.02	0.06

Table 4-4. Required Concentration Reductions: All Species.

				Reduction in All Species (µg/m3) to Eliminate DV Increment					
				Assuming Controls in Proportion of Area-Specific Composition					
RPO	Class I Area	ST	Name	Sulfate	Nitrate	OC	EC	Soil	Coarse
CENRAP	Big Bend Nat'l Park	TX	BIBE	0.77	0.05	0.28	0.03	0.42	1.43
CENRAP	Boundary Waters	MN	BWCA	0.22	0.19	0.15	0.02	0.03	0.27
CENRAP	Breton Island	LA	BRET	0.08	0.01	0.02	0.01	0.01	0.11
CENRAP	Caney Creek	AR	CACR						
CENRAP	Guadalupe Mountains	TX	GUMO	0.53	0.16	0.25	0.02	0.50	2.97
CENRAP	Hercules-Glades	MO	HEGL						
CENRAP	Mingo	MO	MING						
CENRAP	Upper Buffalo	AR	UPBU						
CENRAP	Voyageurs	MN	VOYA2	0.09	0.14	0.23	0.02	0.04	0.44
CENRAP	Wichita Mountains	OK	WIMO	0.09	0.06	0.07	0.01	0.01	0.11
VISTAS	Mammoth Cave	KY	MACA						
VISTAS	Sipsey Wilderness	AL	SIPS						
MRPO	Isle Royale	MI	ISLE	0.19	0.07	0.14	0.02	0.03	0.34
WRAP	Badlands	SD	BADL	0.50	0.16	0.36	0.03	0.14	1.16
WRAP	Great Sand Dunes	CO	GRSA	0.19	0.08	0.29	0.02	0.38	1.13
WRAP	Lostwood Wilderness	ND	LOST	0.75	0.69	0.52	0.05	0.09	1.05
WRAP	Rocky Mtn Nat'l Park	CO	ROMO	0.19	0.11	0.24	0.03	0.17	0.69
WRAP	Salt Creek	NM	SACR	0.73	0.51	0.39	0.05	0.93	2.26
WRAP	Theodore Roosevlt	ND	THRO	0.33	0.34	0.57	0.06	0.13	1.15
WRAP	Wheeler Peak	NM	WHPE	0.15	0.03	0.19	0.03	0.24	0.32
WRAP	White Mountain	NM	WHIT	0.21	0.06	0.28	0.03	0.21	0.84
WRAP	Wind Cave	SD	WICA	0.32	0.20	0.36	0.05	0.13	0.59

Table 4-5. Required Concentration Reductions: One Specie.

				Reduction in One Specie (µg/m3) to Eliminate DV Increment Assuming Controls on Only 1 Specie					
RPO	Class I Area	ST	Name	Sulfate	Nitrate	OC	EC	Soil	Coarse
CENRAP	Big Bend Nat'l Park	TX	BIBE	1.25	1.25	1.97	0.79	7.88	13.13
CENRAP	Boundary Waters	MN	BWCA	0.51	0.51	1.27	0.51	5.08	8.46
CENRAP	Breton Island	LA	BRET	0.12	0.12	0.33	0.13	1.31	2.19
CENRAP	Caney Creek	AR	CACR						
CENRAP	Guadalupe Mountains	TX	GUMO	1.34	1.34	1.81	0.72	7.23	12.05
CENRAP	Hercules-Glades	MO	HEGL						
CENRAP	Mingo	MO	MING						
CENRAP	Upper Buffalo	AR	UPBU						
CENRAP	Voyageurs	MN	VOYA2	0.37	0.37	0.95	0.38	3.81	6.35
CENRAP	Wichita Mountains	OK	WIMO	0.21	0.21	0.40	0.16	1.61	2.68
VISTAS	Mammoth Cave	KY	MACA						
VISTAS	Sipsey Wilderness	AL	SIPS						
MRPO	Isle Royale	MI	ISLE	0.35	0.35	0.92	0.37	3.67	6.12
WRAP	Badlands	SD	BADL	0.99	0.99	1.93	0.77	7.73	12.88
WRAP	Great Sand Dunes	CO	GRSA	0.68	0.68	1.02	0.41	4.07	6.78
WRAP	Lostwood Wilderness	ND	LOST	1.82	1.82	3.96	1.58	15.85	26.41
WRAP	Rocky Mtn Nat'l Park	CO	ROMO	0.59	0.59	0.94	0.37	3.74	6.24
WRAP	Salt Creek	NM	SACR	2.05	2.05	2.77	1.11	11.09	18.49
WRAP	Theodore Roosevlt	ND	THRO	1.00	1.00	2.77	1.11	11.07	18.45
WRAP	Wheeler Peak	NM	WHPE	0.45	0.45	0.63	0.25	2.54	4.23
WRAP	White Mountain	NM	WHIT	0.67	0.67	0.90	0.36	3.60	6.00
WRAP	Wind Cave	SD	WICA	0.85	0.85	1.60	0.64	6.39	10.65

Following the IMPROVE methodology, the relationship between the extinction (Mm^{-1}) of an individual chemical species and the volumetric mass concentration is as follows:

$$b_{Sulfate} = 3 \cdot f(RH) \cdot [SO4]$$

$$b_{Nitrate} = 3 \cdot f(RH) \cdot [NO3]$$

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

$$b_{OM} = 4 \cdot [OM]$$

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

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

$$b_{Ray} = 10\ Mm^{-1}$$

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

The numeric coefficient at the beginning of each equation is the dry scattering or absorption efficiency. The f(RH) term is a monthly-average relative humidity adjustment factor. The terms in the brackets are the concentrations in micrograms per cubic meter ($\mu g/m^3$) that will need to be reduced on the 20% worst days at the Class I monitor to make up for the projected visibility 'increment'.

Rearranging yields a solution for the aerosol concentrations as a function of the measured or modeled extinction:

$[SO4] = b_{Sulfate} / [3 \cdot f(RH)]$

$[NO3] = b_{Nitrate} / [3 \cdot f(RH)]$

$[EC] = b_{EC} / 10$

$[OM] = b_{OM} / 4$

$[Soil] = b_{Soil}$

$[CM] = b_{CM} / 0.6$

Note that the sulfate (SO_4) and nitrate (NO_3) components are hygroscopic because their extinction coefficients depend upon relative humidity. The concentrations, in square brackets, are in $\mu g/m^3$ and b_{ext} is in units of Mm^{-1}. The Rayleigh scattering term (b_{Ray}) has a default value of 10 Mm^{-1}, as recommended in EPA guidance for tracking reasonable progress (EPA, 2003). The effect of relative humidity variability on the extinction coefficients for SO_4 and NO_3 can be estimated in several ways, but given the scope of this analysis, we calculated annual average Class I areas-specific monthly f(RH) values (last column of Table 4-1) from the seasonal f(RH) data provided by EPA in the BART guidelines.

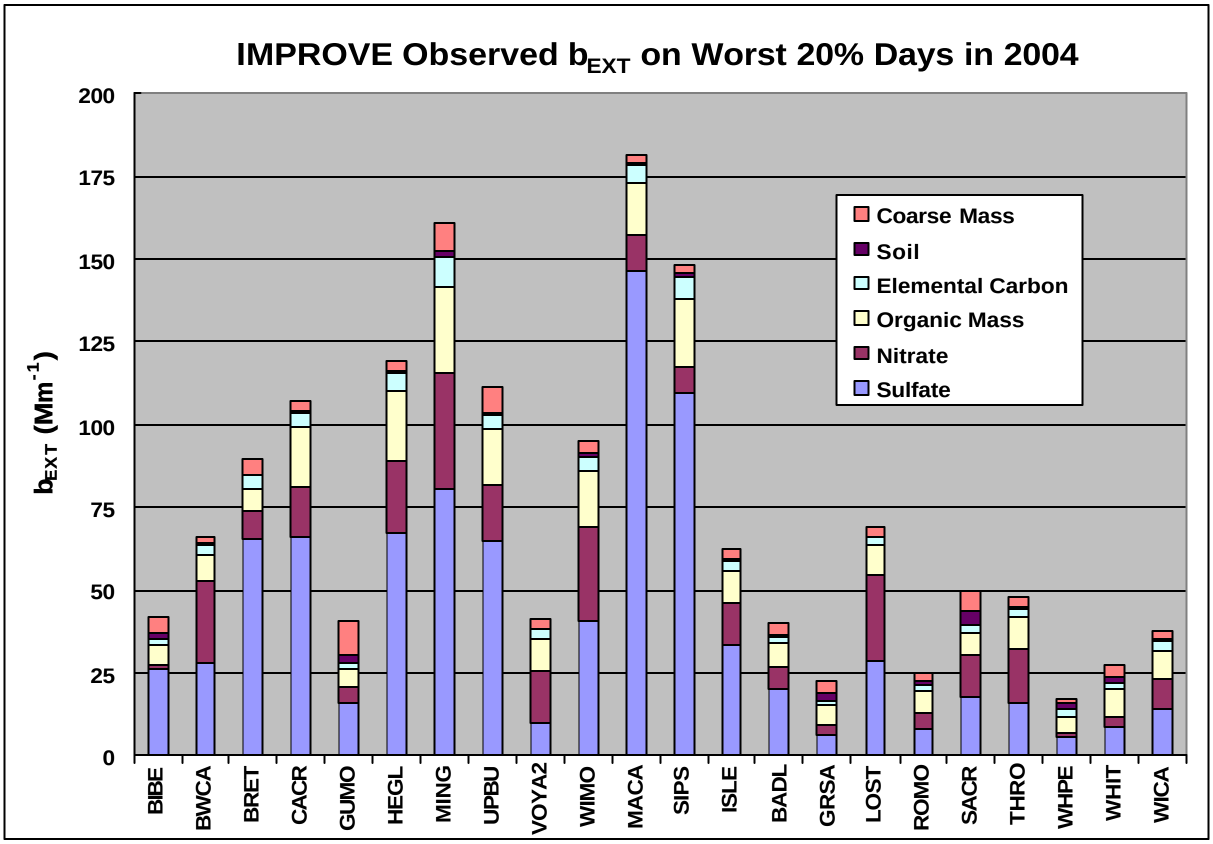


Figure 4-1. Measured Extinction Coefficients at Class I Areas Based on IMPROVE Data.

