Technical Support Document for the Minnesota State Implementation Plan for Regional Haze

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I. Introduction

This document details the modeling analyses conducted to support the policy decisions made in Minnesota's Regional Haze State Implementation Plan (RH SIP). The plan is available at http://www.pca.state.mn.us/air/regionalhaze.html. To comport with the July 1, 1999 publication of the Regional Haze Rule in the Federal Register, modeling analyses support the:

- Establishment of Reasonable Progress Goals (RPG) for Class I areas that ensure visibility on the worst impaired days improves toward natural visibility conditions experienced on those days, and that ensure no degradation of visibility occurs on the least impaired days;
- Determination of future visibility causing pollutant emissions levels needed, and reductions needed from individual states, to meet the RPG;
- Calculation of the resulting degree of visibility improvement that would be achieved at each Class I area;
- Comparison of visibility improvement between proposed control strategies; and the
- Conclusion that the long-term strategy provides for reasonable progress.

I.a. Establishment of RPGs.

The Regional Haze rule requires States to "establish goals that provide for reasonable progress toward achieving natural visibility conditions for each Class I area within a State"[1]; improving visibility on the most impaired days and not degrading visibility on the least impaired days. Minnesota has two federal Class I areas, the Boundary Waters Canoe Area Wilderness (Boundary Waters) and Voyageurs National Park (Voyageurs). Both Minnesota Class I areas are located along the State's Northern border, shared with Canada, as shown in Figure I.1. Also shown in the Figure is Isle Royale, a Michigan Class I area, in close proximity to Boundary Waters and Voyageurs.

Although Minnesota impacts visibility at Class I areas other than those within the State borders, for example Isle Royale, the focus of this document is on Boundary Waters and Voyageurs. This document shows that Minnesota has the greatest visibility impact on these two Class I areas. Any future emissions reductions in the State made to improve visibility in Boundary Waters and Voyageurs should have a commensurate affect on any other Class I areas impacted by Minnesota.

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[1] 40 CFR 51.308(d)(1).

Figure I.1. Minnesota Class I Areas—Voyageurs and Boundary Waters—and Michigan Class I Area—Isle Royale.

The core of the visibility assessment is the baseline and natural visibility conditions based on observed data collected at Interagency Monitoring of Protected Visual Environments (IMPROVE) monitors, made available through the Visibility Information Exchange Web System (VIEWS)[2]. The baseline conditions are developed from five years of monitoring data, and represent the starting point from which reasonable progress is measured. The Regional Haze Rule prescribes the baseline period as the years 2000-2004[3], and defines baseline visibility conditions as the average of the most—or the 20 percent worst—visibility impaired days, and the average of the least—or the 20 percent best—visibility impaired days, calculated from the monitoring data for each year of the baseline, and then averaged over the 5-year baseline period. The ultimate goal is to reach natural visibility conditions in 2064. Reasonable progress goals are established as interim goals representing progress toward that end. The year 2018 is the initial year for developing a reasonable progress goal. This document supports the reasonable progress goal for 2018.

Fine particles less than 2.5 microns (µm) in size ($PM_{2.5}$) are primarily responsible for impaired visibility.[4] $PM_{2.5}$ is composed of several pollutant species; nitrate, sulfate, organic carbon, elemental carbon, fine soil, sea salt (which is negligible in Minnesota Class I areas) and water.

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[2] http://vista.cira.colostate.edu/views/

[3] 40 CFR 51.308(d)(2).

[4] Malm (2000)

Coarse particulate mass (>2.5 µm, but ≤10 µm diameter) is also included in the visibility equation, but—as we show in this document—is an insignificant component of visibility impairment at Boundary Waters and Voyageurs.

We calculate visibility using the individual components described above in the IMPROVE algorithm adopted by the IMPROVE Steering Committee in December 2005[5]. Details on the equation and its use for developing the RPG at Boundary Waters and Voyageurs are provided in this document. The solution to the IMPROVE equation is in the form of extinction (b_{ext}). The Regional Haze rule requires visibility to be converted to, and expressed in, deciviews (dv). In the deciview scale, "a 1 to 2 deciview difference corresponds to a small, visibly perceptible change in scene appearance…"[6] by the human observer.

Models are used to establish an RPG by simulating the future visibility conditions that will result from future emission estimates. EPA guidelines[7] outline the methodology for modeling future conditions and applying modeled results to develop reasonable progress goals.

Emissions from a "base", or known, year (i.e. 2002) representing the baseline period and from a year in the future (i.e. 2018) are each modeled. The model results are used to estimate the air concentration change from base year to future year inventories. These air concentration changes are in the form of ratios of the future year air concentrations to the base year concentrations predicted near a monitor location and averaged over the same 20 percent worst and 20 percent best days in the base year, which were also used to establish baseline visibility conditions. A ratio is developed for each specie comprising $PM_{2.5}$ concentration (sulfate, nitrate, organic carbon, elemental carbon, fine soil [≤2.5 µm diameter], and coarse particulate matter [>2.5 µm, but ≤10 µm diameter]). The ratio is called a Relative Response Factor (RRF). Applying the RRFs to baseline monitoring conditions, for each specie comprising $PM_{2.5}$, provides the estimate of future visibility conditions, the RPG.

Cognizant of the intense resources required to conduct modeling analyses of this nature, EPA guidelines for regional haze do not suggest modeling the multiple years comprising the 5-year baseline period, but discuss modeling one full year as a "logical goal". The methodology in the EPA guidelines attempts to take into account the year-to-year variability of the meteorology in the monitored baseline. The middle year (2002) will have more weight due to the fact that the 2002 emissions and the meteorology are used in the modeling to develop the RRF applied to the baseline conditions. This application of the model results is intended to balance the resource limitations of conducting multiple years of modeling, and to "help reduce the impact of possible over-or under-estimations by the dispersion model due to emissions, meteorology, or general selection of other model input parameters".

Modeled results differ depending on the meteorology used. In this document, we describe how the RRF—and hence the RPG—are sensitive to meteorology and therefore the locations in the United States where the modeled emission reductions occur. Using 2005 meteorology, the RPG for Boundary Waters and Voyageurs is a little more optimistic, apparently taking greater

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[5] http://vista.cira.colostate.edu/views/Web/RHR/RHR_Planning.aspx
[6] Pitchford, et al. (1994)
[7] EPA, OAQPS, (2007)

advantage of emissions reductions occurring in states located Southeast of the Minnesota Class I areas.

In this document we show that in the upper-Midwest Class I areas, most $PM_{2.5}$ causing visibility impairment is secondarily formed from emissions of sulfur dioxide from power plants and other industrial sources, nitrogen oxides from motor vehicles and industrial sources, and ammonia from agricultural operations. These emissions lead to the formation of ammonium nitrate and ammonium sulfate. Volatile organic compounds from natural sources like trees can contribute to secondary organic aerosols, or organic carbon. But wildfires are the source that dictates days of worst visibility impairment due to organic carbon. Of 22-24 days in 2002 comprising the 20 percent worst visibility days at Boundary Waters and Voyageurs, five days are identified as worst-impaired visibility days in 2002 because of organic carbon from wildfires. The remaining worst-impaired days are due to ammonium nitrate and ammonium sulfate.

I.b. Determination of Future Visibility—Pollutant Emissions Levels, and Reductions Needed from Individual States.

The resource requirements for conducting regional scale modeling, and the need to coordinate emission estimates and control strategies, make it necessary to consolidate resources and develop the modeling analyses through a Regional Planning Organization (RPO) process. RPOs were developed to address the need to work in concert with other States and Tribes. Association in the various RPOs is shown in Figure I.2.

Figure I.2. Regional Planning Organizations.

Although Minnesota is affiliated with the Central Regional Air Planning Association (CENRAP), the state also works closely with the Midwest Regional Planning Organization (MRPO) for the technical analysis. Visibility conditions in Isle Royale (see Figure I.1) and Seney Class I areas, both within Michigan, are assessed by the MRPO. Michigan is a member of MRPO. The characteristics of regional haze have greater similarity among the MRPO and

Minnesota's Class I areas than among Minnesota's and the more southern Class I areas in CENRAP. For this reason, Minnesota has recognized the benefit in furthering its technical analyses of the Upper Midwest Class I areas along with the MRPO. There are two additional reasons Minnesota emphasized collaboration with the MRPO in regard to modeling:

1. The MRPO supports contributing states in conducting modeling within each state. This appeals to Minnesota's desire to explore answers to questions that are too specific to Minnesota to be feasible to address through the larger RPO process; and
2. Along with the five member States of the MRPO, Minnesota is the only other State in the U.S. that is within EPA Region V. The staff of this region will review SIPs from the six States. Thus, it is useful to have some technical collaboration with the other Region V States.

In 2004, the MRPO and CENRAP informally agreed to work together to address the Minnesota Class I Areas with the MRPO taking the lead. The MRPO supported Minnesota's modeling capabilities to allow the State to investigate visibility issues that address more localized concerns, for example, the impacts of individual sources located near Boundary Waters and Voyageurs. Ultimately, regional haze modeling at Boundary Waters and Voyageurs was performed by CENRAP, MRPO and by Minnesota; MRPO conducted modeling using both a 2002 base year and 2005 base year.

Minnesota conducted its modeling to specifically assess visibility impacts from Minnesota sources near the Class I areas, as this type of modeling falls outside the scope of RPO work. Minnesota supplemented the MRPO modeling by focusing on the two Minnesota Class I areas and the visibility impacts of nearby point sources located within Minnesota. Because Minnesota would like to better correlate results with CENRAP, and because Minnesota did not have a final version of the State 2005 emissions inventory at the time the new base year modeling commenced, Minnesota retains the MRPO-developed emissions and meteorological data inputs from the 2002 base year and 2018 future year base case with some adjustments. These include some changes reflected in the development of the MRPO 2005 case and some modifications specific to Minnesota, and is referred to throughout this chapter as the $\text{Minnesota}_{\text{(MRPO)}}$ case.

$\text{Minnesota}_{\text{(MRPO)}}$ case modeling for the 2002 base year identifies Minnesota as by far the greatest contributor to impaired visibility in Boundary Waters and Voyageurs. Other significant—approximately five percent or more—contributors are Illinois, Iowa, Missouri, North Dakota, and Wisconsin. Figure I.3 shows State contributions to ammonium nitrate and ammonium sulfate in 2002. During the 16-year period between 2002 and 2018, several emission reduction programs will be implemented despite the Regional Haze Rule. These include Federal and State regulations, legislation and permit actions. Termed "on-the-books" controls, these measures comprise the bulk of the emissions reductions demonstrating reasonable progress. Emissions in 2002 and 2018 for the significant contributing States are shown in Table I.2. From the six significant contributing states alone, SO_2 emissions are reduced by 456,000 tons per year, and NOx are reduced by 1,350,000 tons per year. Ammonia emissions are estimated to increase by 339,000 tons per year, making more ammonia available to form ammonium nitrate and ammonium sulfate.

The emission changes based on on-the-books controls from all contributors, not just the six States listed above, result in an overall decrease in visibility impairment due to ammonium nitrate and ammonium sulfate of about 8 inverse megameters (Mm^{-1}) at Boundary Waters and 5 Mm^{-1} at Voyageurs in 2018. Inverse megameters are the units for extinction. Although reasonable progress goals are depicted in deciviews, contributions of individual components, source sectors and source regions are only evaluated in terms of extinction. An extinction coefficient less than 10 Mm^{-1} will produce a negative value in deciviews. Assessing contributions to visibility with negative values would be confusing. The resulting changes in State contribution to visibility due to ammonium nitrate and ammonium sulfate are shown in Figure I.4.

Figure I.3. State Contributions to Ammonium Nitrate and Ammonium Sulfate Light Extinction at Boundary Waters and Voyageurs for the Year 2002.

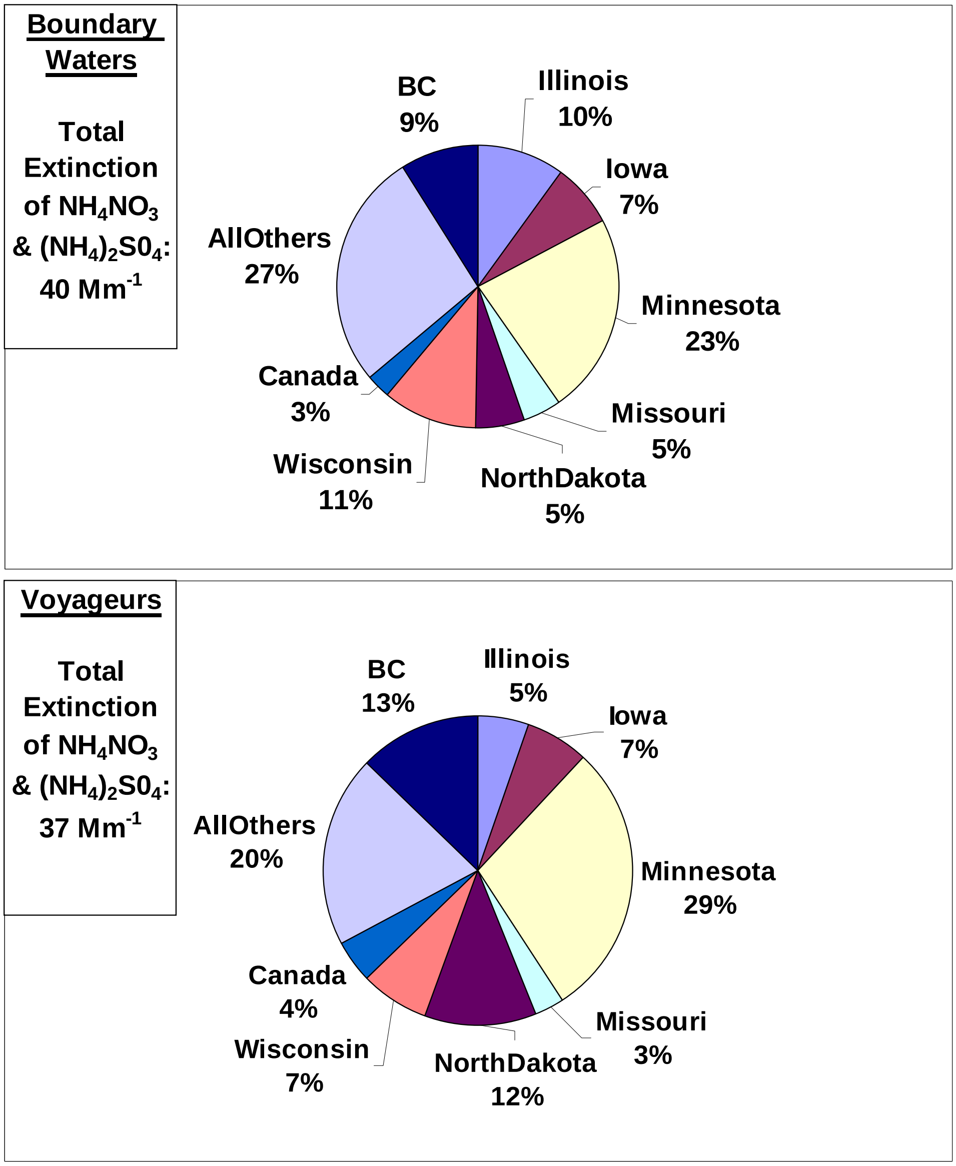
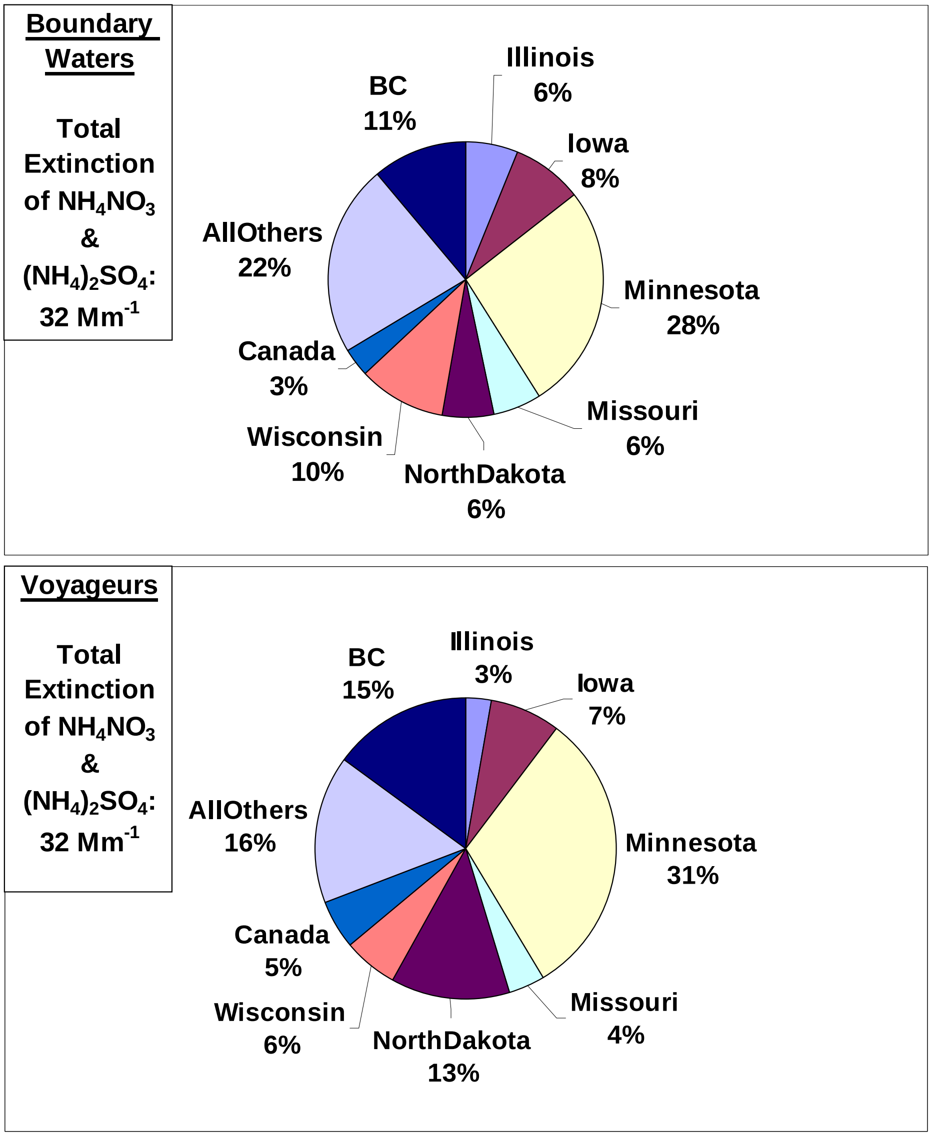


Table I.2. Annual Emissions in Tons for the Significant Contributing States in 2002 and 2018.

State	2002			2018			Difference (2018-2002)		
	SO_2	NO_X	NH_3	SO_2	NO_X	NH_3	SO_2	NO_X	NH_3
Illinois	536,000	936,000	136,000	262,000	440,000	196,000	-274,000	-496,000	60,000
Iowa	192,000	381,000	254,000	173,000	234,000	371,000	-19,000	-147,000	117,000
Minnesota	163,000	516,000	185,000	108,000	317,000	253,000	-55,000	-199,000	68,000
Missouri	394,000	545,000	133,000	416,000	278,000	190,000	22,000	-267,000	57,000
North Dakota	206,000	182,000	70,400	125,000	170,000	103,000	-81,000	-12,000	32,600
Wisconsin	266,000	427,000	123,000	217,000	203,000	127,000	-49,000	-224,000	4,000

Figure I.4. State Contributions to Ammonium Nitrate and Ammonium Sulfate Light Extinction at Boundary Waters and Voyageurs for the Year 2018 after Implementation of On-the-Books Controls.



Minnesota, the host State to Boundary Waters and Voyageurs, will always have the greatest contribution to extinction in the Class I Areas, despite reasonable emission reduction estimates. The percentage contribution from Minnesota and bordering States increases as large emission reductions occur in distant States. A significant shift of contribution to the remaining extinction at Boundary Waters goes to Minnesota apparently due to large modeled SO_2 reductions in more distant States, especially in Illinois. Monitoring data shows us that the majority of worst visibility days at Boundary Waters in 2002 are due to sulfate. Although sulfate is formed all year around, most is formed in the warmer months of the year. Prevailing winds during this period are from the Southeast. Thus, Boundary Waters benefits from emission reductions occurring in those locations.

The contribution shift is also true for Voyageurs, but not as much. At Voyageurs, monitoring data shows us that the cause for most of the worst visibility days in 2002 are about equally divided between sulfate and nitrate. Ammonium nitrate is formed in the winter, when prevailing winds are from the West and Northwest. This may prevent Voyageurs from fully benefiting from the over 1,300,000 tons of NO_X reductions mostly occurring in Minnesota and the four other significantly contributing States located to the East and Southeast.

Further analysis of Minnesota's contribution to impaired visibility at Boundary Waters and Voyageurs indicates that six counties—Carlton, Cook, Itasca, Koochiching, Lake and St. Louis—in Northeast Minnesota contribute more than half of the States total contribution of extinction at Boundary Waters, and just under half of the contribution to extinction at Voyageurs. A plan to reduce SO_2 and NO_X by 30% of 2002 emission levels was determined reasonable in that part of the State. About 20% of that emissions reduction appears in the on-the-books controls, based on measures implemented by the electric generating utility Minnesota Power—Boswell. The remaining 10% of the emission reduction are applied in the $\text{Minnesota}_{(MRPO)}$ case to taconite mines based on permit limits, furnace modifications, fuel switching, new control equipment, newer rate information, and some initial measures taken to comply with the Best Available Retrofit Technology (BART) rule associated with the RH SIP.

The Northeast Minnesota Plan results in an additional reduction of 2,000 tons per year SO_2 and 7,000 tons per year NO_X. Minnesota's RPG is based on the 2018 on-the-books controls and the Northeast Minnesota Plan.

I.c. Calculation of the Resulting Degree of Visibility Improvement that would be Achieved at each Class I Area.

Applying the methodology described in I.a. with future emission estimates that reflect reasonable controls, provides the RPG. Minnesota's RPG for Boundary Waters and Voyageurs based on $\text{Minnesota}_{(MRPO)}$ case modeling are shown in Figures I.5 and I.6. The results are shown in relation to a line representing a uniform rate of progress from the baseline conditions to natural conditions. The top line represents the 20 percent worst visibility days, and the bottom line represents the 20 percent best visibility days.

Overall, an estimated 1.3 deciview improvement at Boundary Waters and a 0.6 deciview improvement at Voyageurs are expected in 2018. At Boundary Waters, a perceptible change in visibility is expected. At Voyageurs, the change may not necessarily be visually perceptible, however, it is a step in the right direction toward reaching the visibility goals at the Minnesota Class I areas.

Figure I.5. RPG at Boundary Waters for 2018.

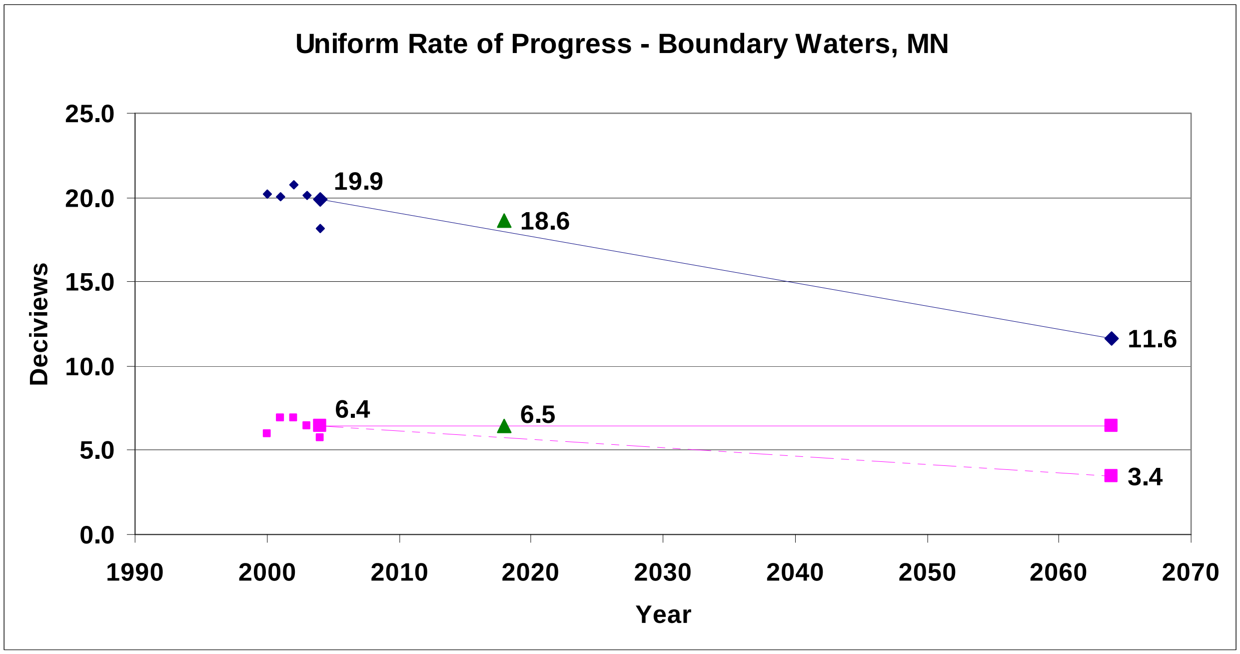
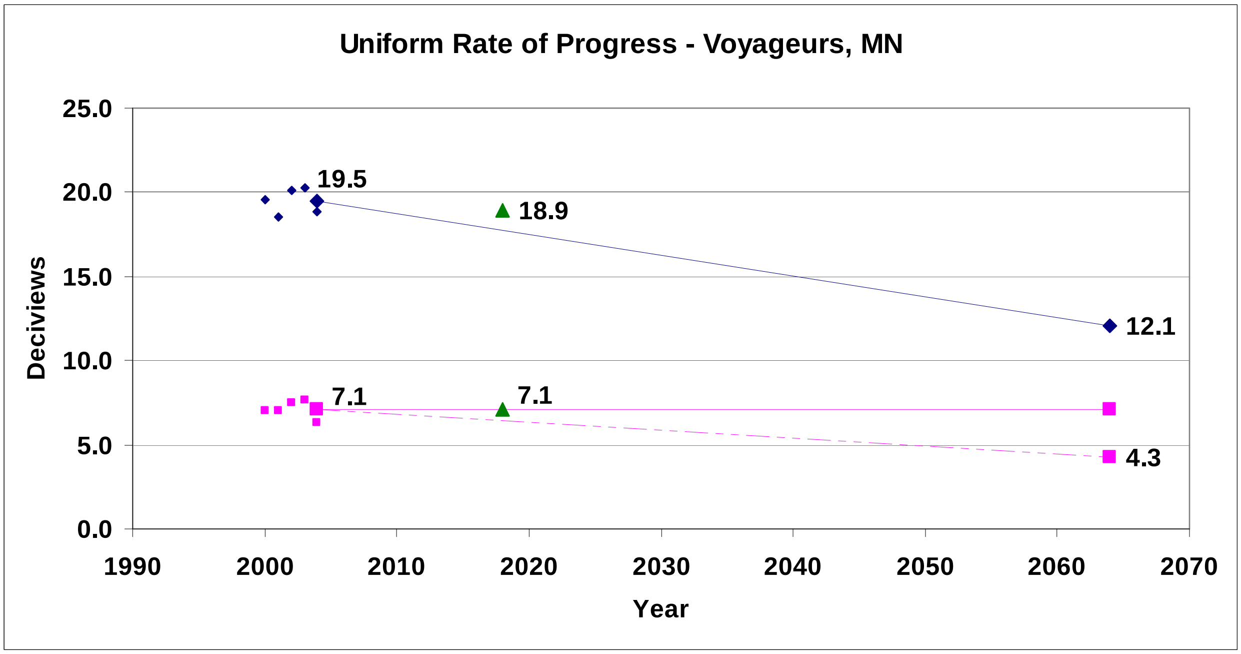


Figure I.6. RPG at Voyageurs for 2018.