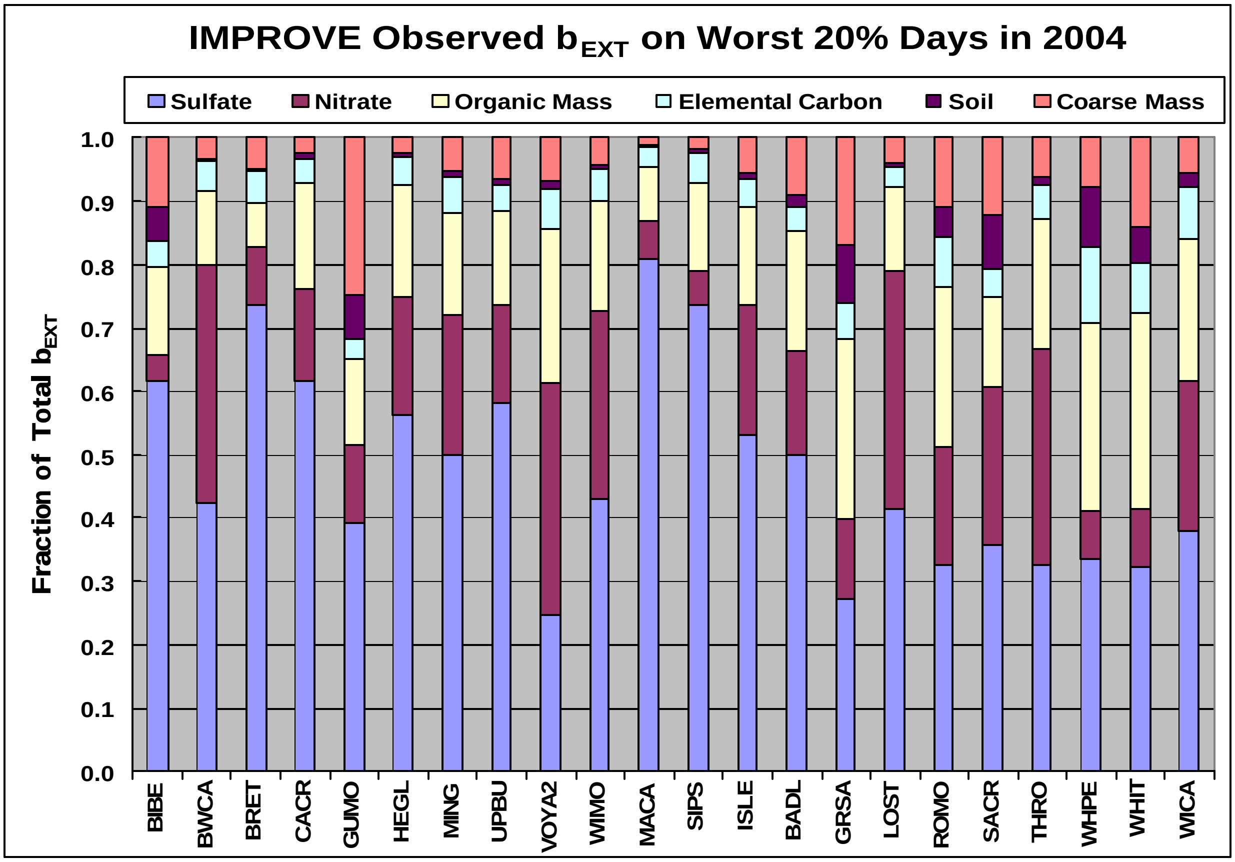


Figure 4-2. Measured Fractional Extinction at Class I Areas Based on IMPROVE Data.

5.0 ESTIMATION OF EMISSIONS REDUCTION NEEDS

5.1 Development of the Areas of Influence (AOI)

To quantify the incremental emissions reductions needed to ameliorate positive visibility increments at Class I areas, it was first necessary to identify those regions that adversely impact visibility at the Class I areas. These Areas of Influence (AOI) directly identify the source regions whose emissions impact a Class I area. Further, an AOI can also be constructed such that it provides a quantitative assessment of the impact of the emissions from a source region on such metrics as $PM_{2.5}$ concentration at a Class I area. This should not be confused with source apportionment where source regions are assigned quantitative culpability to an overall air quality metric such as sulfate concentration or light extinction. Instead, an AOI ideally describes geographically the emissions source regions and magnitude of, say, the impact that a one ton reduction in SO_2 emissions has on sulfate concentration ($\mu g/m^3$) at a Class I area.

An AOI can be constructed based on a variety of data such as: sensitivities derived from the Decoupled Direct Method (DDM) (Yang *et al*., 1997; Mendoza *et al*., 2000); brute force sensitivities; various forms of back trajectory analysis which examine air mass residence time (e.g., Schichtel *et al.*, 2006; DRI, 2005c); and methods that combine back trajectory analyses with such information as emissions impact potential (e.g., Raffuse *et al.*, 2005). Over the last two years, one or more of these methods has been used to construct AOIs or AOI-like diagrams for all the Class I areas of interest to this study. Therefore, it was necessary to identify, gather, and synthesize these data from the many sources so that a consistent set of AOIs could be constructed.

Appendix C is a compendium of AOI data for each Class I area of interest that could be extracted from the body of literature that is available. The first six slides of Appendix C provide examples of the data that were available to construct the AOIs – references are provided on each slide. Ultimately, the Residence Time Difference plots (DRI, 2005c), the Probability of Regional Source Contribution to Haze (PORSCH) plots (Raffuse *et al*., 2005), the Tagged Species Source Apportionment (TSSA) results (Tonnesen and Wang, 2004; UCR, 2006), and a good deal of engineering judgment were used to construct a consistent set of AOIs for each Class I area.

Residence Time Difference (RTD) plots were constructed based on Back Trajectory Residence Time (BTRT) plots. Back trajectory analyses use meteorological fields to estimate the most likely geographical path an air mass traversed to end at a particular receptor. Of note, the meteorological field can be based on interpolation of observations, modeled (e.g., from a prognostic meteorological model such as MM5), or a hybrid field based on combined modeled and observed values. The method essentially reverses the wind field, moving an air mass backward in time. Back trajectories oversimplify actual atmospheric conditions in that dispersion is ignored. Further, the potential emissions source regions that impact a receptor are underestimated given that it is impossible to track every air parcel impacting the receptor.

The BTRT estimates that were developed by DRI (2005b) and used in this study were estimated using HYSPLIT (Draxler and Hess, 1997; NOAA, 2006). HYSPLIT uses archived three dimensional meteorological fields generated from observations and short-term meteorological forecasts. The model produces a series of endpoints representing longitude, latitude, and elevation of the parcel at one-hour intervals. BTRT plots at each site were calculated for all days, by month, and by best and worst twenty percentile days (DRI, 2005c). BTRT plots give the fraction of total hours that an air parcel resided over each specific geographical area. RTD plots were created by subtracting the map for all days at a site from the map for the 20% worst days by pollutant. RTD plots were computed for the twenty percentile worst sulfate, nitrate, organic carbon, elemental carbon, fine soil, and coarse mass days.

The worst twenty percentile sulfate RTD plots, for example, shows the difference in residence time between the worst sulfate days and all days. If the number is positive, then the residence time on the worst sulfate days is greater than on all days. The residence time difference map simply shows the areas that air was more frequently (positive numbers) passing over on worst case days compared to all days.

The PORSCH system is a suite of GIS tools that combines modeled backward wind trajectories, monitored concentrations, meteorological conditions, and emissions estimates to estimate probable regions of influence. PORSCH combines ensemble backward trajectories with chemically speciated emissions data to estimate the trajectory-emissions density-weighted area likely to impact a receptor site. PORSCH can do this for a single day or a suite of days though for purposes of this study, only data relevant to the 20% worst haze days were extracted.

As the name implies Tagged Species Source Apportionment (TSSA) uses “Tagged Chemical Species,” or tracers, to track chemical transformations and transport of each chemical species or precursor species during an air quality model run. Key chemical species are identified for specific emissions source regions or emissions source categories. These tagged chemical species are tracked during all phases of the air quality modeling run (e.g., advection, diffusion, deposition, chemical transformation), and the end results are three dimensional fields in time showing source attribution of the chemical species for any grid cell in model domain. When chemical species are tagged by emissions source region, this provides valuable corroborative evidence for identifying key AOI regions.

Slides 8 through 82 of Appendix C contain the raw data that was extracted from the literature base, which served as the foundation to develop the AOIs for the ten CENRAP Class I areas. Slides 84 through 184 of Appendix C contain the raw data from which AOIs were synthesized for the nine WRAP and two VISTAS Class I areas that border the CENRAP states. Because RTD plots were available for the entire suite of twenty-one Class I areas, they served as the primary basis from which the AOIs were estimated. The RTD plots were manually examined to determine “natural break-points” in residence time difference (only positive values were considered in these plots as positive values indicate air mass residence was greatest in these geographical areas on the 20% worst haze days).

In many cases, these “natural break-points” were difficult to determine given that the scales on the RTD plots were not consistent; hence, engineering judgment was used to place a “break-point.” For virtually all Class I areas, it was possible to determine at least two “break-points” and in some instances, three and four “break-points” were determined. For purposes of this effort, a “break-point” was generally placed where the residence time difference transition was on the order of a factor of ten and over large geographical areas. Little pockets of large RTD transitions, such as might occur over Lake Michigan or the Gulf of Mexico, were merged into a larger "break-point." Once a "break-point" was determined, a hand drawn contour was placed on the plot to indicate the Level 1, 2, or greater "break-point." This was done for each of the chemical species classes: sulfate; nitrate; organic carbon; elemental carbon; fine soils; and coarse material, at each Class I area. For clarification purposes, the Level 1 "break-point" is always the smallest polygon closest to the Class I area, and subsequent Level 2, 3, or greater "break-points" cover progressively larger areas.

Once the RTD "break-points" were determined, the plots were manually compared to the supporting PORSCH and TSSA data in order to determine if a "break-point" needed to expanded, contracted, or moved. The PORSCH data were used primarily to determine if the spatial extent of a "break-point" was adequate and the TSSA data were used to determine if the areas of emissions impact potential were captured within the spatial extent of the RTD "break-points." Based on this reconciliation effort, the Level 1, 2, or greater "break-point" contours were manually adjusted on the plots. Again, a great deal of engineering judgment was used in how these data were combined. This initial effort resulted in the development of 126 plots (six pollutants times twenty-one Class I areas) consisting of one or more "break-point" contours.

Next, each plot was manually compared to the remaining plots to determine if any of the Level 1, 2 or greater "break-point" contours were similar in their geographic placement. If a set of contours from different Class I areas had similar geographic placement, the plots were combined into a single set of contours. In many cases, the "break-point" contours were again manually adjusted so that different plots could be combined into a single set representing multiple Class I areas and multiple pollutants.

This final set of manually created, combined "break-point" contours is what is referred to as the Area of Influence (AOI) for each Class I area. However, these hand drawn AOIs are useless in their current form since it would have been far too time consuming to try to manually extract the counties over which an AOI passed – a step which is necessary if one is to determine the emissions impact potential from a geographic area (i.e., AOI) that impacts a Class I site. Therefore, it is necessary to convert the hand drawn AOIs into a geocoded, electronic file.

Geocoding of the hand drawn AOIs is accomplished by first scanning the image into an electronic file. The scanned image is then registered to a known set of geographical objects. In this case, the geographical objects are the political boundaries of the United States. The function of registering the scanned image, which itself is a political boundaries map of the United States with a set of hand drawn AOIs, is performed using a Geographic Information System (GIS). Secondly, the registered scanned image is rectified so that the image retains its geographic relationship to real world coordinates. Finally, the contours of the rectified image are digitized.

The final set of AOIs is shown in Slides 136 to 143 of Appendix C. These represent the geocoded AOIs that are used to extract a list of counties whose emissions sources have the greatest potential to impact the air quality at a Class I area. Again, ARC/Info was used to extract the counties within each AOI. Figure 5-1 is an example geocoded AOI for the Boundary Waters and Voyageurs Class I areas. Note the distinction between the Level 1 and Level 2 AOIs for both sulfate-to-SO_2 and nitrate-to-NO_X sensitivities.

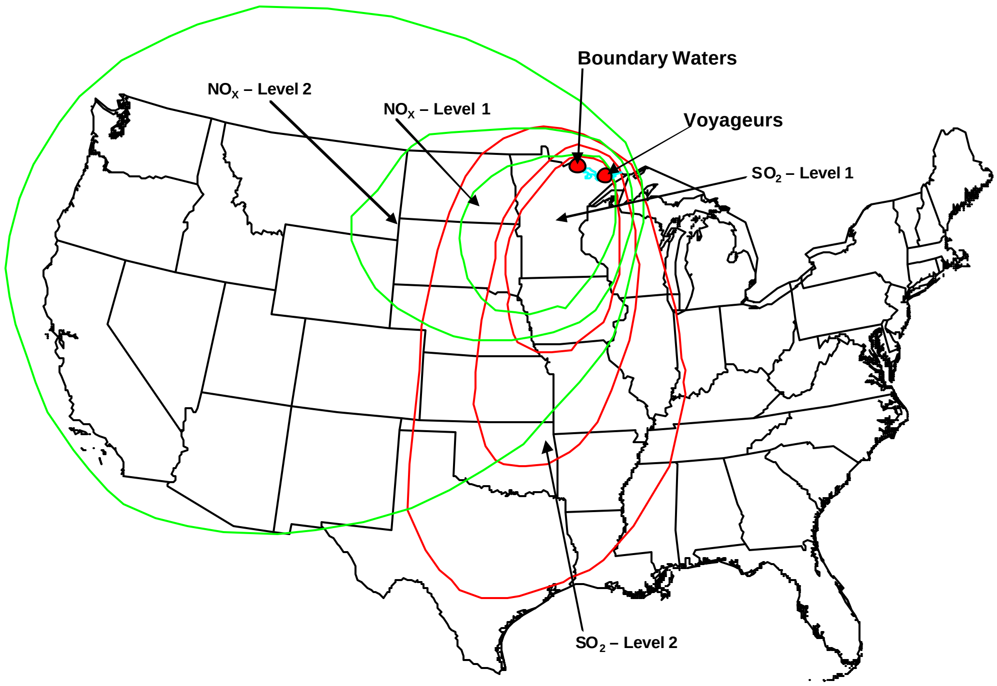


Figure 5-1. Example Geocoded AOI for Boundary Waters and Voyageurs Class I areas. Green contours delineate areas of influence where NO_X emissions impact aerosol nitrate at the Class I areas. Red contours delineate areas of influence where SO_2 emissions impact aerosol sulfate at Class I areas.