I.d. Comparison of Visibility Improvement between Proposed Control Strategies.

Not all potential control strategies have been deemed reasonable, as described in the RH SIP, at the time of SIP preparation and thus are not reflected in the Minnesota RPG. As detailed in the RH SIP, Minnesota did request Iowa, Missouri, North Dakota and Wisconsin—along with Minnesota— to evaluate the reasonableness of emission limits on the electric generating sector that would result in an additional total annual reduction of 222,000 tons SO_2 and 29,700 tons NO_X from 2018 emission estimates. These measures would result in an additional 0.3 deciview improvement (18.3 dv) in visibility at Boundary Waters, and an additional 0.2 deciview improvement (18.7 dv) in visibility at Voyageurs.

I.e. Conclusion that the Long-Term Strategy Provides for Reasonable Progress.

The reasonableness of the long-term strategy—the controls implemented—falls beyond the scope of this technical support document. To be reasonable, factors such as the cost effectiveness of the control measures are assessed. The RH SIP provides discussion on the reasonableness of the long-term strategy. This document does, however, provide detail on emission unit level emissions changes that were modeled to reflect the strategy. The document also provides evidence that the RPG at Boundary Waters and Voyageurs appear to be somewhat conservative estimates. As part of the weight-of-evidence supporting the Minnesota reasonable progress goal, this document features a detailed comparison among the modeling inputs and results by CENRAP, MRPO (2002) and MRPO (2005) as compared to the Minnesota$_{(MRPO)}$ case used to establish the RPG.

In summary, the various modeling results all show slightly varying levels of assurance that visibility on the worst impaired days will improve toward natural conditions. The MRPO 2005 case projects the greatest visibility improvements, showing at least a uniform rate of progress toward natural conditions on the worst impaired days. The CENRAP case projects the next greatest improvements, followed by the Minnesota$_{(MRPO)}$, and lastly by the MRPO 2002 case.

The increased visibility improvement shown by the Minnesota$_{(MRPO)}$ case over the MRPO 2002 case can be explained by the use of improved future emissions projections for the electric generating utility sector and the incorporation of the Northeast Minnesota Plan. Because the Minnesota$_{(MRPO)}$ case uses the improved future emissions projections for the electric generating utility sector and the Northeast Minnesota Plan—resulting in greater projected emission reductions for the future—it is somewhat unexpected that the CENRAP case projects greater improvements in future visibility. The CENRAP case has the same electric generating emissions as the MRPO 2002 case. The cause may be due to the estimated level of NO_x and ammonia emissions.

The CENRAP case over predicts nitrate formation at Boundary Waters and Voyageurs compared to observed values collected at monitoring stations in 2002. This is likely caused by additional NO_x and a significant amount of available ammonia with which to react. Because the CENRAP case has a lot of available ammonia to react with NO_x emissions, the model responds well to future projected reductions in NO_x emissions, possibly even over-stating them.

CENRAP has significantly more ammonia in the modeling system during the winter than the Minnesota$_{(MRPO)}$ case, which under predicts nitrate formation on the same days. The Minnesota$_{(MRPO)}$ case does not appear to have much available ammonia in the winter to form the same level of nitrate from NO_x emissions as observed. In the future projected case, NO_x emissions in the Minnesota$_{(MRPO)}$ case are reduced while ammonia emissions significantly increase. In the future, the increased ammonia allows the model to form nitrate. Even though NO_x emissions decrease, the increased ammonia and nitrate formation may prevent model response to the reduction in NO_x emissions. Thus, the CENRAP case would project greater improvements in visibility.

An additional important factor is that the CENRAP case considers significant emissions reductions from Canada from the base year to the future year. The Minnesota$_{(MRPO)}$ case keeps Canada emissions constant from the base year to the future year, due to concerns about the uncertainty of the Canada emissions.

The MRPO 2005 case has a somewhat similar situation regarding model response to ammonium nitrate formation. Although the MRPO 2005 case does not over predict nitrate in the base case, it does have additional ammonia than the Minnesota$_{(MRPO)}$ case. Also, in the MRPO 2005 future case (2018), ammonia emissions do not increase nearly as much as the Minnesota$_{(MRPO)}$ case. Again, this scenario would allow the model to respond better to reductions in NO_X emissions in the MRPO 2005 case than the Minnesota$_{(MRPO)}$ case.

In this document we quantitatively describe how the RRF—and hence the RPG—are sensitive to the available ammonia. Adding more ammonia in the Minnesota$_{(MRPO)}$ base case and estimating less of an increase in ammonia in the future case results in a more optimistic RPG of 0.2 dv (18.4 dv) at Boundary Waters and 0.3 dv (18.6 dv)Voyageurs. Livestock operations are the major source of ammonia emissions. The MRPO 2005 future year estimates were improved from that used in the Minnesota$_{(MRPO)}$ case. The reduced ammonia growth in the MRPO 2005 case was most impacted by a future estimated decline in dairy operations.

The greater visibility improvement in the MRPO 2005 case can also be attributed to meteorology. It uses 2005 meteorology rather than the 2002 meteorology used in the CENRAP and Minnesota$_{(MRPO)}$ cases. Thus, the MRPO 2005 projections for future visibility are based on different worst visibility days, different visibility components that contribute to those days, and the predominant wind direction from which emission reductions occur.

The MRPO 2005 case shows significantly less contribution from Minnesota and Western States at both Boundary Waters and Voyageurs than the Minnesota$_{(MRPO)}$ case, and greater influence from states located to the East and Southeast of Minnesota, including Indiana, Iowa, Michigan, and Missouri. Modifying the Minnesota$_{(MRPO)}$ case with 2005 meteorology results in a more optimistic RPG – 0.4 dv (18.2 dv) at Boundary Waters and 0.8 dv (18.1 dv) at Voyageurs – than the Minnesota$_{(MRPO)}$ case using 2002 meteorology, but not as optimistic as the MRPO 2005 case. Modifying the Minnesota$_{(MRPO)}$ case with 2005 meteorology and MRPO 2005/2018 ammonia emissions results in an even more optimistic RPG – 0.6 dv (18.0 dv) at Boundary Waters and 0.9 dv (18.0 dv) at Voyageurs.

Overall, the evidence supports a conclusion that the Minnesota$_{(MRPO)}$ case projects a minimum expected future visibility improvement. The model responds better with more winter-time ammonia available in the base year, and less available in the future year. We believe the future year estimates are better with less available ammonia in the future than that reflected in the Minnesota$_{(MRPO)}$ case. The quest for better ammonia emission estimates continues. The model shows more optimistic goals using 2005 meteorology. Because 2002 meteorology emphasizes more contribution to visibility impariment from nitrate in the winter when winds originate form the West and Northwest, the model may show greater visibility improvements if the uncertainty in Canada emissions were resolved and any possible NO_x emission reductions taken into account. As these efforts would entail international relations, it is prudent for the EPA to lead this effort.

The remainder of this document provides the detail on the modeling conducted by Minnesota, and the comparison to the other modeling analyses. These include the emissions input to the model, description of the model options used, performance evaluation of the model compared to observed, the uniform rate of progress analysis, and the assessment of the contributing States and source sectors to visibility impairment.

This part of the document is divided into sections that correlate to the individual steps in the process for making a technical demonstration of reasonable progress. For those with minimal or no direct involvement in the regional haze modeling activities, the document begins with a general explanation of the process by which the technical work was completed.

<u>IMPORTANT NOTE</u> Regarding Future Year Emissions Estimates of Electric Generating Units:

The on-the-books controls for electric generating units (EGUs) used to establish the RPG in this document presume the Clean Air Interstate Rule (CAIR) is in affect. On July 11, 2008, after the end of the public notice period for the Minnesota RH SIP but before submittal to the EPA, the D.C Circuit Court of Appeals issued an opinion pointing out several "fatal flaws" with CAIR, and vacated the rule. The EPA petitioned for rehearing which included changing the remedy from vacatur to a remand.

On December 23, 2008, the Court issued a panel opinion, remanding CAIR to the EPA to be rewritten to address the flaws identified in the July ruling. This action means that CAIR is in effect while the flaws are addressed.

One issue the EPA must address on remand is whether Minnesota should continue to be included in CAIR. The Court ruled in July that the EPA did not adequately respond to claims made by Minnesota Power that data on Minnesota emissions were inaccurate, and that by using better data Minnesota would fall below the threshold impact on a nonattainment area that was used for inclusion.

On May 12, 2009 EPA published in the Federal Register (74 FR 22147) a rule amending CAIR to stay the effectiveness of the rule with respect to sources located in the State of Minnesota. The administrative stay will remain in effect until such time as EPA determines through a rulemaking under the Clean Air Act whether Minnesota should be included in the CAIR region for fine particulate matter. In a letter dated October 31, 2008, from the EPA to Minnesota Power counsel, the EPA indicated its belief "that in light of the Court's decision, sources in Minnesota should not be required to make any additional expenditures to comply with CAIR prior to the expiration of the administrative stay of the rule".

Minnesota has determined that the known controls in 2018 with CAIR in place—as modeled to establish the RPG—and without CAIR in place are nearly identical for Minnesota. The resulting emission projections are also very similar. Dissimilarities in emissions projections are attributed to differences in emission projection methods. CAIR emissions were estimated with the Integrated Planning Model (IPM), while emissions without CAIR were developed using electricity generation forecasts by the Department of Energy "Electricity Market Module Supply Regions" by fuel type, and then applying known controls. IPM projections used to establish the RPG contain 6 percent less NO_X (-2,900 tons from 52,400 tons) and 9 percent more SO_2 (4,400 tons from 49,400 tons) from Minnesota EGUs. Without detailed documentation available for the IPM estimates, we can not definitively explain the differences, however, we believe the additional SO_2 may be attributed to IPM's tendency to allow SO_2 emissions to rise close to the permitted SO_2 emissions rate. Detail on the control measures and emission estimate methodologies are provided in this document.

Minnesota will continue to establish the RPG based on CAIR in place. Future electric generating unit emission projections will be re-evaluated after EPA re-writes the CAIR rule.

II. Process for Developing Technical Support for Regional Haze

The modeling system is composed of an atmospheric transport and chemistry model, also known as the “air quality model”, an emissions model and a meteorological model. The emissions and meteorology models create inputs for use by the air quality model. In general, Minnesota chose to use the modeling system chosen by MRPO. The modeling system[8],[9] used in the Minnesota$_{\text{(MRPO)}}$ case is made up of the following:

- Comprehensive Air Quality Model (CAMx). CAMx simulates atmospheric and surface processes affecting the transport, chemical transformation and deposition of air pollutants and their precursors. Some advantages of CAMx are two-way nesting, a subgrid scale plume-in-grid module to treat the early dispersion and chemistry of point source plumes, a fast chemistry solver, and Particulate Source Apportionment Technology (PSAT), which tracks the original source of particulate species by geographic region and source category. CAMx is a Eulerian model that computes a numerical solution on a fixed grid. Minnesota used version 4.42.
- The Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Meteorological Model (MM5). MM5 output data is used in the emissions model and in the air quality model.
- Emissions Modeling System (EMS-2003). EMS-2003 generates hourly speciated emissions on a gridded basis for mobile, nonroad, area, point, natural (biogenic) and fires. The emissions are input to an air quality model.

Many steps are required when using models to support a reasonable progress goal for Regional Haze. Although many parts of the process overlap in practice, for ease of discussion they are identified in this document as a series of steps. The first step in conducting the demonstration is to select the period of time to model. Visibility issues occur throughout the year, and modeling must coincide with a year scheduled for emissions inventory development. States develop emissions inventories every three years.

The second step is to develop an emissions inventory of the primarily formed fine particulate and the precursors to the secondarily formed portion of fine particulate. These precursors include sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH_3), fine particulate ($PM_{2.5}$) and coarse particulate mass. Sources of these precursors are both human (anthropogenic) and natural (biogenic). Biogenic releases are those from vegetation, for example trees, and are primarily VOCs. Anthropogenic sources of $PM_{2.5}$ precursors are stationary “point” sources (industrial

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[8] The MRPO conducted modeling for a 2005 base year analysis using CAMx version 4.50, a combination of EMS-2003 and Concept (for mobile source), and MM5 run by Alpine Geophysics.

[9] CENRAP chose the Community Multiscale Air Quality Model (CMAQ) as its air quality model, the Sparse Matrix Operator Kernel Emissions (SMOKE) model as its emissions model, and MM5 as its meteorological model.

facilities), “mobile” sources (on-road and off-road vehicles, airplanes locomotives and marine vessels) and “area” sources (i.e. residential wood burning).

That leads to steps 3 through 5; emissions modeling, meteorological modeling and atmospheric chemistry and transport (or air quality) modeling. Although meteorological modeling output is an input to emissions models, emissions modeling is identified as the third step in this document. Emissions models take the emissions inventory from the second step and prepare them for input to the air quality model.

The fourth step is to process meteorological data through meteorological models. Some aspects of the meteorological modeling are used both as input to the emissions model and as direct inputs to the air quality model.

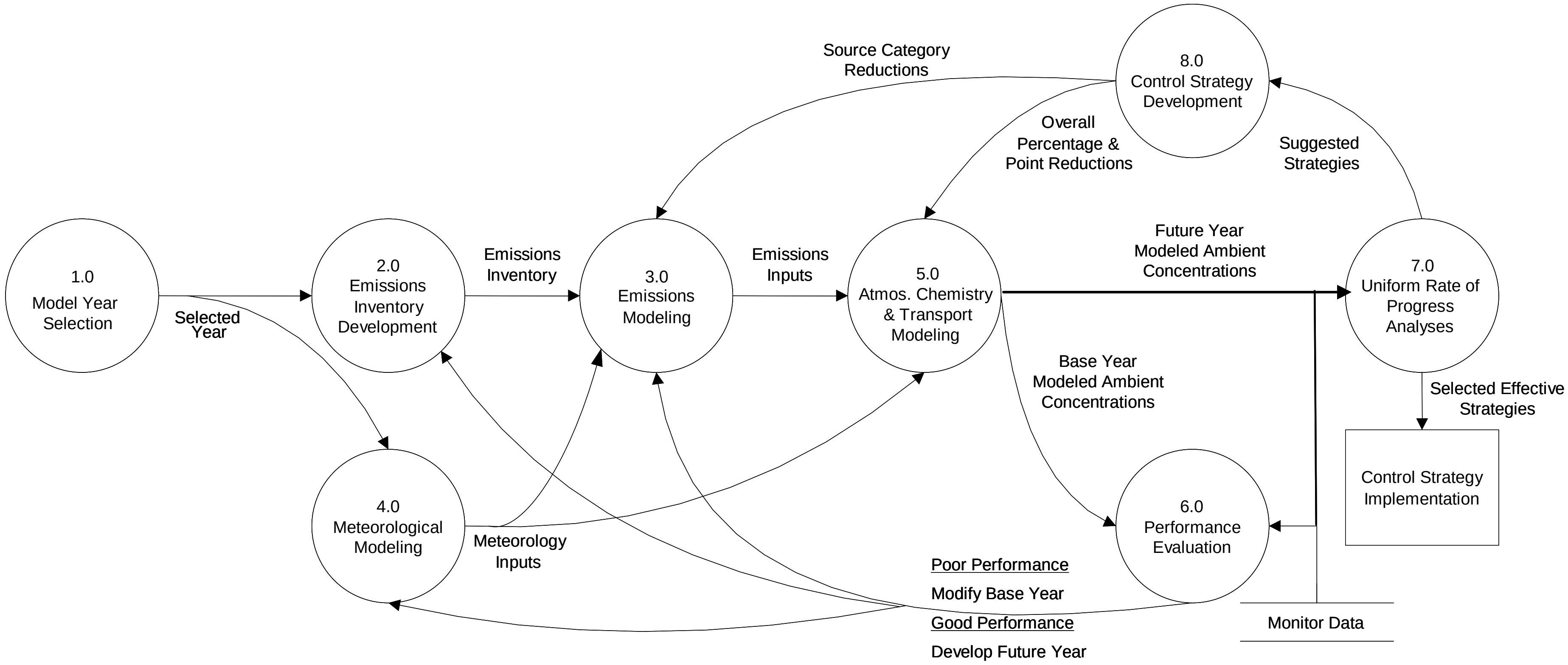
In the fifth step, the air quality model simulates transport of the emissions and chemical reactions in the atmosphere to produce ambient air concentrations of the individual components of $PM_{2.5}$; sulfate (SO_4), nitrate (NO_3), organic carbon (OC), elemental carbon (EC) ammonium (NH_4), and fine and coarse particulate. The results are evaluated against monitoring data of the same period in the sixth step, model performance evaluation. Statistical analyses and other means are used to compare modeled results with observed concentrations.

If the model/monitor evaluation indicates a poor correlation, adjustments are made to the modeling system. Adjustments could be made to the size, coverage and grid-resolution of the domain; the time period modeled; the inventory; the emissions modeling; and/or the meteorological modeling or the air quality model (i.e. revising code). The ambient monitors and how they collect samples also could be explored during a model/monitor performance assessment. Good model performance means that various permutations—such as attempts to predict emissions for future years—can be incorporated in the modeling with some degree of accuracy.

Successful development of a future year emissions inventory leads to the seventh step, the uniform rate of progress analysis. This analysis establishes where future visibility falls on a uniform rate of progress, or “glidepath” toward natural background visibility conditions. The modeling alone does not dictate reasonable progress goals, neither does it determine whether the goals have been met. It does, however, provide a deciview value that reflects reasonable control measures, which in turn is the goal. Potentially reasonable control measures are quantified in step eight.

The flow diagram in Figure II.1 shows the procedural flow for demonstrating attainment of air quality goals for Regional Haze. The diagram illustrates the iterative nature of these analyses. Specifics on each step are described throughout the remainder of this document supporting reasonable progress goals in the Minnesota Class I areas, Boundary Waters and Voyageurs.

Figure II.1 – Procedural Flow for Demonstrating Attainment of Air Quality Goals for Regional Haze.



III. Description of Each Step in the Process

This section contains the detail on the data used for each step in the process flow diagram shown and described above. Each sub-section (or step) begins with a description of the modeling work conducted by Minnesota for the $\text{Minnesota}_{(\text{MRPO})}$ case. As part of the weight-of-evidence the description is followed by a comparison with work conducted by CENRAP, and where applicable, with the MRPO 2005 case.

1.0: Model Year Selection

Regional haze issues appear throughout the year in the Minnesota Class I areas, which make it necessary to model a full year rather than a shorter episode period. A model year must coincide with a year scheduled for emissions inventory development. States develop full emissions inventories every three years, the latest being the fully completed 2002 inventory and the 2005 inventory which was still in development at the time of this analysis. EPA guidance suggests choosing a model year that has monitoring data available that straddles the model year. Minnesota has selected 2002 as the base year for modeling.

During the iterative process of regional scale modeling, the MRPO decided to switch to a 2005 base year for reasons unrelated to regional haze. The MRPO uses the modeling system to address issues related to ozone and $PM_{2.5}$ nonattainment in member states in addition to regional haze. Although Minnesota still uses MRPO inputs in its $\text{Minnesota}_{(\text{MRPO})}$ model analyses, they remain the 2002 base year; while incorporating some aspects of the 2005 inventory, as described in section 2.0. The 2002 base year allows Minnesota to better correlate results with CENRAP, which also uses 2002 as its base year, and allows for using monitoring data that straddles the inventory year (2000-2004) to establish baseline conditions.

2.0: Emissions Inventory Development

Emissions are lumped into sectors based on the similarity of the techniques used to process the emissions. These sectors are:

- Point or industrial sources that are identified by locational coordinate and stack parameters (i.e. facilities with state permits);
- Mobile Onroad or automobile and truck traffic on paved roadways;
- Nonroad or mobile equipment not traveling on roadways (i.e. recreational vehicles, construction and agricultural equipment);
- Marine vessels, airplanes and locomotives (also considered “nonroad” sources although emission estimation techniques vary);
- Area or stationary sources that are not identified by locational coordinate and stack parameters (i.e. agricultural operations, residential heating); and
- Biogenic or natural emissions (i.e. trees).

Emissions modeled for regional haze are sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH_3), fine particulate ($PM_{2.5}$) and coarse particulate ($PM_{2.5} – PM_{10}$) mass.

The base year inventory, based on actual emissions calculated and recorded, is developed first. The base year inventory is processed through an emissions model and air quality model. Once the base year model results pass performance evaluation goals, they are deemed ready to become the basis from which future year emissions predictions are developed. For regional haze, the future year modeling inventory is for the year 2018.

This section is divided in two parts. The first part describes the base year inventory development and the second part describes the future year inventory development.

2.1. The Base Year Inventory—2002.

For the most part, base year inventories are developed by each individual State. These are the same inventories States submit to the EPA for the National Emissions Inventory (NEI). For some sectors, methods initially available to states for developing an inventory are inadequate for air quality modeling.

For these sectors, both CENRAP and MRPO have independently, and in some cases cooperatively, hired contractors to develop emissions data to support State-developed inventories where older methodology, insufficient for modeling purposes, was used. For example, the development of accurate ammonia emissions is important because ammonia combines with sulfuric and nitric acid to form aerosol sulfate and nitrate, significant components of $PM_{2.5}$ and of visibility impairment. Considerable effort[10] has been expended by the RPOs to improve calculation methodologies for ammonia emissions from livestock and agricultural practices, and to appropriately allocate these emissions to each month of the year. Also, States do not typically develop inventories for biogenics, so these inventories had to be created.

Both CENRAP and the MRPO incorporated the inventories developed by the States within their respective RPOs and shared modeling inventories with one another and other RPOs. Due to the iterative nature of the work (illustrated in Figure II.1), a variety of emission inventories have been developed and used by organizations conducting haze modeling. Therefore, each RPO might have a different version of their member States' inventories. Each subsequent version of a modeling emissions inventory might include the addition of emission sources that were missed, corrections to location coordinates and stack parameters of industrial point sources, and revisions to the inventory methodology.

The CENRAP case incorporates its latest inventory "baseG", while the MRPO 2002 case and the $\text{Minnesota}_{\text{(MRPO)}}$ case incorporate the MRPOs latest 2002 inventory "baseK". Unfortunately, based on each RPO's timing in the creation of these modeling inventories, the latest base year inventory of one RPO is not necessarily included in another RPO's base year[11]. For example, the MRPO 2002 case contains CENRAP's baseC. The CENRAP case contains the MRPO baseK.

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[10] This effort is ongoing in MRPO.

[11] CENRAP and WRAP retained the same contractors for emissions modeling and atmospheric chemistry and transport modeling. The CENRAP baseG contains the most recent WRAP Plan02b inventory. North and South Dakota, located immediately to the West of Minnesota, are in the WRAP RPO.

Revisions to CENRAP baseC in baseG emissions include[12]:

- Some changes to the Oklahoma point source inventory;
- Some stack parameter and emissions updates from some CENRAP states, including removal of double-counting of electric generating unit emissions in Missouri that resulted in a reduction of about 11,000 tons per year;
- Updated Mexico emissions; and
- Increased Gulf of Mexico NO_X/SO_2 emissions.

Of these changes, the change to the Missouri inventory would be relevant to the Minnesota Class I areas. However, the MRPO 2002 case does not have this double-counting of emissions in Missouri. Other CENRAP inventory changes between the versions are related to the future year emissions and are described in section 2.2.

More recently, MRPO changed to a 2005 inventory year, termed "baseM". The MRPO2005 case incorporates VISTAS baseG except for the five MRPO states, Minnesota nonroad, mobile and point, and Iowa and Missouri agricultural nonroad. VISTAS baseG contains CENRAP baseG, WRAP Plan02b and MANE-VU 3.1 with estimated growth from 2002 to 2005. The MRPO temporalized the EGU emissions from all States using CEM data.

Minnesota worked with both CENRAP and MRPO. Each organization has separately developed a Minnesota modeling inventory. Thus, MRPO developed a baseK inventory for Minnesota, rather than using the CENRAP baseC. CENRAP developed a baseG inventory for Minnesota rather than using the MRPO baseK. Table 2.1 summarizes the supplementary base year emissions inventory development activities for the MRPO 2002 case and the CENRAP case. More detail on the inventory used by each of the two RPOs can be found in their respective technical support documents.

Minnesota did not make alterations to the MRPO 2002 case emissions in the $\text{Minnesota}_{(\text{MRPO})}$ modeling. However, some changes were made to Minnesota stack locations and parameters as described in Appendix B.

A summary of the base year emissions for Minnesota and the surrounding states used in the $\text{Minnesota}_{(\text{MRPO})}$ case are in Table 2.2. Unit by unit point source emissions for Minnesota are provided in Appendix A. Emissions totals for CENRAP are not included in this table. Further evaluation of information supplied by CENRAP indicates that CENRAP model inputs[13] do not support some of the annual emissions totals provided. The MRPO 2005 inventory methodology is not detailed in this document, but a table containing annual emissions estimates is provided in Appendix C.

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[12] These changes exclude those made to Minnesota and Iowa, where MRPO developed their own inventory and CENRAP baseC was not used.

[13] CENRAP model inputs for one winter day and one summer day, which Minnesota has in-house, were evaluated to make this determination. See Section 2.2 for detail on the CENRAP winter and summer day model inputs.

Table 2.1. Summary of MRPO 2002 Case (used in Minnesota$_{(MRPO)}$ case) and CENRAP Case Inventories.