5.2 Development of Visibility Impairing Pollutant Concentrations to Precursor Emissions Sensitivity Coefficients

Though a list of counties can now be identified whose emissions sources have the greatest potential to impact air quality at a Class I area, this list has limited value until a quantitative value to associate emissions to air quality is estimated. Ideally, these associative values take the form of µg/m^3 of pollutant reduced per ton per day of precursor emissions reduced. For example, -0.001 µg/m^3 of sulfate per ton per day SO_2 reduced tells one that for each ton of SO_2 reduced within an AOI, the Class I area will exhibit a decrease of 0.001 µg/m^3 in sulfate concentration. This value is referred to as a sensitivity value and is very powerful at informing efforts such as those pursued in this study. A great deal of work has been performed to ascertain such sensitivities, and it is from this body of knowledge that sensitivities specific to the current efforts have been derived.

Tesche *et al.* (2003c) conducted a suite of brute force sensitivity runs using the CAMx and CMAQ air quality modeling (AQM) systems over the eastern United States on behalf of VISTAS. By systematically perturbing the global inventory (e.g., reducing global NO_X emissions by 10%) and rerunning the AQM, they developed a suite of metrics that provided the maximum reduction to say the peak, modeled ammonium nitrate. By converting the 10% NO_X reduction to actual tons per day NO_X reduction, which is simply done by taking 10% of the emissions in the AQM-ready emissions files, and dividing that into the peak concentration reduction, the sensitivity that is of most importance is realized. Though this value is a more global sensitivity, its use is still valid for our needs. Indeed, by assuming that such a sensitivity is valid across the domain, this general purpose sensitivity value can be extended to all the AOIs of interest by computing the value of a 10% reduction in each of the AOIs and dividing this number into the general sensitivity value derived from the average of all the sensitivities, by pollutant of course, estimated by Tesche *et al.* (2003c).

Appendix D shows an Excel workbook containing the summary data (i.e., worksheet named "General") from Tesche *et al.* (2003c). The worksheet shows the results of the specific sensitivity analyses conducted, and the results of our efforts to compute a general purpose sensitivity value. Once a general purpose sensitivity value was computed, it was recast in a form specific to the Class I areas of interest. This was done by assuming that the general purpose sensitivity (e.g., $\mu g/m^3$ sulfate reduction per 10% reduction in SO_2 emissions) was valid across the domain and dividing this number by the tons per day value deduced from a 10% reduction of a precursor pollutant in the AOI of interest.

Though a general purpose sensitivity value was estimated for all Class I areas and AOIs of interest, other sensitivity information that was more specific to certain Class I areas was available from work done at the Georgia Institute of Technology (GIT, 2006). Researchers at GIT conducted numerous brute force sensitivity runs of the CMAQ AQM on behalf of VISTAS. One component of these efforts was to conduct specific emissions source region and emissions source category sensitivity experiments to determine light extinction sensitivities to a reduction in one ton of precursor emissions at Mingo Wilderness, Upper Buffalo, Caney Creek, Hercules Glade, Breton Island, Sipsey, and Mammoth Cave. The emissions source regions for the GIT efforts (GIT, 2006) included the individual VISTAS states, the clustered CENRAP states, and the clustered MANE-VU states. The GIT (2006) results were extracted and summaries were prepared for the combined Mingo Wilderness-Upper Buffalo-Caney Creek-Hercules Glade AOIs, the Breton Island AOI, the Sipsey AOI, and the Mammoth Cave AOI. The results of these efforts were summarized in Appendix D, Excel worksheet "Class I Specific."

Finally, the results of the sensitivity summary efforts were combined in order to prepare a consistent set of sensitivity values by AOI. This summary is presented in Appendix D, Excel worksheet "Summary" and in Table 5-1.

Table 5-1. Synthesis of Sensitivity Values for Each Class I Area by AOI level. Units should be interpreted as reduction in nitrate (sulfate) concentration (µg/m^3) per average daily ton reduction in NO_X (SO_2) emissions in the specified AOI Level (see Figure 4-5 for an example of the delineation of the AOI Level).

Abb	Class I	RPO	Level 1 NOX ug/m**3/ton	Level 1 SO2 ug/m**3/ton	Level 2 NOX ug/m**3/ton	Level 2 SO2 ug/m**3/ton
badl	Badlands	WRAP	-0.001	-0.008	-0.003	-0.002
bibe	Big Bend	CENRAP	-0.002	-0.004	-0.001	-0.001
bowa	Boundary Waters	CENRAP	-0.002	-0.006	-0.004	-0.002
bret	Breton Island	CENRAP	-0.00008	-0.002	-0.00005	-0.0007
cacr	Caney Creek	CENRAP	-0.0004	-0.003	-0.002	-0.002
grsa	Great Sand Dunes	WRAP	-0.003	-0.02	--	-0.0005
gumo	Guadalupe Mountains	CENRAP	-0.01	-0.004	-0.002	-0.001
herc	Hercules Glade	CENRAP	-0.0004	-0.003	-0.002	-0.002
lost	Lostwood Wilderness	WRAP	-0.01	-0.008	-0.003	-0.002
maca	Mammoth Cave	VISTAS	-0.001	-0.005	-0.0008	-0.005
ming	Mingo Wilderness	CENRAP	-0.0004	-0.003	-0.002	-0.002
romo	Rocky Mountain	WRAP	-0.007	-0.02	-0.003	-0.0005
sacr	Salt Creek	WRAP	-0.01	-0.08	-0.002	-0.0007
sips	Sipsey Wilderness	VISTAS	-0.001	-0.007	-0.0008	-0.005
thro	Theodore Roosevelt	WRAP	-0.01	-0.008	-0.003	-0.002
upbu	Upper Buffalo	CENRAP	-0.0004	-0.003	-0.002	-0.002
voya	Voyageurs	CENRAP	-0.002	-0.006	-0.004	-0.002
whmo	White Mountain	WRAP	-0.01	-0.08	-0.002	-0.0007
whpe	Wheeler Peak	WRAP	-0.01	-0.08	-0.002	-0.0007
wica	Wind Cave	WRAP	-0.001	-0.008	-0.003	-0.002
wich	Wichita Mountain	CENRAP	-0.005	-0.001	-0.003	-0.0004

5.3 Estimated Emissions Reductions Necessary to Attain 2018 Glide Path

Now that the visibility 'increment' (Table 4-4 [proportional species reduction] and Table 4-5 [single specie reduction]) and the chemical species-to-precursor emissions sensitivity coefficients (Table 5-1) are known by Class I area, it is a simple matter to compute the annualized, incremental emissions reductions that are needed at each Class I area to attain the 2018 glide path. This is accomplished by dividing the visibility 'increment' by the sensitivity coefficient and multiplying by 365.

Table 5-2 shows the required incremental reductions of SO_2 and NO_X emissions that are estimated to be required in order for the Class I areas to meet the glide slope by 2018. The estimated SO_2 and NO_X reductions in Table 5-2 are proportional to chemical species contributions during the 20% worst haze days. In contrast, Table 5-3 shows the estimated SO_2 and NO_X emissions reductions if only one chemical species is reduced. The emissions reductions requirements in Tables 5-2 and 5-3 are reported to two significant figures.

For example, in order for Big Bend to meet the 2018 visibility glide path, approximately 73,000 tons per year of incremental SO_2 emissions reductions (Table 5-2) from SO_2 emissions source residing in the Level 1 AOI (Figure 5-2) are required assuming that incremental emissions reductions are developed based on a proportional reduction in the chemical species. Hence, in addition to the estimated incremental SO_2 emissions reductions of 73,000 tons per year, estimated incremental NO_X emissions reductions of 8,000 tons per year are also expected to be required. Additionally, incremental emissions reductions in coarse material, soil, elemental carbon, and organic compounds are also necessary if, again, emissions reductions are based on proportional reductions in the chemical species, though these reductions were not estimated given that reasonably available emissions control scenarios exist only for NO_X and SO_2.

If only one chemical specie is controlled, for example sulfate, then precursor SO_2 incremental emissions reductions from emissions sources located within the SO_2 Level 1 AOI (Figure 5-2) are estimated to be 120,000 tons per year (Table 5-3). On the other hand, if only nitrate is controlled, precursor NO_X incremental emissions reductions from emissions sources located within the NO_X Level 1 AOI (Figure 5-2) are estimated to be 210,000 tons per year.

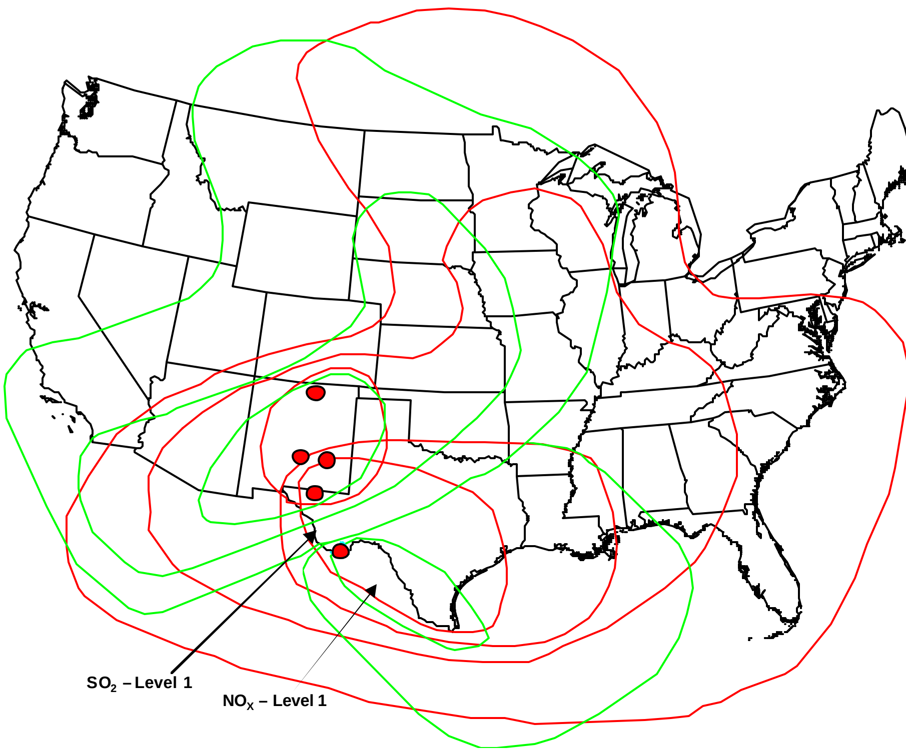


Figure 5-2. Geocoded AOIs for Big Bend, Guadalupe Mountain, Salt Creek, White Mountain, and Wheeler Peak. The Big Bend Level 1 AOI for SO_2 and NO_X are identified.

Table 5-2. SO_2 and NO_X Emissions Reduction Requirements (tons per year) Assuming Proportional Reductions in Sulfate and Nitrate.

Class I Area	ST	Proportional Reduction Requirements (ug/m3) Sulfate	Nitrate	OC	EC	Soil	Coarse	Level 1 AOI (ug/m3/ton reduced) sulfate-to-SO2	nitrate-to-NOX	Required SO2 Emissions Reductions (tons / year)	Required NOX Emissions Reductions (tons / year)
Big Bend Nat'l Park	TX	0.77	0.05	0.28	0.03	0.42	1.43	-0.004	-0.002	73,000	8,000
Boundary Waters	MN	0.22	0.19	0.15	0.02	0.03	0.27	-0.006	-0.004	13,000	19,000
Breton Island	LA	0.08	0.01	0.02	0.01	0.01	0.11	-0.0001	-0.000007	226,000	572,000
Caney Creek	AR							-0.0002	-0.00001		
Guadalupe Mountains	TX	0.53	0.16	0.25	0.02	0.50	2.97	-0.004	-0.01	50,000	4,000
Hercules-Glades	MO							-0.00019	0.0000		
Mingo	MO							-0.0002	-0.00001		
Upper Buffalo	AR							-0.0002	-0.00001		
Voyageurs	MN	0.09	0.14	0.23	0.02	0.04	0.44	-0.006	-0.004	5,700	14,000
Wichita Mountains	OK	0.09	0.06	0.07	0.01	0.01	0.11	-0.001	-0.005	32,000	4,500
Mammoth Cave	KY							-0.005	-0.001		
Sipsey Wilderness	AL							-0.007	-0.001		
Isle Royale	MI	0.19	0.07	0.14	0.02	0.03	0.34	-0.006	-0.004	11,000	7,000
Badlands	SD	0.50	0.16	0.36	0.03	0.14	1.16	-0.008	-0.001	23,000	45,000
Great Sand Dunes	CO	0.19	0.08	0.29	0.02	0.38	1.13	-0.02	-0.003	3,400	10,000
Lostwood Wilderness	ND	0.75	0.69	0.52	0.05	0.09	1.05	-0.008	-0.01	35,000	19,000
Rocky Mtn Nat'l Park	CO	0.19	0.11	0.24	0.03	0.17	0.69	-0.02	-0.007	3,500	5,800
Salt Creek	NM	0.73	0.51	0.39	0.05	0.93	2.26	-0.004	-0.01	68,800	13,000
Theodore Roosevlt	ND	0.33	0.34	0.57	0.06	0.13	1.15	-0.008	-0.01	15,000	12,000
Wheeler Peak	NM	0.15	0.03	0.19	0.03	0.24	0.32	-0.08	-0.01	690	800
White Mountain	NM	0.21	0.06	0.28	0.03	0.21	0.84	-0.08	-0.01	990	1,500
Wind Cave	SD	0.32	0.20	0.36	0.05	0.13	0.59	-0.008	-0.001	15,000	56,000

Table 5-3. SO_2 and NO_X Emissions Reduction Requirements (tons per year) Assuming a Single Chemical Species is Controlled.

Class I Area	ST	Reduction Requirement Assuming Single Species Control (ug/m3) Sulfate	Nitrate	OC	EC	Soil	Coarse	Level 1 AOI (ug/m3/ton reduced) sulfate-to-SO2	nitrate-to-NOX	Required SO2 Emissions Reductions (tons / year)	Required NOX Emissions Reductions (tons / year)
Big Bend Nat'l Park	TX	1.25	1.25	1.97	0.79	7.88	13.13	-0.004	-0.002	120,000	210,000
Boundary Waters	MN	0.51	0.51	1.27	0.51	5.08	8.46	-0.006	-0.004	32,000	51,000
Breton Island	LA	0.12	0.12	0.33	0.13	1.31	2.19	-0.0001	-0.000007	308,000	6,010,000
Caney Creek	AR							-0.0002	-0.00001		
Guadalupe Mountains	TX	1.34	1.34	1.81	0.72	7.23	12.05	-0.004	-0.01	130,000	33,000
Hercules-Glades	MO							-0.00019	0.0000		
Mingo	MO							-0.0002	-0.00001		
Upper Buffalo	AR							-0.0002	-0.00001		
Voyageurs	MN	0.37	0.37	0.95	0.38	3.81	6.35	-0.006	-0.004	23,000	37,000
Wichita Mountains	OK	0.21	0.21	0.40	0.16	1.61	2.68	-0.001	-0.005	75,000	15,000
Mammoth Cave	KY							-0.005	-0.001		
Sipsey Wilderness	AL							-0.007	-0.001		
Isle Royale	MI	0.35	0.35	0.92	0.37	3.67	6.12	-0.006	-0.004	22,000	35,000
Badlands	SD	0.99	0.99	1.93	0.77	7.73	12.88	-0.008	-0.001	46,000	280,000
Great Sand Dunes	CO	0.68	0.68	1.02	0.41	4.07	6.78	-0.02	-0.003	12,000	82,000
Lostwood Wilderness	ND	1.82	1.82	3.96	1.58	15.85	26.41	-0.008	-0.01	84,000	52,000
Rocky Mtn Nat'l Park	CO	0.59	0.59	0.94	0.37	3.74	6.24	-0.02	-0.007	11,000	31,000
Salt Creek	NM	2.05	2.05	2.77	1.11	11.09	18.49	-0.004	-0.01	192,800	50,000
Theodore Roosevlt	ND	1.00	1.00	2.77	1.11	11.07	18.45	-0.008	-0.01	45,000	36,000
Wheeler Peak	NM	0.45	0.45	0.63	0.25	2.54	4.23	-0.08	-0.01	2,100	11,000
White Mountain	NM	0.67	0.67	0.90	0.36	3.60	6.00	-0.08	-0.01	3,100	16,000
Wind Cave	SD	0.85	0.85	1.60	0.64	6.39	10.65	-0.008	-0.001	39,000	240,000

6.0 PRIORITIZED CENRAP EMISSIONS REDUCTION SCENARIOS

6.1 Summary of Emission Inventories Used in Control Plan Development

A necessary component of the control strategy design is a thorough review of the emission inventories that are used in the modeling of the future year base case. This inventory can shed light on the residual emissions from sources or source categories defined to be within areas of transport or impact of a Class I area. We obtained and used the current CENRAP future year (2018) base case and 2002 base year emissions to conduct a review of the top emitting categories and pollutants within identified impact areas.

The SMOKE-ready modeling files for both 2002 and 2018 base year and base cases were obtained from CENRAP's emissions modeling contractor (UCR) in addition to a supplementary county level summary of onroad source emissions produced from the gridded, temporalized MOBILE6-based emissions output. Using the annualization methods confirmed with UCR and identified in the SMOKE file headers, each SMOKE input file was converted to annual emissions and summed for the geography and domain of interest.

Tables 6-1 and 6-2 present the major source category breakdown of these emissions for the entire CENRAP domain. AOI-specific breakdowns are presented in Appendix E of this document for those CENRAP Class I areas projected to be above the reasonable progress glide slope. Because the SMOKE-ready files were used in this analysis, the particulate matter transport factor is included in the PM emission summaries. This factor is applied to account for the removal of a substantial portion of fugitive dust emissions near a source by surrounding vegetation and structures when such emissions are used in regional scale modeling analyses.

Table 6-1. CENRAP 2002 Base Year Annual Emissions Summary.

	CENRAP 2002 Base Year Annual Emissions (Tons)						
Source Category	**VOC**	**NOx**	**CO**	**SO2**	**PM-10**	**PM-2.5**	**NH3**
Fuel Comb. Elec. Util.	13,838	1,006,914	290,478	1,545,327	79,429	53,475	4,462
Fuel Comb. Industrial	74,226	907,445	387,579	568,270	118,626	78,412	6,243
Fuel Comb. Other	151,527	98,457	435,320	34,605	67,380	65,556	4,870
Chemical & Allied Product Mfg	56,154	37,002	117,918	140,403	10,946	8,503	13,254
Metals Processing	8,178	16,197	115,827	86,425	14,930	6,486	4
Petroleum & Related Industries	486,785	306,947	274,187	81,950	10,442	7,408	819
Other Industrial Processes	150,388	107,908	119,678	89,127	235,401	74,228	206,676
Solvent Utilization	799,050	392	248	21	1,338	1,110	17
Storage & Transport	200,946	9,023	39,075	2,416	17,321	5,294	220
Waste Disposal & Recycling	58,790	16,836	248,560	5,319	57,500	53,804	9,914
Highway Vehicles	985,527	1,780,289	13,178,713	51,829	100,256	94,514	51,512
Off-highway	660,216	966,296	4,358,200	95,522	83,090	76,924	1,365
Natural Sources	0	0	0	0	0	0	80,213
Miscellaneous	310,871	150,474	4,538,131	47,040	4,325,839	1,062,364	1,440,416
CENRAP Total	**3,956,494**	**5,404,181**	**24,103,914**	**2,748,255**	**5,122,496**	**1,588,078**	**1,819,983**

Table 6-2. 2018 Base Case Annual Emissions Summary.

Source Category	CENRAP 2018 Base Case Annual Emissions (Tons)						
	VOC	NOx	CO	SO2	PM-10	PM-2.5	NH3
Fuel Comb. Elec. Util.	15,963	800,509	231,161	1,397,945	125,999	106,402	12,188
Fuel Comb. Industrial	87,300	985,108	470,053	562,732	134,652	93,244	7,942
Fuel Comb. Other	139,826	93,527	348,628	33,555	57,292	55,498	4,932
Chemical & Allied Product Mfg	91,937	52,915	200,036	229,435	17,361	13,383	23,977
Metals Processing	14,600	24,603	200,166	154,071	23,811	10,838	6
Petroleum & Related Industries	519,225	320,126	287,198	106,536	13,818	9,753	1,077
Other Industrial Processes	215,126	162,931	163,154	133,203	316,220	100,922	285,113
Solvent Utilization	1,095,270	663	426	35	2,563	2,116	19
Storage & Transport	227,269	12,122	69,548	3,325	23,808	7,380	298
Waste Disposal & Recycling	73,117	19,379	296,493	7,704	67,637	63,084	14,019
Highway Vehicles	447,496	445,651	7,466,397	7,335	24,845	12,522	73,128
Off-highway	384,203	263,701	5,067,432	995	43,831	40,311	606
Natural Sources	0	0	0	0	0	0	80,213
Miscellaneous	212,436	107,761	3,200,076	57,923	3,968,055	903,434	1,921,843
CENRAP Total	**3,523,767**	**3,288,994**	**18,000,769**	**2,694,795**	**4,819,893**	**1,418,889**	**2,425,360**

As 2002 pre- and post-modeled emission summaries were provided on the input data files, we were able to verify the emission totals for each State and SCC in the modeling domain (Pechan, 2006). However, as 2018 summaries were not available in time to review the files for this analysis, we have not confirmed that these 2018 emission totals are as expected by the ICS.

Our review was conducted in a top down fashion starting with an analysis of the major source categories in the domains of interest to determine which major categories have the highest residual contribution to the area. Once the highest source types were identified, subcategories within those source types were reviewed. Again, a ranking of the highest residual sub source types was performed and additional analyses on these categories were conducted. Table 6-3 presents a percentage based contribution of residual emissions by major source category for the CENRAP domain. Tables for each CENRAP Class I AOI projected to be above the glide slope for reasonable progress are presented in Appendix E of this document.

In addition to reviewing the residual emission categories in the future year base, it was important to identify reductions that have already occurred within each category or at specific units. This will allow the ICS to determine if certain source categories that have yet to be controlled under the future year base case have the potential for reduction or if source types already reduced have reached the full cost-effective potential. Table 6-4 presents this information in annual tons for all sources in the CENRAP domain, while Table 6-5 presents the same information in terms of percent change from 2002.

Finally, once each subcategory was identified, unit level tables of emission comparisons from 2002 to 2018 were developed allowing the ICS to review existing emission reductions and providing the ability to assign new cost-effective controls to units using the best control for the scenario. These tables present comparisons of 2002 and 2018 emission levels, by pollutant, and future year control technology assignment (by IPM forecasting) for EGU sources. Since unit-specific technology assignments were not identified in the SMOKE control packets nor in documentation obtained for use in this project, these units do not have associated future year technology identification data.