Source Sector	MRPO[14] 2002 Case	CENRAP[15] Case
Point	State prepared 2002 inventories for five MRPO states (Illinois, Indiana, Michigan, Ohio and Wisconsin) plus Iowa and Minnesota. For other states, emissions are those reflected in other RPO work, VISTAS baseF CENRAP 6/24/05 (baseC excluding Minnesota and Iowa) WRAP pre02d MANE-VU 1/31/05—no version number available.	State prepared 2002 inventories for nine CENRAP states (Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, Oklahoma, and Texas) For other states, emissions generated from EPA NEI02 v. 1 and other information from RPOs VISTAS baseG MRPO baseK WRAP plan02b MANE-VU base
Mobile Onroad	MRPO calculated emissions for all U.S. States based on VMT and MOBILE6.2 obtained from the 2002 NEI. MRPO states, Minnesota and Iowa provided comments on these inputs. MOBILE6.2 was used as a module within the EMS-2003 emissions model system described further in Section 3.0.	CENRAP calculated emissions based on VMT and MOBILE6 inputs for CENRAP, MRPO, VISTAS and MANE-VU. MOBILE6 emissions were used for the WRAP states. MOBILE6 was used as a module within the SMOKE emissions model system described further in Section 3.0.
Nonroad	MRPO calculated monthly emissions for all nonroad categories using the NONROAD 2004 model for its five states and Minnesota. Monthly NONROAD emissions were also calculated for Iowa and Missouri agricultural equipment. RPO supplied data was used for all other states and for the remaining nonroad categories for Iowa and Missouri.	CENRAP calculated 2002 annual emissions using the NONROAD model for all states, except Minnesota, and Iowa agricultural equipment, and California. The MRPO baseK monthly NONROAD2004 emissions were used for Minnesota and Iowa agricultural equipment.
Marine, Aircraft & Rail	MRPO contracted with ENVIRON to estimate emissions for marine, locomotive and aircraft for MRPO states.[16],[17]	
Fire	MRPO contracted with EC/R to develop a fire inventory[18] The University of Wisconsin conducted a wildfire emissions study for the period May through September 2002. Though calculated, neither prescribed	CENRAP calculated fire emissions using the Emission Production Model (EPM)/CONSUME within the BlueSky framework. CENRAP characterized some fires as

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[14] MRPO (April 2005)

[15] ENVIRON (September 2007)

[16] ENVIRON (December 2004)

[17] After baseK, it was discovered that marine emissions are overestimated in Lake Superior. New emission factors developed for Base M (2005), but were not incorporated into the Minnesota (MRPO) modeling.

[18] MRPO (September 2004)

	(excluding elevated point sources in Minnesota)[19] nor wildfires were included in the air quality modeling.[20]	area sources, and some fires (within CENRAP, WRAP, VISTAS and Canada) as point sources.
Area Ammonia	MRPO used CMU Ammonia Model (version 3.6) with 2002 agricultural census data for monthly and diurnal fertilizer application and livestock related emissions. Emissions estimates from soils, humans, dogs, cats and deer were excluded. Data within the CMU model was modified to reflect improvements made in temporal profiles (see Section 3.0).	CENRAP used the CMU Ammonia Model for 13 source categories, with improvements to livestock and fertilizer activity data or emission factors. Some area source categories (i.e. landfills and ammonia refrigeration) were calculated outside the CMU model.
Other Area Sources	State direct supplied NEI submittals for MRPO states plus Minnesota and Iowa, EPA NEI for other states.	EPA NEI02 v. 1 and other information from other RPO base year inventories
Biogenic (Natural)	MRPO used BIOME3 (BEIS3 written in SAS within EMS-2003) with day-specific meteorology from MM5 and hourly satellite-based photosynthetically activated radiation values. Biogenic Emissions Landcover Database version 3 (BELD3) was used for fractional land-use and vegetative speciation.	Environ used SMOKE with BEIS3.12, with day-specific meteorology from MM5. BELD3 land use data was used, with BEIS3 summer and winter emission factors.
Dust	Wind-blown and agricultural tilling dust emissions were eliminated from the modeling inventory due to concerns over the transportable fraction of fugitive dust. Road dust is included.	CENRAP calculated windblown dust emissions using a process based model developed by ENIVRON. Fugitive dust emissions were eliminated from the inventory.

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[19] Prescribed burning emissions in Minnesota were inadvertently left in the Minnesota base year and future year inventories.

[20] MRPO conducted a sensitivity analysis to estimate the affect of fire emissions. The result showed an impact a small impact (i.e. less than 0.2 ug/m3) in modeled organic carbon and elemental carbon concentrations.

Table 2.2. Annual 2002 Emissions in Tons[21] in Minnesota$_{(MRPO)}$ Case by Source and Category for Minnesota and Surrounding States.

	SrcGroup		SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
MINNESOTA	**Point**		131,000	155,000	2,310	12,500	31,100	33,700
	Area		22,800	58,100	175,000	19,500	72,200	133,000
	Mobile	**On-road**	29	172,000	7,200	2,200	2,200	97,600
		Non-road	9,210	102,000	98	5,600	6,380	96,800
	Biogenics		0	28,700	0	0	0	698,000
	Minnesota TOTAL:		**163,000**	**516,000**	**185,000**	**39,900**	**112,000**	**1,060,000**
	(no biogenics) TOTAL:		163,000	487,000	185,000	39,900	112,000	361,000
IOWA	**Point**		179,000	120,000	3,220	10,900	25,000	45,400
	Area		5,330	9,290	246,000	9,280	36,900	79,100
	Mobile	**On-road**	43	117,000	4,280	1,290	1,290	87,500
		Non-road	7,600	93,900	80	5,450	6,240	65,700
	Biogenics		0	40,700	0	0	0	227,000
	Iowa TOTAL:		**192,000**	**381,000**	**254,000**	**26,900**	**69,400**	**504,000**
	(no biogenics) TOTAL:		192,000	340,000	254,000	26,900	69,400	278,000
NORTH DAKOTA	**Point**		159,000	85,500	29	14	258	2,310
	Area		45,800	15,500	69,400	3,400	16,700	43,100
	Mobile	**On-road**	16	26,600	887	318	318	14,200
		Non-road	1,190	20,900	16	395	469	4,790
	Biogenics		0	33,600	0	0	0	158,000
	North Dakota TOTAL:		**206,000**	**182,000**	**70,400**	**4,120**	**17,800**	**223,000**
	(no biogenics) TOTAL:		206,000	148,000	70,400	4,120	17,800	64,500
SOUTH DAKOTA	**Point**		14,100	20,700	12	245	1,310	1,620
	Area		18,500	6,140	106,000	3,510	15,800	26,800
	Mobile	**On-road**	21	33,200	1,120	403	403	16,800
		Non-road	432	6,710	3	292	346	4,430
	Biogenics		0	40,700	0	0	0	266,000
	South Dakota TOTAL:		**33,000**	**107,000**	**107,000**	**4,450**	**17,800**	**315,000**
	(no biogenics) TOTAL:		33,000	66,700	107,000	4,450	17,800	49,600
WISCONSIN	**Point**		252,000	129,000	308	5,200	10,300	28,700
	Area		6,150	21,700	114,000	7,950	10,300	140,000
	Mobile	**On-road**	411	181,000	8,600	1,860	1,860	92,700
		Non-road	7,430	76,600	94	4,580	5,240	112,000
	Biogenics		0	18,600	0	0	0	413,000
	Wisconsin TOTAL:		**266,000**	**427,000**	**123,000**	**19,600**	**27,700**	**787,000**
	(no biogenics) TOTAL:		266,000	408,000	123,000	19,600	27,700	374,000

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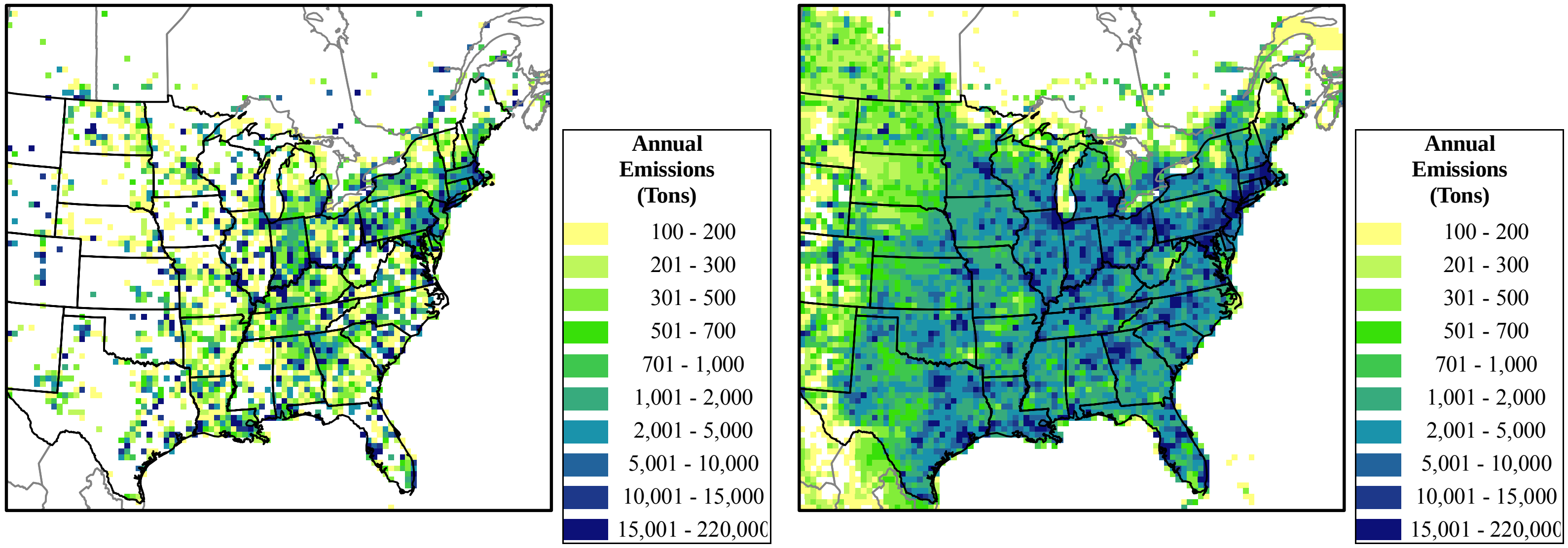
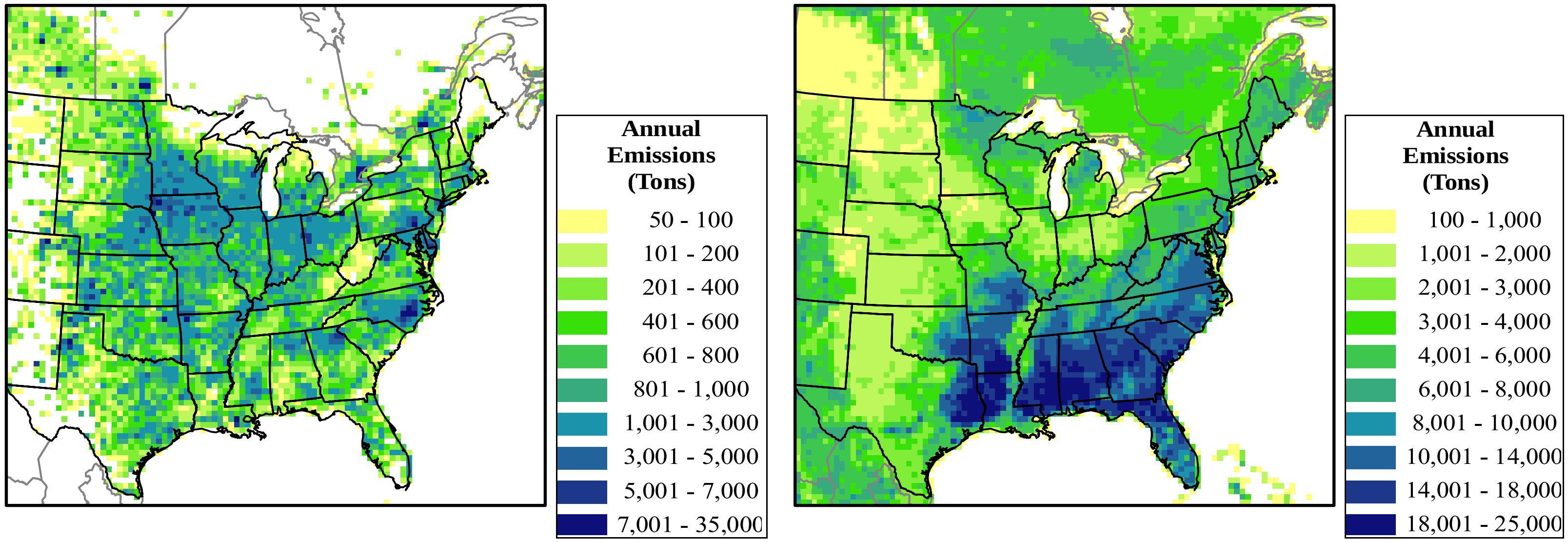
[21] Values are reported to three significant digits. Sum totals may not add up due to rounding.

Figures 2.1 through 2.4. Annual 2002 SO_2, NO_x, NH_3 and biogenic VOC emissions in Tons for Minnesota$_{(MRPO)}$ Case.



Sulfur Dioxide:

Nitrogen Oxides:



Ammonia:

Biogenic Volatile Organic Compounds:

Underestimation of Minnesota Nonroad Emissions. Some concerns have been raised about the potential impact of emissions from the fleets of large trucks operated at taconite mines located in St. Louis County, which is in northeastern Minnesota, near the Minnesota Class I areas. Emissions from these sources were underestimated in both the CENRAP and MRPO inventories.

The trucks used for hauling material at the mine sites are nonroad mobile sources and operate throughout the year. In the baseline inventory, nonroad mobile source emissions were estimated by county based on population. Because St. Louis County is relatively low in population, NO_X emissions from the nonroad sector are likely underestimated in this county.

One facility, which uses newer model trucks, estimates its truck emissions at about 170 tons per year. Based on this number, Minnesota estimates that the mining trucks at a total of six taconite facilities could add between 1200 – 2500 tons per year of NO_X. Because this underestimation was noted late in the modeling process, the inventory has not been modified to include these emissions.

2.2 The Future Year Inventory—2018.

The base year inventory must be processed through the emissions model (see section 3.0) and the air quality model (see section 5.0). The base year model results must pass the performance evaluation goals (see section 6.0) before it is ready to become the basis from which future year emissions predictions are developed. For regional haze SIP, the future year modeling inventory is developed for the year 2018.

Both CENRAP and MRPO primarily used the Economic Growth Analysis System (EGAS) model to estimate the growth of emissions from 2002 to 2018 for all source categories, except onroad mobile sources and EGUs. Onroad mobile sources were grown using the MOBILE6 model. EGUs were grown using the Integrated Planning Model (IPM).

MOBILE6. On-road mobile sources were grown using MOBILE6 within the emissions model EMS-2003 (see section 3.0). The MRPO used State Metropolitan Planning Organization and Department of Transportation modeled future year networks and local MOBILE6 inputs to generate emissions estimates for the five MRPO states and Minnesota. Alpine Geophysics provided the information for other states.

EGAS5. Emissions for all source sectors, except on-road mobile sources and EGUs, were grown using EGAS version 5. EGAS is a forecast model used to predict national and regional economic activity in order to estimate air quality levels. EGAS is based on the premise that growth in emissions largely depends on the growth in economic activity, particularly changes in sales forecasts, in an area. Therefore, the growth factors are based on things like projected changes in fuel consumption, or increases in population that may result in a greater use of a product or service, increases in production of a product, or the closing of industrial facilities.

Growth factors are applied to 2002 emissions from existing units by SCC code, and are meant to represent total growth for that particular SCC including the addition of new sources, retirement of existing sources, and output changes from existing sources. Growth factors cannot predict the development of new facilities and do not take into account future controls on new units. They merely grow emissions from existing facilities within an SCC in order to capture the overall emissions growth by 2018 for that SCC. The growth factors assume constant growth rates each year.

The MRPO capped growth rates for the MRPO states and Minnesota, Iowa and Missouri. It was assumed there was no growth for residential wood combustion and pesticides All other area source categories were capped at 3 percent per year based on 1.5 times the growth in the Midwest Manufacturing Index over the seven years 1998-2004, which is 21 percent over seven years. Minnesota requested that CENRAP use the same cap for similar SCCs for the State, and provided a list of specific SCC with growth factor modifications by specie (NO_X and SO_2).

For several categories where the EGAS-supplied growth factors were suspect, the MRPO contracted for the development of alternative growth factors. Alternative growth factors were developed for 22 priority area source categories, which mainly included fuel combustion point sources. E.H. Pechan[22] developed growth and control factors for all area, and point sources. They developed growth rates for fuel combustion categories based on Department of Energy historical and projected fuel consumption data for industrial sources, for the five MRPO states. Minnesota and Iowa were included by developing a composite SCC-by-SCC data set analyzed to determine more appropriate growth rates. Other categories, for example ammonia forecasts, were based on the Regional Economic Models Incorporate (REMI) State-level economic model and sector-specific equations relating emission activity trends to trends associated with a REMI socioeconomic variable.

MRPO 2005 Growth Factor Refinements. While Minnesota-specific historical and forecast growth indicator data was not specifically included in the 22 priority source category review in the MRPO 2002 case, Minnesota-specific data was included in the MRPO 2005 update. Also, the overall MRPO 2002 case growth factors were revised to reflect more updated growth indicators. Of particular interest for this TSD is the revision in ammonia growth methodology from agricultural livestock sources because of the demonstrated model sensitivity to ammonia levels in the development of the RPG. Rather than the REMI model and the regression equations used for this category in the MRPO 2002 case, growth from agricultural livestock sources was based on interpolated SCC animal count projections by State from the EPA ammonia inventory[23]. The reduced ammonia growth in the MRPO 2005 case was most impacted by a future estimated decline in dairy operations. The resulting difference in estimated ammonia area source emissions between the MRPO 2002 case and the MRPO 2005 case is shown in Table 2.3.

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[22] E.H. Pechan (December 2005)

[23] EPA (January 2004)

Table 2.3 Annual Ammonia Emissions in Tons in the MRPO 2002 and MRPO 2005 cases.

Case	Emission Category	Annual Emissions (tons) 2002/2005	Percent Growth	Annual Emissions (tons) 2018
MRPO 2002	Total Area Ammonia	175,000		239,000
	Fertilizer	65,600	49%	97,600
	Livestock	109,000	29%	141,000
MRPO 2005*	Total Area Ammonia	187,000		218,000
	Fertilizer	70,100	37%	95,900
	Livestock	117,000	4%	122,000

* Note that about seven percent growth is assumed between the MRPO 2002 and MRPO 2005 base cases. Adjusting for growth in the MRPO 2005 case—from 2002 to 2005—results in 46 percent growth in emissions from fertilizer application and 12 percent growth in emissions from livestock from 2002 to 2018.

Taconite Facility Adjustments. Minnesota made further changes to the growth estimates in the Minnesota$_{(MRPO)}$ case for taconite mining sources located in Northeastern Minnesota. Due to the general proximity of many facilities within Minnesota's mining industry (largely taconite extraction and processing) to Minnesota's Class I Areas, particular attention was paid to future year emission projections from these sources.

While investigating the 2018 taconite industry emissions, it was discovered that Minnesota's 2002 emissions inventory often used SCCs for taconite indurating furnaces that are outside of the taconite-specific SCCs. Ideally the SCC used for the taconite indurating furnaces would be 303023xx (Industrial processes, primary metal production, taconite ore processing). However, Minnesota emission inventory staff has used other SCCs (such as 39000699 - Industrial processes, in-process fuel use, natural gas, general, or 10200802 – Industrial External Combustion boiler, petroleum coke) as a means to keep track of fuel usage.

Because emissions at some facilities have, in some cases, been assigned to more general SCCs, different growth factors were assigned to different facilities for essentially the same process. The growth factor used for indurating furnaces (and all SCC related to taconite mining) should be the same. Starting with the 2006 point source inventory, Minnesota emissions inventory staff began assigning emissions from taconite facilities only to taconite-specific SCCs.

As shown in Table 2.4, for any given taconite indurating furnace SCC (except 39000699) MRPO and CENRAP have used different growth factors. In addition, MRPO has used different growth factors for non-MRPO and MRPO states. The growth factor used for indurating furnaces (and all SCC related to taconite mining) should be the same for all taconite facilities.

Minnesota does not expect any growth in emissions from existing taconite mining plants from 2002 levels, however, some growth is expected due to new sources. Therefore, the Minnesota$_{(MRPO)}$ modeling assigned a growth factor of 1.0, and revised control factors, to all existing taconite mines, and added location information and projected emissions for new mining facilities. Two facilities were added as proposed "east mine" and "west mine" projects. The emissions projections reflect those for Polymet and Minnesota Steel, and lines at UTAC (EVTAC)[24] line 1 and Northshore Mining Silver Bay Furnace 5, that did not operate during 2002. Emissions for the Mesabi Nugget taconite plant were also added to the future year inventory.

Table 2.4. Taconite Growth Factors from 2002 to 2018 Used By MRPO and CENRAP

SCC	SCC Description	CENRAP Growth Factor.[25]	MRPO Growth Factor for MRPO states[26]	MRPO Growth Factor for MN[27]
10200802	Industrial External Combustion Boilers, Petroleum Coke	1.126	1.095	1.126
30302312	Industrial Process, Primary Metal Production, Taconite Ore Processing, Gas-Fired Indurating Furnace	1.357	1.275	1.357
39000699	Industrial Processes, In-Process Fuel Use, Natural Gas	1.0	1.0	1.0

Changes made to the future year inventory used in the Minnesota$_{(MRPO)}$ case are in Appendix B.[28] Overall, these changes result in less NO_x (original 83 tons/day, revised 77 tons/day) and less SO_2 (original 13 tons/day, revised 10 tons/day) emissions from these facilities in 2018.

Integrated Planning Model (IPM). All RPOs agreed to predict future EGU emissions with IPM, which is a model developed by ICF that EPA uses to evaluate future impact of policies on EGUs in combination with projected energy needs. For example, the EPA used IPM to support the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR).

IPM version 2.1.9(VISTAS) was used in both CENRAP and MRPO 2002 future year inventories. The IPM model output presumes CAIR and CAMR are implemented. While developing its 2005 future year modeling inventory, the MRPO switched to IPM3.0. IPM3.0 also presumes CAIR and CAMR are in place, but makes different assumptions (i.e. fuel cost)

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[24] Although United Taconite LLC (UTAC) is the current name of the facility, this document retains the name "EVTAC" to maintain consistency with the naming convention of the 2002 modeling inventory. Other facilities that retain former facility names include: ArcelorMittal Minorca Mine, which retains the name "Ispat" Inland Steel, and Ainsworth Engineered (USA) LLC, which retains the name "Potlatch" Corp.

[25] Obtained from CENRAP spreadsheet provided by Lee Warden on Dec. 6, 2006 of top non-EGU facilities (250 TPY in 2018 or greater) of SO_2 and NO_x

[26] Obtained from MI/WI growth factor spreadsheets done by MRPO – overall percent growth.(http://www.ladco.org/tech/emis/basek/reports/control/argnc.scc.all4one26.020712.r4s1_nonegu_2018.lst)

[27] Obtained from "argnc.gnc.all4one" from MRPO website.

[28] Appendix B also includes changes made to some stack parameters and locations.

when estimating future EGU emissions. Minnesota's review of the IPM results concluded that IPM3.0 better reflects Minnesota's estimation of the future EGU scenario.
Although the IPM3.0 predictions are improved, they could still use some adjustments. MRPO requested its member states plus Minnesota, North Dakota, Iowa and Missouri to make corrections or adjustments to the IPM3.0 outputs. For example, Minnesota made a correction to the Minnesota Power-Boswell EGU emissions to account for an underestimation of the facility's capacity in IPM. Adjustments were limited to committed control projects that occurred after the scheduled deadline for submission to EPA for the IPM3.0 base model run. All corrections and adjustments made to Minnesota EGUs were done in consultation with industry representatives. Table 2.5 summarizes Minnesota's adjustments and corrections to IPM3.0.

Table 2.5. Minnesota Adjustments and Corrections to IPM3.0.

Facility Name	**Basis for Correction/Adjustment**	**Unit #**	**IPM base Total Emissions (Mton)**		**IPM "will do" Total Emissions (Mton)**	
			NO_x	**SO_2**	**NO_x**	**SO_2**
Minnesota Power-Boswell	Unit 3 adjusted to reflect NO_X permit limit, SO_2 decreased with addition of FGD*	3	0.79	6.11	0.93	1.19
	Unit 4 capacity was increased from 425 MW to 535 MW	4	3.75	4.00	4.72	3.22
Xcel—A.S. King	Adjusted based on permit limit.	1	1.43	1.87	2.08	2.49
Xcel—Black Dog	Adjusted based on current performance in response to Xcel Energy comments.	3	1.17		3.92	
		4	1.63		5.47	
Minnesota Power-Taconite Harbor	Retrofit SO_2 FSI** on Units 1 through 3.	1		1.56		0.67
		2		1.39		0.68
		3		1.37		0.67

*Fabric Filter/Flue Gas Desulfurization.
**Furnace Sorbent Injection.

The modifications made to the IPM3.0 base model run, are called the IPM3.0 "will do" run. Table 2.6, created by MRPO, shows the overall difference in emissions among IPM2.1.9(VISTAS), the IPM3.0 base, and the IPM3.0 "will do" scenario for each state in the upper mid-West.

Concerns have been raised as to whether adjusting IPM output would compromise the integrity of the IPM model predications. IPM assumes an energy balance throughout the sector, and the concern is that modifications at a handful of facilities can throw the system off-balance. However, Minnesota views IPM as one method for predicting future EGU emissions and if States and affected industry believe that the predicted emissions are incorrect, they should change them in order to get the most accurate estimation of future emissions in the state. The corrections and adjustments made by Minnesota should not throw the system off-balance because they generally address only changes in the performance of equipment that result in emission changes, and not overall energy balance.

VISTAS states have also made post-IPM model adjustments for their states to the IPM2.1.9—VISTAS output. CENRAP has not made any adjustments to the IPM2.1.9—VISTAS output used in their modeling. CENRAP intended to switch to IPM3.0, but did not due to timing and financial reasons.

Although the Minnesota$_{\text{(MRPO)}}$ case was conducted with the MPRO 2002/2018 case emissions from the non-utility source categories (with modifications described above), the IPM3.0 EGU emissions were used for the future year inventory. This substitution is possible because, unlike other sectors, future year EGU emissions calculated with IPM are independent of the base year inventory. They are not based on a growth factor applied to base year emissions.