Ultimately, the ICS' final control strategy decisions will include the application of BART applicable source reductions in the future year base case. However, as these sources and their associated reductions were unavailable for this project, they too are not included in this analysis.

Table 6-3. CENRAP 2018 Base Case Annual Residual Emissions Contribution Summary.

	CENRAP 2018 Base Case Annual Emissions (Percent of Total)						
Source Category	**VOC**	**NOx**	**CO**	**SO2**	**PM-10**	**PM-2.5**	**NH3**
Fuel Comb. Elec. Util.	0%	24%	1%	52%	3%	7%	1%
Fuel Comb. Industrial	2%	30%	3%	21%	3%	7%	0%
Fuel Comb. Other	4%	3%	2%	1%	1%	4%	0%
Chemical & Allied Product Mfg	3%	2%	1%	9%	0%	1%	1%
Metals Processing	0%	1%	1%	6%	0%	1%	0%
Petroleum & Related Industries	15%	10%	2%	4%	0%	1%	0%
Other Industrial Processes	6%	5%	1%	5%	7%	7%	12%
Solvent Utilization	31%	0%	0%	0%	0%	0%	0%
Storage & Transport	6%	0%	0%	0%	0%	1%	0%
Waste Disposal & Recycling	2%	1%	2%	0%	1%	4%	1%
Highway Vehicles	13%	14%	41%	0%	1%	1%	3%
Off-highway	11%	8%	28%	0%	1%	3%	0%
Natural Sources	0%	0%	0%	0%	0%	0%	3%
Miscellaneous	6%	3%	18%	2%	82%	64%	79%
CENRAP Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 6-4. CENRAP Annual Emissions Change (Tons).

	CENRAP Annual Emissions Change -- 2002 to 2018 (Tons)						
Source Category	**VOC**	**NOx**	**CO**	**SO2**	**PM-10**	**PM-2.5**	**NH3**
Fuel Comb. Elec. Util.	2,125	-206,405	-59,317	-147,382	46,570	52,927	7,727
Fuel Comb. Industrial	13,075	77,663	82,475	-5,538	16,025	14,832	1,699
Fuel Comb. Other	-11,701	-4,930	-86,692	-1,050	-10,087	-10,058	62
Chemical & Allied Product Mfg	35,783	15,913	82,118	89,032	6,416	4,880	10,723
Metals Processing	6,422	8,405	84,338	67,647	8,882	4,352	3
Petroleum & Related Industries	32,441	13,179	13,011	24,587	3,377	2,346	258
Other Industrial Processes	64,738	55,023	43,475	44,076	80,819	26,694	78,437
Solvent Utilization	296,220	271	178	14	1,225	1,006	2
Storage & Transport	26,323	3,099	30,473	909	6,487	2,086	77
Waste Disposal & Recycling	14,328	2,542	47,933	2,385	10,137	9,281	4,105
Highway Vehicles	-538,032	-1,334,638	-5,712,316	-44,495	-75,411	-81,992	21,616
Off-highway	-276,012	-702,595	709,233	-94,527	-39,258	-36,612	-759
Natural Sources	0	0	0	0	0	0	0
Miscellaneous	-98,436	-42,714	-1,338,055	10,883	-357,784	-158,930	481,427
CENRAP Total	**-432,727**	**-2,115,187**	**-6,103,145**	**-53,460**	**-302,603**	**-169,189**	**605,376**

Table 6-5. CENRAP Annual Emissions Change (Percent).

	CENRAP Annual Emissions Change -- 2002 to 2018 (Percent)						
Source Category	**VOC**	**NOx**	**CO**	**SO2**	**PM-10**	**PM-2.5**	**NH3**
Fuel Comb. Elec. Util.	15%	-20%	-20%	-10%	59%	99%	173%
Fuel Comb. Industrial	18%	9%	21%	-1%	14%	19%	27%
Fuel Comb. Other	-8%	-5%	-20%	-3%	-15%	-15%	1%
Chemical & Allied Product Mfg	64%	43%	70%	63%	59%	57%	81%
Metals Processing	79%	52%	73%	78%	59%	67%	67%
Petroleum & Related Industries	7%	4%	5%	30%	32%	32%	31%
Other Industrial Processes	43%	51%	36%	49%	34%	36%	38%
Solvent Utilization	37%	69%	72%	66%	92%	91%	13%
Storage & Transport	13%	34%	78%	38%	37%	39%	35%
Waste Disposal & Recycling	24%	15%	19%	45%	18%	17%	41%
Highway Vehicles	-55%	-75%	-43%	-86%	-75%	-87%	42%
Off-highway	-42%	-73%	16%	-99%	-47%	-48%	-56%
Natural Sources	0%	0%	0%	0%	0%	0%	0%
Miscellaneous	-32%	-28%	-29%	23%	-8%	-15%	33%
CENRAP Total	**-11%**	**-39%**	**-25%**	**-2%**	**-6%**	**-11%**	**33%**

6.2 Process in Preparing Files for Control Plan Modeling

In addition to the SMOKE emission files, the 2018 growth and control packets were obtained from UCR for additional application and verification of future year scenario assignment. Since the CENRAP utilized version of the SMOKE processor does not replace control efficiency, rule effectiveness, and rule penetration values in the output files generated using the growth and control modules of the model, Alpine manually applied these values to the 2018 non-EGU and stationary area source files for which the packets were applied. This step was necessary to duplicate the inventories that went into the results of CENRAP's reasonable progress modeling and to ensure that any incremental assignment of control technologies did not duplicate emission reductions already assumed in the future year base case.

The 2018 IPM file used by CENRAP for EGU sources was also obtained and matched to the 2018 base case inventory of EGU sources. This step was conducted for reasons similar to those identified above for non-EGU and stationary area sources and to ensure that incremental controls assigned to these source types did not duplicate existing base case assumptions. Because IPM does not assign a control efficiency with each control device applied to SO_2 and NO_X, we made some assumptions, based on IPM documentation, as to what pollutant specific level of reduction was applied in the future year base case runs. These assumptions, by primary and secondary control device code combinations for SO_2 and NO_X, are presented in Tables 6-6 and 6-7, respectively.

Since many of the control technology control cost equations within AirControlNET require additional unit-level characteristic data, we also made matches of the SMOKE IDA files to CENRAP NIF, EPA NEI, or EPA CAMD CEM data sets to obtain these variables when missing.

Unit level boiler capacity (MMBtu/hr) or NETDC (MW) values are required for capital and operating and maintenance cost calculations for many of the EGU technologies. In cases where these nameplate capacity values could not be identified, emission weighted (based on the final EPA 2002 NEI) were assigned to boilers using a primary (highest emitting) SCC. Table 6-8 presents these weighted capacities. Additionally, stack flow, sulfur content, and primary SCC assignment were necessary to cross-reference available incremental control technologies to the base case emissions inventory data. These variables were obtained where matches could be found, in priority order of CENRAP, CAMD, and EPA datasets, respectively.

Table 6-6. IPM Post Processing Assigned Device Codes and Applied SO_2 Control Efficiencies.

Primary Device Code	Secondary Device Code	Description	CE	RE
0	0	No Control	0	0
119	0	Dry Scrubber	90	100
141	0	Wet Scrubber	90	100

Table 6-7. IPM Post Processing Assigned Device Codes and Applied NO_X Control Efficiencies.

Primary Device Code	Secondary Device Code	Description	CE	RE
0	0	UNCONTROLLED	0	0
26	0	FLUE GAS RECIRCULATION	35	100
26	29	FLUE GAS RECIRCULATION + LOW EXCESS AIR FIRING	35	100
26	204	FLUE GAS RECIRCULATION + OVERFIRE AIR	40	100
28	0	STEAM OR WATER INJECTION	65	100
28	32	STEAM OR WATER INJECTION + AMMONIA INJECTION	65	100
28	204	STEAM OR WATER INJECTION + OVERFIRE AIR	90	100
28	205	STEAM OR WATER INJECTION + LOW NOX BURNERS	90	100
29	0	LOW EXCESS AIR FIRING	35	100
32	0	AMMONIA INJECTION	55	100
32	28	AMMONIA INJECTION + STEAM OR WATER INJECTION	65	100
139	0	SCR (SELECTIVE CATALYTIC REDUCTION)	90	100
139	28	SCR (SELECTIVE CATALYTIC REDUCTION) + STEAM OR WATER INJECTION	95	100
139	71	SCR (SELECTIVE CATALYTIC REDUCTION) + FLUID BED DRY SCRUBBER	90	100
139	204	SCR (SELECTIVE CATALYTIC REDUCTION) + OVERFIRE AIR	90	100
139	205	SCR (SELECTIVE CATALYTIC REDUCTION) + LOW NOX BURNERS	94	100
140	0	NSCR (NON-SELECTIVE CATALYTIC REDUCTION)	90	100
140	29	NSCR (NON-SELECTIVE CATALYTIC REDUCTION) + LOW EXCESS AIR FIRING	90	100
140	71	NSCR (NON-SELECTIVE CATALYTIC REDUCTION) + FLUID BED DRY SCRUBBER	90	100
140	204	NSCR (NON-SELECTIVE CATALYTIC REDUCTION) + OVERFIRE AIR	90	100
140	205	NSCR (NON-SELECTIVE CATALYTIC REDUCTION) + LOW NOX BURNERS	90	100
204	0	OVERFIRE AIR	40	100
204	26	OVERFIRE AIR + FLUE GAS RECIRCULATION	40	100
204	205	OVERFIRE AIR + LOW NOX BURNERS	50	100
205	0	LOW NOX BURNERS	50	100
205	26	LOW NOX BURNERS + FLUE GAS RECIRCULATION	60	100
205	28	LOW NOX BURNERS + STEAM OR WATER INJECTION	50	100
205	32	LOW NOX BURNERS + AMMONIA INJECTION	50	100
205	204	LOW NOX BURNERS + OVERFIRE AIR	50	100

6.3 Application of AirControlNET Technologies

AirControlNET is a control technology analysis tool developed to support the U.S. EPA in its analyses of air pollution policies and regulations (Pechan, 2005). The tool provides data on emission sources, potential pollution control measures and emission reductions, and the costs of implementing those controls.

The core of AirControlNET is a relational database system in which control technologies are linked to sources within EPA emissions inventories. The system contains a database of control measure applicability, efficiency, and cost information for reducing the emissions contributing to ambient concentrations of ozone, PM_{10}, $PM_{2.5}$, SO_2, NO_X, as well as visibility impairment (regional haze) from point, area, and mobile sources. PM_{10} and $PM_{2.5}$ as included in AirControlNET represent primary emissions of PM. The control measure data file in AirControlNET includes not only the technology's control efficiency, and calculated emission reductions for that source, but also estimates the costs (annual and capital) for application of the control measure.

Since the existing version of AirControlNET contains the preprocessed application of control technologies to a predetermined set of EPA emission inventories, direct use of the model in this analysis was not possible. However, Alpine received approval from EPA's Innovative Strategies and Economics Group (ISEG) to modify the AirControlNET version 4.1 source code and data tables in order to make it useful to this study (Sorrels, 2006). The results of the application of this modified version of the code still retain the applicability, efficiency, and cost information from the unmodified version of the source code, but were applied to the CENRAP modeling inventories with updated price index scalars to reflect control costs in 2005-dollars.

Using the modified inventories identified in Section 6.2 above, we ran every available control strategy in AirControlNET against the EGU, non-EGU point, and stationary area source inventories to develop a master list of available, *incremental* control strategies for the entire CENRAP 36 km domain necessary for the ICS to design command-and-control or cost-effectiveness based control strategies by source or domain. Mobile source controls were not processed under this assignment as it would have required multiple iterative runs of the EPA NONROAD and MOBILE6 models to generate the appropriate information. This master list of controls was used in the final development of the control strategy plan as described in the following sections.

Since AirControlNET's control cost equations take into consideration the useful remaining life of installed equipment and estimate the costs of compliance with these measures, two of the four reasonable progress goal considerations (see Section 6.6) are directly met through the results of the model's output.

ALPINE GEOPHYSICS

Table 6-8. Emissions Weighted NETDC (MW) Association.

SCC	Description	NETDC (MW)
10100201	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Wet Bottom (Bituminous Coal)	200
10100202	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Bituminous Coal)	500
10100203	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Cyclone Furnace (Bituminous Coal)	200
10100212	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Tangential) (Bituminous Coal)	500
10100215	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Cell Burner (Bituminous Coal)	1300
10100218	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Atmospheric Fluidized Bed Combustion: Circulating Bed (Bitum. Coal)	200
10100222	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Subbituminous Coal)	400
10100223	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Cyclone Furnace (Subbituminous Coal)	400
10100226	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom Tangential (Subbituminous Coal)	500
10100401	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Normal Firing	400
10100404	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Tangential Firing	500
10100501	External Combustion Boilers; Electric Generation; Distillate Oil; Grades 1 and 2 Oil	400
10100601	External Combustion Boilers; Electric Generation; Natural Gas; Boilers > 100 Million Btu/hr except Tangential	400
10100701	External Combustion Boilers; Electric Generation; Process Gas; Boilers > 100 Million Btu/hr	200
10100801	External Combustion Boilers; Electric Generation; Petroleum Coke; All Boiler Sizes	600
10101204	External Combustion Boilers; Electric Generation; Solid Waste; Tire Derived Fuel : Shredded	200
10300811	External Combustion Boilers; Commercial/Institutional; Landfill Gas; Landfill Gas	200
20100101	Internal Combustion Engines; Electric Generation; Distillate Oil (Diesel); Turbine	200
20100109	Internal Combustion Engines; Electric Generation; Distillate Oil (Diesel); Turbine: Exhaust	200
20100201	Internal Combustion Engines; Electric Generation; Natural Gas; Turbine	200
	All other boilers	100

6.4 Development of AOI-Based Cost Curves

Each Class I area in the CENRAP modeling domain has an associated set of AOIs as identified in other areas of this document. In order to best determine where emission reduction has the greatest benefit, this geography was designed to limit the available source type list from including all sources within the entire domain.

Using a geocoded county list from these AOIs, we parsed the master list of incremental control measures from all non-mobile source types and sources located within the boundaries of the AOIs. This parsed list was then sorted on in incremental cost-effectiveness (marginal cost) basis to determine the most cost effective control suite necessary to attain emission reduction targets for specific pollutants within each AOI. Each individual source or source category (unit or county-SCC combination) had its own cost effectiveness curve generated. In aggregate, the results of these applications are cost curves for each visibility impairing pollutant for all EGU, non-EGU point, and stationary area source within the geographic domain of the AOI. Incremental controls on mobile sources were not considered in this analysis. An illustrative example of the steps involved with the cost effectiveness curve design can be found in the Appendix F of this document. Figures 6-1, 6-2 and Appendix G present actual cost curves for AOI-1 areas associated with the six CENRAP Class I areas projected to be above the reasonable progress glide path.

6.5 Application of Cost Curves to Emission Reduction Needs

Two sets of cost curves have been developed for each pollutant-Class I AOI-1 combination identified as of interest to the ICS. The first marginal cost curve includes the application of all available control measures to all applicable source types within the AOI. The second curve is the result of limiting the control measure application to only the top three residual emission subcategories identified in the 2018 base case for each AOI-pollutant combination. These two curves will allow the ICS to determine if limiting the control scenario to only the highest residual categories will attain reasonable glide path emission reduction objectives while presumably minimizing the number and type of controlled sources in each AOI.

Within each AOI, an emissions reduction target has been established based on the review of relevant and available regional haze aerometric analyses and source attribution modeling. Each emissions reduction target sets the “solve point” of the cost curve and allows us to identify the most cost effective sources of reduction for the pollutants of interest within each impacted AOI.

It is noted that each pollutant-based cost curve developed for this analysis is mutually exclusive of each other pollutant’s cost curve and does not consider the feasibility of multiple control technologies being applied to any one source. Additionally, the information provided in these cost curves is representative of the primary pollutant of control and does not reflect any co-control applicability or disbenefit as a result of the application of that control.

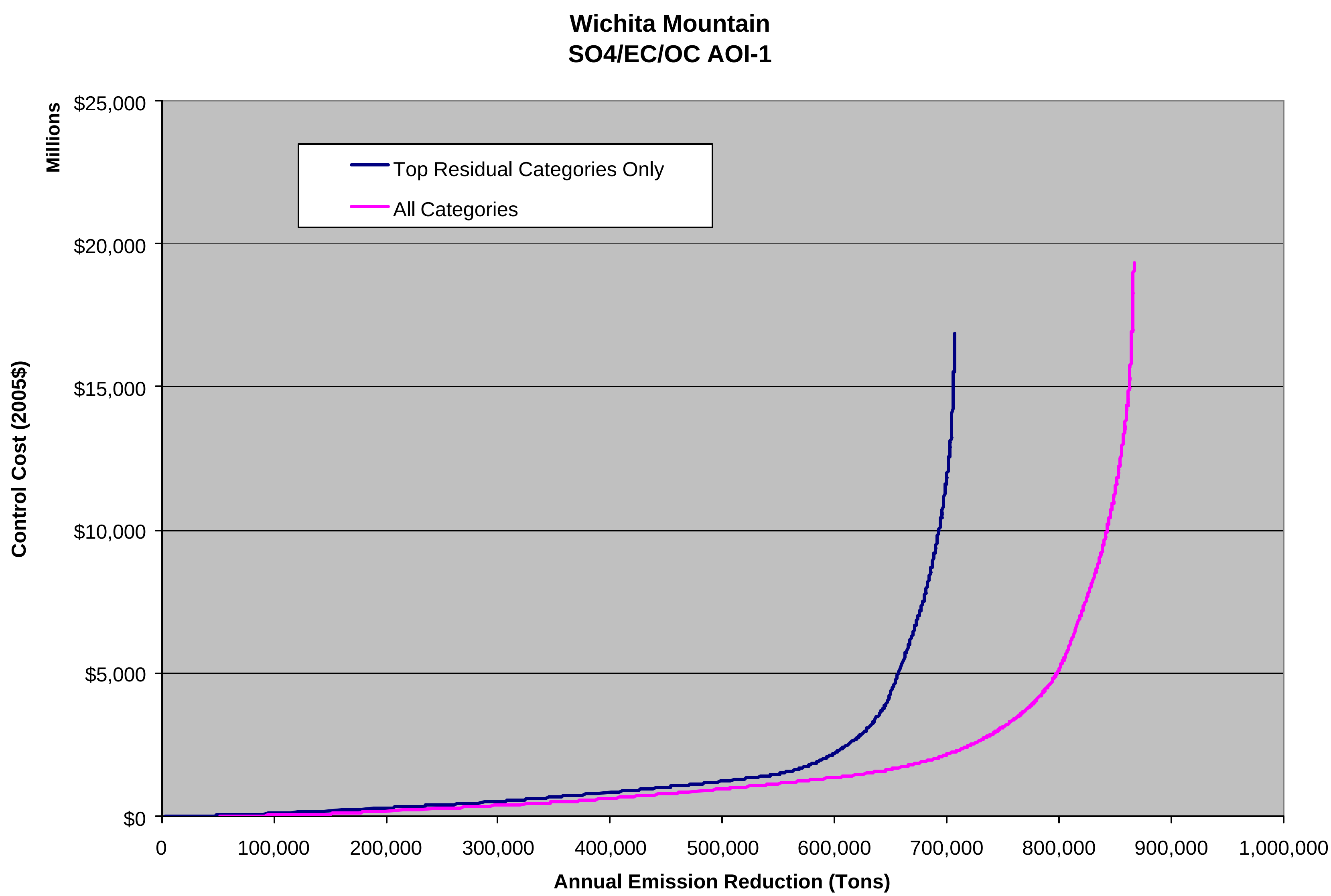


Figure 6-1. Marginal Cost Curve for Wichita Mountain SO4/EC/OC AOI-1.

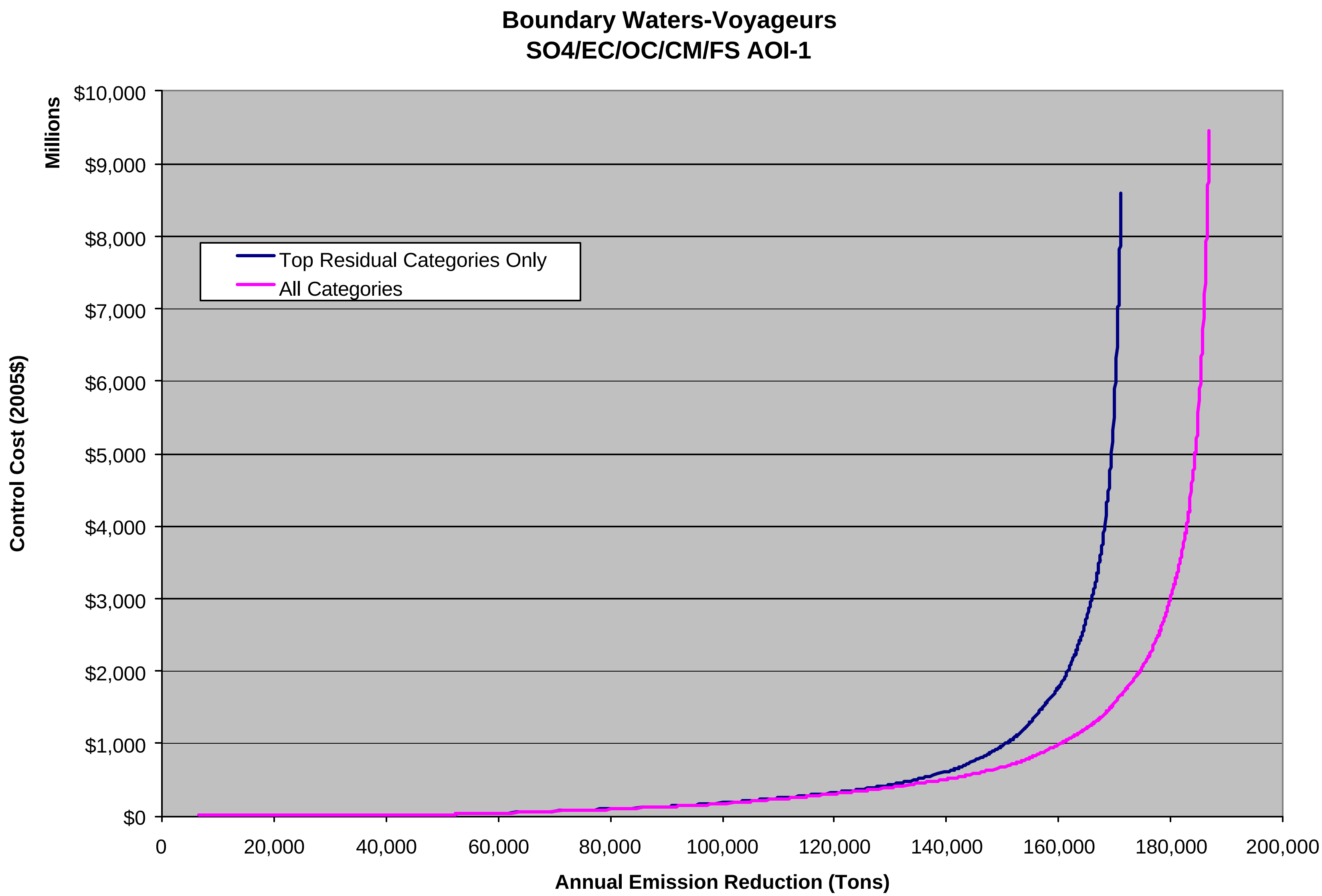


Figure 6-2. Marginal Cost Curve for Boundary Waters – Voyageurs SO4/EC/OC/CM/FS AOI-1.