Controls on Future Year Inventory. Control is applied after growth and may be a due to the addition of physical controls to a process. These controls may be voluntary or due to regulatory requirements. Controls also reflect Federal and State regulations and legislation and permit actions. MRPO contracted with E.H. Pechan and Associates to identify control implemented—termed “on-the-books” control—between 2002 and 2018 source sectors except EGUs. In the MRPO emissions, the control on all sectors, including EGUs, include[29]:

On-Highway Mobile Sources

- Tier II/Low sulfur fuel;
- Inspection/Maintenance programs in nonattainment areas (does not apply in Minnesota); and
- Reformulated gasoline in nonattainment areas (does not apply in Minnesota);

Off-Highway Mobile

- Federal control programs incorporated into NONROAD model (e.g. nonroad diesel rule), and the evaporative Large Spark Ignition and Recreational Vehicle standards;
- Heavy-duty diesel (2007) engine standard/Low sulfur fuel;
- Federal railroad/locomotive standards; and
- Federal commercial marine vessel engine standards.

Electric Generating Units[30]

- Title IV Acid Rain Program (Phases I and II);
- NOx SIP Call (does not apply in Minnesota);
- Clean Air Interstate Rule; and
- Clean Air Mercury Rule.

Other Point Sources

- VOC 2-, 4-, 7-, and 10-year MACT standards;
- Combustion turbine MACT; and
- Industrial boiler/process heater/RICE MACT.

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[29] MRPO (April 2008)

[30] These controls are included in the IPM3.0 projections.

- The MRPO also included control factors to reflect settlement agreements for petroleum refineries and other non-EGU sources in MRPO states plus Minnesota.[31]

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[31] MACTEC (January 2006)

Table 2.6. IPM2.1.9 (VISTAS), and IPM3.0 “base” and “will do” Alterations[32]

State	**Heat Input (MMBTU/year)**	**Scenario**	**SO2 (tons/year)**	**SO2 (lb/MMBTU)**	**NOx (tons/year)**	**NOx (lb/MMBTU)**
IL	**980,197,198**	**2001 - 2003 (average)**	**362,417**	**0.74**	**173,296**	**0.35**
		IPM 2.1.9	241,000		73,000	
	1,310,188,544	IPM3.0 (base)	277,337	0.423	70,378	0.107
		IPM3.0 - will do	140,296	0.214	62,990	0.096
IN	**1,266,957,401**	**2001 - 2003 (average)**	**793,067**	**1.25**	**285,848**	**0.45**
		IPM 2.1.9	377,000		95,000	
	1,509,616,931	IPM3.0 (base)	361,835	0.479	90,913	0.120
		IPM3.0 - will do	628,286	0.832	128,625	0.170
IA	**390,791,671**	**2001 - 2003 (average)**	**131,080**	**0.67**	**77,935**	**0.40**
		IPM 2.1.9	147,000		51,000	
	534,824,314	IPM3.0 (base)	115,938	0.434	59,994	0.224
		IPM3.0 - will do	115,938	0.434	59,994	0.224
MI	**756,148,700**	**2001 - 2003 (average)**	**346,959**	**0.92**	**132,995**	**0.35**
		IPM 2.1.9	399,000		100,000	
	1,009,140,047	IPM3.0 (base)	244,151	0.484	79,962	0.158
		IPM3.0 - will do	244,151	0.484	79,962	0.158
MN	**401,344,495**	**2001 - 2003 (average)**	**101,605**	**0.50**	**85,955**	**0.42**
		IPM 2.1.9	86,000		42,000	
	447,645,758	IPM3.0 (base)	61,739	0.276	41,550	0.186
		IPM3.0 - will do	54,315	0.243	49,488	0.221
MO	**759,902,542**	**2001 - 2003 (average)**	**241,375**	**0.63**	**143,116**	**0.37**
		IPM 2.1.9	281,000		78,000	
	893,454,905	IPM3.0 (base)	243,684	0.545	72,950	0.163
		IPM3.0 - will do	237,600	0.532	72,950	0.163
ND	**339,952,821**	**2001 - 2003 (average)**	**145,096**	**0.85**	**76,788**	**0.45**
		IPM 2.1.9	109,000		72,000	
	342,685,501	IPM3.0 (base)	41,149	0.240	44,164	0.258
		IPM3.0 - will do	56,175	0.328	58,850	0.343
SD	**39,768,357**	**2001 - 2003 (average)**	**12,545**	**0.63**	**15,852**	**0.80**
		IPM 2.1.9	12,000		15,000	
	44,856,223	IPM3.0 (base)	4,464	0.199	2,548	0.114
		IPM3.0 - will do	4,464	0.199	2,548	0.114
WI	**495,475,007**	**2001 - 2003 (average)**	**191,137**	**0.77**	**90,703**	**0.36**
		IPM 2.1.9	155,000		46,000	
	675,863,447	IPM3.0 (base)	127,930	0.379	56,526	0.167
		IPM3.0 - will do	150,340	0.445	55,019	0.163

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[32] MRPO (April 2008)

Alternative EGU Emissions Projections. At the time CAIR was vacated by the courts, the MRPO developed future year EGU emissions without CAIR in place. Rather than use the IPM model, which was used to model CAIR, the emissions without-CAIR were developed using electricity generation forecasts by the Department of Energy "Electricity Market Module Supply Regions by fuel type, and then applying known controls.

There are 13 supply regions. Minnesota is in Region 5, Mid-Continent Area Power Pool (MAPP) in the National Energy Modeling System that projects energy needs in billions of kilowatt hours. There are six fuel categories: coal, petroleum, natural gas, nuclear, pumped storage, and renewables. The MRPO used only coal, natural gas and petroleum in the future year estimates. The ratio of future year to base year for each fuel category was applied to the appropriate Source Classification Codes (SCCs) in the 2007 EGU base year emissions by emission unit. Major SCCs are 101, 102, 103, 201 and 202. Minor SCCs 001, 002, and 003 were assigned coal; 004, 005, 008 were assigned petroleum; and 006, 007 and 009 were assigned natural gas. Where a minor code does not fit into any of these categories, the default is coal.

Future year projections were estimated based on 2007 EGU emissions. Minnesota reviewed the 2007 emissions and found that not all facilities operated throughout the year. For example, Xcel Energy—Allen S. King was installing controls during that year and did not operate all of 2007. In this case, future year estimates were adjusted to reflect 2018 as if the facility operated the full year. Table 2.7 shows the growth rates applied to Minnesota EGUs. Growth factors were applied to all facilities in the State.

Table 2.7. Growth Rates Applied to Minnesota EGUs based on Electricity Generation by Electricity Market Module Region and Source in Billion Kilowatt Hours for the MAPP Region[33].

Mid-Continent Area Power Pool	Base Year 2007 (Bkwh)	Future Year 2018 (Bkwh)	Percent Change 2005-2030	Growth Factor 2007-2018
Coal	120.81	139.14	0.8%	1.152
Petroleum	0.77	0.62	0.8%	0.805
Natural Gas	1.74	3.47	-1.0%	1.997

Known legally enforceable controls were then applied to the emissions grown to 2018. These controls include BART on all applicable EGUs in Minnesota including Power Boiler #2 at Northshore Mining-Silver Bay, whose BART determination was not complete at the time the emission projections were made. The legally enforceable BART controls on Power Boiler #2 includes the Low NO_X burners in the preliminary stages of the BART determination, but does not include the Dry Sorbent Injection to control SO_2 which completes the BART determination for that unit.

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[33] http://www.eia.doe.gov/oiaf/archive/aeo08/supplement, Table 76.

The resulting controls were nearly identical to those assumed in the IPM version 3.0 “will do” scenario described above and used to establish the RPG for the RH SIP. The control assumptions in the IPM 3.0 “will do” scenario and the controls without-CAIR are shown in Table 2.8.

A review of the total Minnesota EGU SO_2 and NO_X for 2018 shows very similar emissions projections using the different methodologies. Emission projections used to establish the RPG with IPM 3.0 “will do” contain 6 percent less NO_X (-2,900 tons from 52,400 tons) and 9 percent more SO_2 (4,400 tons from 49,400 tons) from Minnesota EGUs. Without detailed documentation available for the IPM estimates, the differences can not be definitively explained. However, the overall increased SO_2 projection by IPM may be due to its tendency to allow SO_2 emissions to rise close to the permitted SO_2 emissions rate. Some examples include Rochester Public Utilities, Hibbing Public Utilities and Virginia Public Utilities, where IPM allows emissions to rise to 4 lbs/MMBtu permitted rate when actuals are less than 1 lb/MMBtu. IPM v3.0 assumes no control changes at Northshore Mining-Silver Bay in 2018, however, the model predicts a low annual emissions rate for 2018 regardless. It is unclear why this is the case.

Since these alternative EGU projections were developed, the Court remanded the CAIR rule to EPA. Thus, CAIR is in effect while EPA addresses the flaws in the rule specified by the Court. Included in that effort, EPA will determine whether or not CAIR applies in Minnesota. Whether or not CAIR applies has no effect on the known future year controls projected to 2018 already modeled for the RH SIP (with CAIR in place). Also, at this time it is not possible to project future year emissions for other States without knowing how EPA will fix the flaws in the rule. Thus, Minnesota will continue to establish the RPG using the IPM 3.0 “will do” projections for EGUs as described above.

Table 2.8. Future Year Control Assumptions in IPM 3.0 “will do” (with CAIR) and MRPO Case B 2018 (without CAIR).

Facility Name	Facility ID	Stack ID	Emission Unit ID	Specie	Controls Without CAIR		Controls With CAIR	
					Case B: Legally Enforceable		Modeled in SIP (IPM v3.0"will do")	
					2018 Control EF	Control Type	2018 Control EF	Control Type*
Xcel Energy - Riverside Generating Plant	2705300015	SV001	EU001	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
			EU002	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
		SV003	EU003	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
			EU009	NO_X	*	new unit natural gas	*	new unit natural gas
				SO_2	*	new unit natural gas	*	new unit natural gas
		SV008	EU010	NO_X	*	new unit natural gas	*	new unit natural gas
				SO_2	*	new unit natural gas	*	new unit natural gas
		SV009	EU011	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
Minnesota Power Inc - Boswell Energy Ctr	2706100004	SV003	EU003	NO_X	80%	SCR	80%	SCR
				SO2	85%	FGD	85%	FGD
Rochester Public Utilities - Silver Lake	2710900011	SV003	EU004	NO_X	40%	SNCR	**	**
				SO_2	85%	SCRUBBER	95%	SCRUBBER
Xcel Energy - High Bridge Generating	2712300012	SV001	EU001	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
			EU002	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
			EU003	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
			EU004	NO_X	100%	removed	100%	removed
				SO_2	100%	removed	100%	removed
		SV008	EU010	NO_X	*	new unit natural gas	*	new unit natural gas
				SO_2	*	new unit natural gas	*	new unit natural gas
		SV009	EU011	NO_X	*	new unit natural gas	*	new unit natural gas
				SO_2	*	new unit natural gas	*	new unit natural gas

Facility Name	Facility ID	Stack ID	Emission Unit ID	Specie	Controls Without CAIR Case B: Legally Enforceable		Controls With CAIR Modeled in SIP (IPM v3.0"will do")	
					2018 Control EF	Control Type	2018 Control EF	Control Type*
NSP - Sherburne Generating Plant	2714100004	SV001	EU001	NO_X	50%	LNB	**	**
				SO_2	85%	SCRUBBER	**	**
			EU002	NO_X	50%	LNB	**	**
				SO_2	85%	SCRUBBER	**	**
		SV002	EU003	NO_X	50%	LNB	**	**
Xcel Energy - Allen S King Generating	2716300005	SV001	EU001	NO_X	80%	SCR	90%	SCR
				SO_2	82%	SCRUBBER	82%	SCRUBBER
Minnesota Power Inc - Taconite Harbor Ctr	2703100001	SV001	EU001	NO_X	50%	ROFA/SNCR	50%	ROFA/SNCR
				SO_2	40%	FSI	40%	FSI
		SV002	EU002	NO_X	50%	ROFA/SNCR	50%	ROFA/SNCR
				SO_2	40%	FSI	40%	FSI
		SV003	EU003	NO_X	50%	ROFA/SNCR	50%	ROFA/SNCR
				SO_2	40%	FSI	40%	FSI
Northshore Mining Silver Bay	2707500003	SV001	EU001	NO_X	40%	LNB		
				SO_2	20%***	biomass***		
		SV002	EU002	NO_X	40%	LNB		
				SO_2	20%***	biomass***		

* Additional emissions for new units in the without-CAIR case were projected to be comparable to the IPM 3.0 projections

** These projects became legally enforceable after the IPM 3.0 "will do" case was developed.

***This control, which is part of the BART determination for the unit, was not included in the final “Controls without CAIR” because the BART determination was incomplete at that time.

Biomass: Co-firing biomass with existing fuel
FGD: Fabric Filter/Flue Gas Desulfurization
FSI: Furnace Sorbent Injection
LNB: Low NOx Burner
ROFA: Rotating Opposed Fire Air System
SCR: Selective Catalytic Reduction
SNCR: Selective Non-Catalytic Reduction

Comparison Between MRPO and CENRAP Future Year Emission Estimates. Because the MRPO 2002 and Minnesota$_{(MRPO)}$ cases include the CENRAP baseC2018 inventory, it is imperative to understand the changes made to the CENRAP future year inventory between baseC2018 and baseG2018. These changes include:

- Modified growth and control factors for point sources in CENRAP:
  - BART on American Electric Power (SWEPCO)/Gentry in Arkansas;
  - Cement kiln emissions held constant (NO_X SIP Call), early CAIR controls for Ameren with changed SO_2 and stack parameters, shut-down of Doe Run Glover Smelter and held remaining smelter to 2002 emission levels in Missouri;

  - BART for OPPD Nebraska Unit #1 and OPPD Gerald Gentleman, Units 1 and 2 in Nebraska;
  - BART controls for Westar Energy and Kansas City Power and Light BART affected units, and MACT control assumptions in Kansas;
  - Added several new points and modified emissions at Lehigh Cement Company, Lafarge North America, ADM Corn Processing Clinton and ADM Corn Processing Cedar Rapids in Iowa;
  - BART for PSO Comanche, Northeastern, Riverside and Jenks and OG&E Sooner and Muskogee in Oklahoma.
- Added new emissions for non-platforms in the Gulf of Mexico;
- Corrected onroad mobile inputs for some Texas counties; and
- Included refinery settlements in Oklahoma, Texas and Louisiana.