6.6 Four Factor Analysis for RPG

As part of the regional haze program requirements outlined in 40 CFR 51.308, there are four factors which have been identified as mandatory for purposes of establishing a reasonable progress goal for any mandatory Class I area within a State.

40 CFR 51.308(d)(1)(i)(A) Consider the costs of compliance, the time necessary for compliance, the energy and non-air quality environmental impacts of compliance, and the remaining useful life of any potentially affected sources, and include a demonstration showing how these factors were taken into consideration in selecting the goal.

6.6.1 Cost of Compliance

The cost of compliance factor is used to determine whether compliance costs for sources are reasonable compared to the emission reductions and visibility improvement they will achieve. Costs should be determined for one-time capital costs and ongoing annual operation, maintenance, and upkeep costs.

Through the application of control technologies using the cost equations from the AirControlNET source code, we have identified individual units for control application, identified the design parameters for emission controls, and developed cost estimates based on those design parameters. An estimation of annualized cost of control, based on a one-time capital cost and continual operating and maintenance costs are included in this estimate, where parameters were available in the AirControlNET equations. This application of control cost analysis as applied to the incremental reduction sources defined in this study meets the application of the cost of compliance statutory factor.

6.6.2 Time Necessary for Compliance

The time necessary for compliance factor may be used to adjust the reasonable progress goals to reflect the degree of improvement achievable within the long term strategy period, as opposed to the improvement expected at full implementation of a control measure, if the time needed for full compliance exceeds the length of the long term strategy period. For example, if vendor availability within the period of the long term strategy could not meet the full requirements of the installation schedule outlined by the control strategy, the reasonable progress goals should reflect the visibility improvement anticipated from installation of controls at the percentage of sources that *could* be controlled within the strategy period.

In this particular analysis, a time necessary for compliance factor could not be determined simply based on the emissions inventory and a list of control measures applicable to controllable sources. An eventual SIP could include control strategies that extend beyond the 2018 milestone and the visibility improvement anticipated from installation of controls at the percentage of sources that *could not* be controlled within the first strategy period would have to be counted in a later SIP. Each of these elements would need to be determined on a unit by unit basis.

6.6.3 Energy and Non-Air Quality Environmental Impacts of Compliance

The energy and non-air impacts factor is meant to consider whether the energy requirements (the amount, type, and availability of energy) of the control technology result in energy penalties or benefits. For example, a particular control may require a fuel, water may be required for a cooling tower, or a landfill may be required for disposal of solid waste byproduct, each which are directly unavailable in the area. Since these impacts are State and site specific, they are not addressed in this analysis. Upon the final configuration of the control strategies by the ICS, each participating State, tribe and affected entity should review the control plan to determine whether significant energy burdens or benefits comes as a direct result of the application of a control technology. If determined to be so, the State should quantify this value and include it in the final submitted SIP.

6.6.4 Remaining Useful Life of Potentially Affected Sources

The statutory factor of the remaining useful life of the source is applicable only to those measures which would require retrofitting of control devices at *existing* sources. The remaining useful life of a source affects the annualized costs of retrofit controls and is included in the methods used for calculating annualized costs in the control cost equations modified from EPA's AirControlNET.

CENRAP's emission projections, as well as the control cost equations applied by Alpine, account for the remaining useful life between the year of the reasonable progress analysis and the date the facility permanently stops operations. Since source specific retirements are taken into consideration with the CENRAP forecasts (units are shut down in the year of their retirement) and average retirement rates are applied to control technologies within the control analysis equations, the statutory factor of the remaining useful life of the source has been considered.

In summary, the basis of our resulting control strategy recommendations provide a demonstration of those reasonable progress goal requirements which could be taken into consideration to meet visibility objectives with the data provided for this analysis. The remaining factors are State, tribal and site dependant and could not be addressed here.

7.0 SUMMARY AND RECOMMENDATIONS

7.1 Summary

Alpine's review of all data discussed in the previous sections of this document have identified six Class I areas (Big Bend National Park, Breton Island, Boundary Waters, Guadalupe Mountains, Wichita Mountain, and Voyageurs) within the CENRAP domain, their particular AOIs, ICS defined emission reduction targets, and potential incremental emission reductions recommended for CENRAP modeling. For each area, sulfate and to a lesser extent, nitrate reductions were shown to be most beneficial during the 20 percent worst visibility days in 2002.

Alpine has configured subregional control strategies based on direction provided by the ICS to use single precursor emission reduction assumptions with a marginal cost per ton cutoff of $5,000 per ton reduced. Emission targets were identified by the ICS for each Class I area AOI to exceed the reasonable progress glide slope. These targets were established as 25 percent more reduction than was identified in Table 5-3 and were to be taken from any available source, not just those identified as having the highest residual emissions contribution to the Class I area AOI. Table 7-1 presents a summary of each of these strategies.

Table 7-1. Subregional control strategy summary for single precursor emission reduction targets.

		SO2 Annual Emission Reduction (Tons)			Control Strategy
Class I Area	ST	ICS Established Reduction Target	Subregional Control Strategy Reductions	Control Strategy Total Cost ($2005)	Average Cost Per Ton ($/ton reduced)
Breton Island	LA	385,000	119,966	$203,443,093	$1,696
Boundary Waters	MN	40,000	46,301	$107,233,124	$2,316
Voyageurs	MN	28,750			
Wichita Mountains	OK	93,750	99,479	$21,752,713	$219
Guadalupe Mountains	TX	162,500	115,936	$319,001,184	$2,752
Big Bend Nat'l Park	TX	150,000			

For three of the six CENRAP Class I areas projected to be above the reasonable progress glide slope in 2018, control strategies have been prepared which meet the emission reduction targets recommended by the ICS. These areas (Boundary Waters, Wichita Mountains, and Voyageurs) all can meet the ICS defined targets while staying within the single precursor, $5,000 per ton reduced limitations.

We also have determined that as a result of the implementation of the list of additional point and area source controls in each primary AOI the remaining three Class I areas within the CENRAP domain (Big Bend National Park, Breton Island, and Guadalupe Mountains) modeled to be above the reasonable progress glide slope will be unable to achieve a level of emissions reduction necessary to bring these areas under the glide slope by 2018 using the ICS identified control strategy definitions. Influences such as incrementally uncontrollable source categories, marginal cost effectiveness values greater than $5,000 per ton reduced, and international and inter-RPO emission transport prevent strategies from being configured for these Class I areas.

In particular, recent BRAVO research (see, for example Barna et al. 2006) shows that Mexican SO_2 sources account for up to 23% of the observed annual sulfate levels at Big Bend. During the summer months, Mexican SO_2 emissions sources can account for as much as 70% of the sulfate at Big Bend. Barna et al. also show that SO_2 emission sources for the Eastern U.S. are the biggest culprit to high sulfate at Big Bend during the high $PM_{2.5}$ summer days; and SO_2 from the Eastern US and Texas are the biggest contributor to high sulfate at Big Bend during the high $PM_{2.5}$ fall days.

In both of these episode examples, regardless of the emissions reduction achieved by CENRAP with the available source category and technology applications, there still is an emissions component which is directly out of their control. Additional consultation with inter-RPO and international agencies may be required to adequately co-configure strategies to bring these areas into attainment.

7.2 Recommendations

7.2.1 Regional Controls

As each of the six Class I areas projected to be above the reasonable progress glide path (and all of the other Class I AOIs in the CENRAP domain) are dominated by EGU SO_2 and NO_X emissions and many of these area AOIs intersect with States currently excluded by the EPA CAIR rule, *we recommend that CENRAP consider a control scenario which would reduce EGU emissions in non-CAIR States to levels comparable to those promulgated by EPA in the final CAIR regulation.* In addition to this regional strategy proposal, *we further recommend that the ICS consider individual CENRAP States within Class I area AOIs projected above the reasonable progress glide slope to meet CAIR emissions budgets without the interstate trading aspect of the rule*. This nuance may prevent emission reductions from being transferred to areas outside of the influential zones of the affected Class I areas and focus the reductions in those upwind areas with greatest impact on meeting visibility objective goals.

These regional controls could be modeled in multiple ways. Two noted methods being to develop an additional IPM run configured to take into account the CAIR reductions within non-CAIR States with or without the constraint of trading noted above. The second method would be to determine an emission budget (following EPA methods in the CAIR final rule) to determine State level targets for emission reduction. Using these targets, CENRAP could then apply the marginal cost curves developed for this analysis, but limit the solution to only EGU sources identified as “CAIR eligible”. This approach would not take into account any trading or participation in the bank and trade system, but would give an estimate of the regional emission reductions associated with the strategy.

7.2.2 Subregional Controls

In lieu of a single regional control option applied consistently across the entire CENRAP domain, individual subregional controls could be applied to reduce emissions within certain Class I area AOIs. Based on the single precursor emission reduction target calculations defined elsewhere in this document, subregional control strategies can be defined for three of the Class I areas projected to be above the reasonable progress glide path. In each case, the marginal cost curves (based on the application of all available control options on all controllable industries and source types) allow the selection of control technologies for sources within an AOI-1 that attains the ICS defined emission reduction targets. Details of these control strategies are presented in Tables 7-2 and 7-3. Note that as Boundary Waters and Voyageurs are associated within the same AOI-1, the larger of the two emission reduction targets was used to configure a control strategy that would meet both areas' needs.

However, as noted in this document, the application of incremental control on all controllable point and area sources within the AOIs still fails to meet the visibility objectives of three Class I areas modeled to be above the reasonable progress glide slope. For this reason, *we additionally recommend that the ICS consider applying the remaining reasonably cost effective control technologies to sources within States and tribal lands contained in the boundaries of the three target Class I area AOIs.* As part of the demonstration of reasonable progress, the application of reasonably cost effective controls to all emission sources and source types through a process as described in this document appears to provide support that the four reasonable progress goal considerations were taken into account where available. As is demonstrated for the Boundary Waters and Voyageurs AOI-1 above, the AOI-1 for Big Bend and Guadalupe Mountains share the same emission reduction target. In this case, however, the target cannot be fully achieved. Tables 7-4 and 7-5 present the details of these strategies.

For those Class I areas outside of CENRAP's domain who based on CENRAP modeling did not forecast below the reasonable progress glide slope, we submit to the ICS our data of incremental control strategy application and cost curves based on existing modeling and inventory assumptions provided by CENRAP to date for purposes of consultation with those States in which the affected Class I areas are located. We have not presented these non-CENRAP data as part of this document but much of the basic information is presented, where appropriate, in the supporting appendixes.

Table 7-2. Subregional control strategy defined for Boundary Waters / Voyageurs SO4 AOI-1.

									BOWA/VOYA SO2 Control Application		
FIPSST	FIPSCNTY	State	County	Plant ID	Plant Name	Point ID	SIC	Control Measure	Ton Reduced	Cost ($2005)	Marginal CPT
27	037	Minnesota	Dakota Co	2703700011	FLINT HILLS RESOURCES LP - PINE BEND	EU111	2911	Sulfur Recovery and/or Tail Gas Treatment	290	$401,526	$1,383
27	037	Minnesota	Dakota Co	2703700011	FLINT HILLS RESOURCES LP - PINE BEND	EU045	2911	Sulfur Recovery and/or Tail Gas Treatment	286	$395,189	$1,383
27	037	Minnesota	Dakota Co	2703700011	FLINT HILLS RESOURCES LP - PINE BEND	EU088	2911	Sulfur Recovery and/or Tail Gas Treatment	62	$86,034	$1,383
27	163	Minnesota	Washington Co	2716300003	MARATHON ASHLAND PETROLEUM LLC	EU019	2911	Sulfur Recovery and/or Tail Gas Treatment	11	$14,854	$1,383
~~55~~	~~123~~	~~Wisconsin~~	~~Vernon Co~~	~~663020930~~	~~DAIRYLAND POWER COOP GENOA STATION-EOP~~	~~B20~~	~~4911~~	~~FGD Wet Scrubber~~	~~16,904~~	~~$28,492,444~~	~~$1,686~~
19	179	Iowa	Wapello Co	90-07-001	IPL - OTTUMWA GENERATING STATION	143977	4911	FGD Wet Scrubber	15,897	$28,492,444	$1,792
19	113	Iowa	Linn Co	57-01-004	0	0	0	FGD	2,042	$4,302,128	$2,107
55	123	Wisconsin	Vernon Co	663020930	DAIRYLAND POWER COOP GENOA STATION-EOP	B20	4911	FGD Wet Scrubber	12,569	$28,492,444	$2,267
31	109	Nebraska	Lancaster Co	0005	NPPD SHELDON STATION	001	4911	FGD Wet Scrubber	6,079	$16,556,061	$2,724
19	193	Iowa	Woodbury Co	97-04-010	MIDAMERICAN ENERGY CO. - GEORGE NEAL NOR	148780	4911	FGD Wet Scrubber	9,065	$28,492,444	$3,143
								Overall Control Strategy	**46,301**	**$107,233,124**	**$2,316**

Duplicate entry in 2018d modeling inventory.

Table 7-3. Subregional control strategy defined for Wichita Mountains SO4 AOI-1.

									WIMO SO2 Control Application		
FIPSST	FIPSCNTY	State	County	Plant ID	Plant Name	Point ID	SIC	Control Measure	Ton Reduced	Cost ($2005)	Marginal CPT
29	093	Missouri	Iron Co	0008	DOE RUN COMPANY-GLOVER SMELTER	8390	3339	FGD	51,834	$4,351,167	$84
48	201	Texas	Harris Co	37	HOUSTON PLANT	000008	2819	Increase % Conversion to Meet NSPS (99.7)	3,486	$670,008	$192
22	033	Louisiana	East Baton Rouge Par	0033	RHODIA INC/BR FAC	02	2869	Increase % Conversion to Meet NSPS (99.7)	7,090	$1,884,093	$266
22	005	Louisiana	Ascension Par	0007	DUPONT CHEMICALS/BURNSIDE PLANT	01	2819	Increase % Conversion to Meet NSPS (99.7)	11,284	$3,896,018	$345
29	099	Missouri	Jefferson Co	0003	DOE RUN COMPANY-HERCULANEUM SMELTER	11722	3339	FGD	10,653	$4,320,204	$406
48	201	Texas	Harris Co	37	HOUSTON PLANT	000011	2819	Increase % Conversion to Meet NSPS (99.7)	5,953	$2,510,908	$422
22	005	Louisiana	Ascension Par	0028	PCS NITROGEN FERTILIZER,L.P./GEISMAR	01	2873	Increase % Conversion to Meet NSPS (99.7)	9,179	$4,120,315	$449
								Overall Control Strategy	**99,479**	**$21,752,713**	**$219**

Table 7-4. Subregional control strategy defined for Breton Island SO4 AOI-1.

FIPSST	FIPSCNTY	State	County	Plant ID	Plant Name	Point ID	SIC	Control Measure	BRET SO2 Control Application Ton Reduced	Cost ($2005)	Marginal CPT
22	033	Louisiana	East Baton Rouge Par	0033	RHODIA INC/BR FAC	02	2869	Increase % Conversion to Meet NSPS (99.7)	7,090	$1,884,093	$266
22	005	Louisiana	Ascension Par	0007	DUPONT CHEMICALS/BURNSIDE PLANT	01	2819	Increase % Conversion to Meet NSPS (99.7)	11,284	$3,896,018	$345
22	005	Louisiana	Ascension Par	0028	PCS NITROGEN FERTILIZER,L.P./GEISMAR	01	2873	Increase % Conversion to Meet NSPS (99.7)	9,179	$4,120,315	$449
22	033	Louisiana	East Baton Rouge Par	0033	RHODIA INC/BR FAC	03	2869	Increase % Conversion to Meet NSPS (99.7)	2,693	$1,884,093	$700
01	097	Alabama	Mobile Co	5009	AKZO NOBEL CHEMICALS INC	004	2819	Increase % Conversion to Meet NSPS (99.7)	2,183	$1,817,521	$832
12	113	Florida	Santa Rosa Co	1130005	EXXONMOBIL PRODUCTION COMPANY	34	1311	Sulfur Recovery and/or Tail Gas Treatment	1,702	$2,354,901	$1,383
22	033	Louisiana	East Baton Rouge Par	0015	EXXONMOBIL REF & SUPPLY CO/B R REFINERY	68	2911	Sulfur Recovery and/or Tail Gas Treatment	64	$88,364	$1,383
22	033	Louisiana	East Baton Rouge Par	0015	EXXONMOBIL REF & SUPPLY CO/B R REFINERY	69	2911	Sulfur Recovery and/or Tail Gas Treatment	64	$88,364	$1,383
22	095	Louisiana	St. John The Baptist	0013	MARATHON ASHLAND PETROLEUM LLC/LA REFINI	14	2911	Sulfur Recovery and/or Tail Gas Treatment	47	$64,441	$1,383
22	095	Louisiana	St. John The Baptist	0013	MARATHON ASHLAND PETROLEUM LLC/LA REFINI	70	2911	Sulfur Recovery and/or Tail Gas Treatment	31	$42,396	$1,383
22	095	Louisiana	St. John The Baptist	0013	MARATHON ASHLAND PETROLEUM LLC/LA REFINI	V2	2911	Sulfur Recovery and/or Tail Gas Treatment	26	$35,613	$1,383
22	077	Louisiana	Pointe Coupee Par	0005	LA GENERATING LLC/BIG CAJUN 2 PWR PLNT	01	4911	FGD Wet Scrubber	16,126	$28,492,444	$1,767
22	077	Louisiana	Pointe Coupee Par	0005	LA GENERATING LLC/BIG CAJUN 2 PWR PLNT	02	4911	FGD Wet Scrubber	15,618	$28,492,444	$1,824
12	033	Florida	Escambia Co	0330045	GULF POWER COMPANY CRIST ELECTRIC GENERA	6	4911	FGD Wet Scrubber	11,179	$20,964,424	$1,875
22	077	Louisiana	Pointe Coupee Par	0005	LA GENERATING LLC/BIG CAJUN 2 PWR PLNT	03	4911	FGD Wet Scrubber	15,022	$28,492,444	$1,897
01	097	Alabama	Mobile Co	1001	ALABAMA POWER COMPANY - BARRY	004	4911	FGD Wet Scrubber	8,396	$18,827,395	$2,242
28	059	Mississippi	Jackson Co	2805900058	CHEVRON PRODUCTS COMPANY, PASCAGOULA REF	051	2911	FGD	1,638	$4,349,179	$2,655
22	051	Louisiana	Jefferson Par	0004	CYTEC INDUSTRIES,INC/FORTIER PLNT	57	2821	Increase % Conversion to Meet NSPS (99.7)	1,087	$3,027,047	$2,784
01	097	Alabama	Mobile Co	1001	ALABAMA POWER COMPANY - BARRY	003	4911	FGD Wet Scrubber	4,712	$13,574,846	$2,881
01	097	Alabama	Mobile Co	1001	ALABAMA POWER COMPANY - BARRY	002	4911	FGD Wet Scrubber	4,631	$13,522,645	$2,920
01	047	Alabama	Dallas Co	0003	INTERNATIONAL PAPER COMPANY	003	2611	FGD	1,971	$7,156,048	$3,630
12	033	Florida	Escambia Co	0330045	GULF POWER COMPANY CRIST ELECTRIC GENERA	4	4911	FGD Wet Scrubber	2,734	$10,069,644	$3,683
12	033	Florida	Escambia Co	0330045	GULF POWER COMPANY CRIST ELECTRIC GENERA	5	4911	FGD Wet Scrubber	2,489	$10,198,414	$4,097
								Overall Control Strategy	**119,966**	**$203,443,093**	**$1,696**

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Table 7-5. Subregional control strategy defined for Big Bend / Guadalupe Mountains SO4 AOI-1.

									BIBE/GUMO SO2 Control Application		
FIPSST	**FIPSCNTY**	**State**	**County**	**Plant ID**	**Plant Name**	**Point ID**	**SIC**	**Control Measure**	**Ton Reduced**	**Cost ($2005)**	**Marginal CPT**
48	201	Texas	Harris Co	37	HOUSTON PLANT	000008	2819	Increase % Conversion to Meet NSPS (99.7)	3,486	$670,008	$192
48	201	Texas	Harris Co	37	HOUSTON PLANT	000011	2819	Increase % Conversion to Meet NSPS (99.7)	5,953	$2,510,908	$422
48	039	Texas	Brazoria Co	10	SWEENY REFINERY PETROCHEM	000203	2911	FGD	883	$429,763	$487
48	355	Texas	Nueces Co	3	CORPUS CHRISTI REFINERY	000174	2911	Sulfur Recovery and/or Tail Gas Treatment	1,430	$1,978,038	$1,383
48	167	Texas	Galveston Co	1	TEXAS CITY REFINERY	000239	2911	Sulfur Recovery and/or Tail Gas Treatment	478	$660,954	$1,383
48	039	Texas	Brazoria Co	10	SWEENY REFINERY PETROCHEM	000205	2911	Sulfur Recovery and/or Tail Gas Treatment	374	$518,052	$1,383
48	161	Texas	Freestone Co	9	EMBRIDGE ENERGY TEAGUE PL	000004	1311	Sulfur Recovery and/or Tail Gas Treatment	324	$448,705	$1,383
48	355	Texas	Nueces Co	3	CORPUS CHRISTI REFINERY	000174	2911	Sulfur Recovery and/or Tail Gas Treatment	63	$86,977	$1,383
48	201	Texas	Harris Co	39	DEER PARK PLANT	001295	2911	Sulfur Recovery and/or Tail Gas Treatment	56	$77,549	$1,383
48	355	Texas	Nueces Co	3	CORPUS CHRISTI REFINERY	000174	2911	Sulfur Recovery and/or Tail Gas Treatment	49	$67,251	$1,383
48	355	Texas	Nueces Co	20	CORPUS CHRISTI EAST PLANT	000156	2911	Sulfur Recovery and/or Tail Gas Treatment	27	$37,762	$1,383
48	201	Texas	Harris Co	39	DEER PARK PLANT	000208	2911	FGD	4,942	$8,474,217	$1,715
48	175	Texas	Goliad Co	2	COLETO CREEK PLANT	000001	4911	FGD Wet Scrubber	14,490	$28,492,444	$1,966
48	389	Texas	Reeves Co	2	WAHA PLANT	000031	4922	FGD	3,653	$8,153,168	$2,232
48	167	Texas	Galveston Co	5	TEXAS CITY REFINERY	000068	2911	FGD	2,293	$5,993,771	$2,614
48	029	Texas	Bexar Co	63	SOMMERS DEELY SPRUCE PWR	000002	4911	FGD Wet Scrubber	9,755	$28,492,444	$2,921
48	029	Texas	Bexar Co	63	SOMMERS DEELY SPRUCE PWR	000004	4911	FGD Wet Scrubber	9,595	$28,492,444	$2,970
48	029	Texas	Bexar Co	63	SOMMERS DEELY SPRUCE PWR	000004	4911	FGD Wet Scrubber	9,128	$28,492,444	$3,121
48	331	Texas	Milam Co	1	ALCOA SANDOW PLANT	000011	3334	FGD	14,306	$49,048,714	$3,429
48	331	Texas	Milam Co	1	ALCOA SANDOW PLANT	000010	3334	FGD	14,305	$49,048,714	$3,429
48	331	Texas	Milam Co	1	ALCOA SANDOW PLANT	000012	3334	FGD	14,143	$49,048,714	$3,468
48	349	Texas	Navarro Co	11	STREETMAN PLANT	000015	3295	FGD	2,443	$9,903,980	$4,054
48	227	Texas	Howard Co	1	BIG SPRING REFINERY	000267	2911	FGD	2,060	$9,638,812	$4,679
48	135	Texas	Ector Co	22	GOLDSMITH GASOLINE PLANT	000133	1321	FGD	1,700	$8,235,351	$4,844
								Overall Control Strategy	**115,936**	**$319,001,184**	**$2,752**

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