None of the above states have significant visibility impacts on Boundary Waters and Voyageurs except Iowa and Missouri. Modifications made to Iowa sources reduced up to 23,000 tons per year of SO_2 (some to EGUs as well as nonEGUs) in the 2018 inventory. An emissions summary provided by CENRAP suggests that the CENRAP case contains annually 37,000 tons more point source SO_2 than the $\text{Minnesota}_{(MRPO)}$ case for Iowa. EGU SO_2 emissions from Iowa decreased significantly between the IPM2.1.9 and IPM3.0, which conceals any other changes and makes it unclear whether the $\text{Minnesota}_{(MRPO)}$ inventory includes the Iowa non-utility point emissions changes. For the same reason, it is also unclear whether the Missouri changes are included. However, for both Iowa and Missouri, the $\text{Minnesota}_{(MRPO)}$ inventory contains a conservative growth estimate for SO_2.

A summary of the projected 2018 emissions for Minnesota and the surrounding states used in the $\text{Minnesota}_{(MRPO)}$ case are in Table 2.9. Unit by unit point source emissions for Minnesota are provided in Appendix A. Emissions totals for CENRAP are not included in this table. Further evaluation of information supplied by CENRAP indicates that CENRAP model inputs[34] do not support some of the annual emissions totals provided. The MRPO 2005 inventory methodology is not detailed in this document, but a table containing annual emissions estimates is provided in Appendix C.

Table 2.10 shows the difference between the 2002 and 2018 projected emissions modeled in the $\text{Minnesota}_{(MRPO)}$ case. The largest reductions are associated with NO_X from mobile sources, which is the main source of NO_X in each of the States except North Dakota and South Dakota in the base year. The most significant reductions in SO_2 emissions are from point sources, which are the main source of SO_2. Ammonia significantly increases from 2002 to 2018 in all States except Wisconsin, where State-specific historical and forecast growth indicator data was used.

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[34] CENRAP model inputs for one winter day and one summer day, which Minnesota has in-house, were evaluated to make this determination. See Section 2.2 for detail on the CENRAP winter and summer day model inputs.

Table 2.9. Annual 2018 Emissions in Tons[35] in Minnesota$_{(MRPO)}$ Case by Source and Category for Minnesota and Surrounding States.

	SrcGroup		SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
MINNESOTA	**Point**		83,500	117,000	3,420	25,100	47,900	42,800
	Area		22,700	62,100	239,000	19,500	72,400	129,000
	Mobile	**On-road**	2	31,400	10,100	514	514	20,000
		Non-road	2,170	76,900	125	4,410	5,030	86,700
	Biogenics		0	28,700	0	0	0	698,000
	Minnesota TOTAL:		**108,000**	**317,000**	**253,000**	**49,600**	**126,000**	**977,000**
	(no biogenics) TOTAL:		108,000	288,000	253,000	49,600	126,000	279,000
IOWA	**Point**		167,000	101,000	6,100	12,300	22,100	58,600
	Area		6,100	10,700	359,000	10,900	44,600	84,200
	Mobile	**On-road**	3	18,200	6,000	302	302	12,200
		Non-road	842	63,900	105	3,120	3,570	30,300
	Biogenics		0	40,700	0	0	0	227,000
	Iowa TOTAL:		**173,000**	**234,000**	**371,000**	**26,700**	**70,600**	**412,000**
	(no biogenics) TOTAL:		173,000	193,000	371,000	26,700	70,600	185,000
NORTH DAKOTA	**Point**		79,900	70,800	400	5,300	6,600	2,600
	Area		44,200	17,400	102,000	3,910	19,400	47,500
	Mobile	**On-road**	1	4,020	1,230	73	73	2,620
		Non-road	803	44,600	69	2,240	2,570	13,400
	Biogenics		0	33,600	0	0	0	158,000
	North Dakota TOTAL:		**125,000**	**170,000**	**103,000**	**11,500**	**28,700**	**224,000**
	(no biogenics) TOTAL:		125,000	137,000	103,000	11,500	28,700	66,100
SOUTH DAKOTA	**Point**		6,480	9,540	66	478	1,700	1,700
	Area		18,900	6,620	153,000	4,040	18,500	27,800
	Mobile	**On-road**	1	4,950	1,570	95	95	3,080
		Non-road	543	27,900	44	1,670	1,910	11,200
	Biogenics		0	40,700	0	0	0	266,000
	South Dakota TOTAL:		**25,900**	**89,700**	**155,000**	**6,280**	**22,200**	**309,000**
	(no biogenics) TOTAL:		25,900	49,000	155,000	6,280	22,200	43,700
WISCONSIN	**Point**		210,000	89,100	1,080	12,100	18,400	37,300
	Area		6,280	23,400	114,000	7,630	10,300	127,000
	Mobile	**On-road**	16	27,200	12,100	428	428	16,700
		Non-road	1,410	45,000	127	2,810	3,240	71,700
	Biogenics		0	18,600	0	0	0	413,000
	Wisconsin TOTAL:		**217,000**	**203,000**	**127,000**	**22,900**	**32,400**	**666,000**
	(no biogenics) TOTAL:		217,000	185,000	127,000	22,900	32,400	253,000

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[35] Values are reported to three significant digits. Sum totals may not add up due to rounding.

Table 2.10. Difference Between Annual 2002 and 2018 Emissions in Tons[36] in Minnesota$_{(MRPO)}$ Case by Source and Category for Minnesota and Surrounding States.

	SrcGroup		SO$_2$	NO$_X$	NH$_3$	PM$_{25}$	PM$_{10}$	VOC
MINNESOTA	Point		-47,000	-38,000	1,120	12,600	16,900	9,040
	Area		-150	3,970	63,400	13	254	-3,800
	Mobile	On-road	-26	-140,000	2,890	-1,700	-1,700	-78,000
		Non-road	-7,000	-25,000	27	-1,200	-1,400	-10,000
	Minnesota TOTAL:		**-54,000**	**-200,000**	**67,500**	**9,690**	**14,100**	**-82,000**
IOWA	Point		-13,000	-20,000	2,870	1,430	-2,800	13,200
	Area		772	1,400	113,000	1,630	7,780	5,130
	Mobile	On-road	-40	-99,000	1,720	-990	-990	-75,000
		Non-road	-6,800	-30,000	26	-2,300	-2,700	-35,000
	Iowa TOTAL:		**-19,000**	**-150,000**	**117,000**	**-260**	**1,280**	**-92,000**
NORTH DAKOTA	Point		-79,000	-15,000	371	5,290	6,350	287
	Area		-1,600	1,890	32,100	512	2,670	4,400
	Mobile	On-road	-15	-23,000	348	-250	-250	-12,000
		Non-road	-390	23,700	53	1,850	2,100	8,570
	North Dakota TOTAL:		**-81,000**	**-12,000**	**32,900**	**7,410**	**10,900**	**1,630**
SOUTH DAKOTA	Point		-7,600	-11,000	54	233	391	74
	Area		412	480	47,300	527	2,750	973
	Mobile	On-road	-19	-28,000	454	-310	-310	-14,000
		Non-road	111	21,200	40	1,380	1,570	6,750
	South Dakota TOTAL:		**-7,100**	**-18,000**	**47,900**	**1,830**	**4,400**	**-5,900**
WISCONSIN	Point		-43,000	-40,000	767	6,860	8,090	8,570
	Area		130	1,640	65	-320	-21	-13,000
	Mobile	On-road	-400	-150,000	3,530	-1,400	-1,400	-76,000
		Non-road	-6,000	-32,000	33	-1,800	-2,000	-41,000
	Wisconsin TOTAL:		**-49,000**	**-220,000**	**4,390**	**3,340**	**4,640**	**-120,000**

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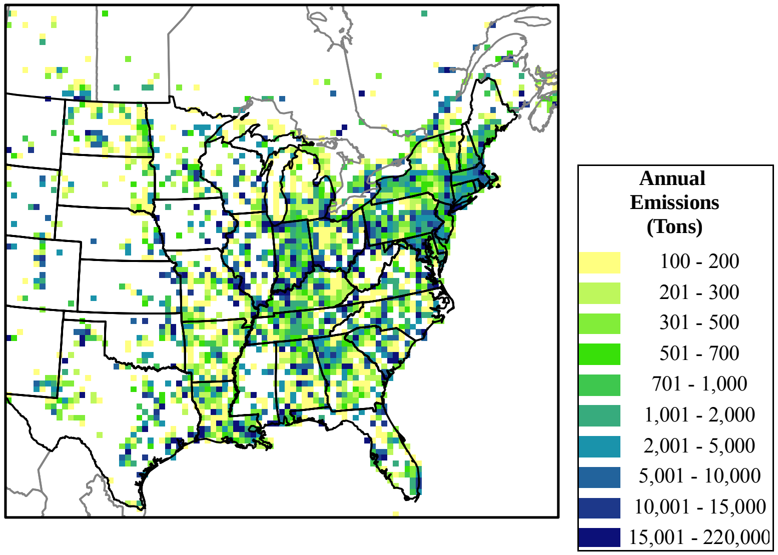
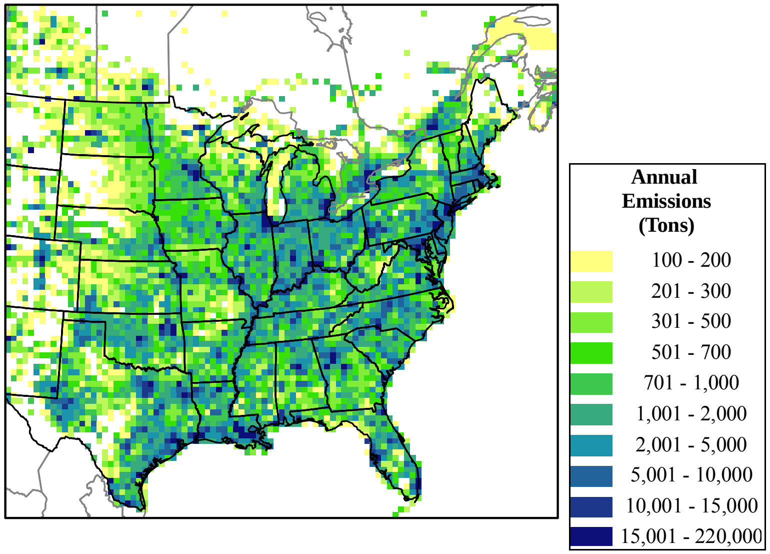
[36] Values are reported to three significant digits. Sum totals may not add up due to rounding.

Figures 2.5 through 2.7. Annual 2018 SO_2, NO_x, NH_3 emissions in Tons for Minnesota$_{(MRPO)}$ Case.

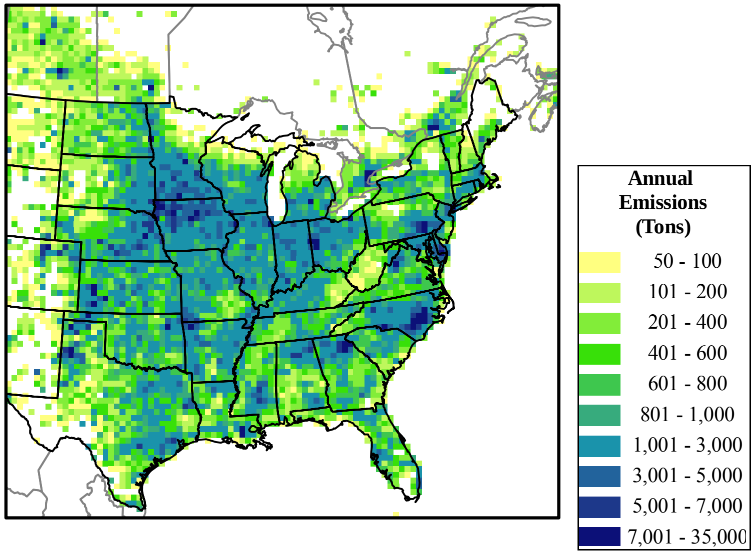
Sulfur Dioxide:



Nitrogen Oxides:



Ammonia:



2.3 Canada Emissions Inventory

In addition to including emissions from the individual States in the United States, CENRAP and MRPO included emissions from Canada in an attempt to reflect the base year 2002. Canada's provinces report an emissions inventory to Environment Canada, similar to the States reporting the NEI to the EPA. The subset of the Canadian inventory—or Pollutant Release and Transfer Register (PRTR)—that includes the relevant pollutants is the Criteria Air Contaminants Emission Inventory. Canadians do not report their emissions on the same schedule as the United States, and did not provide a 2002 inventory. Both the CENRAP case and MRPO 2002 case include the Canadian 2000 inventory. The Canadian inventory is confidential and specifics are not shared freely outside the country. This makes it difficult to quality assure the data and fully understand whether the estimation methods are comparable. The MRPO are collaborating with staff in Ontario and are becoming more familiar with the emissions in Ontario.

During the iterative modeling process, it was determined that much of the emissions from Canada were assigned no stack height and as a result were modeled as if released in the surface layer of the atmosphere. These included some very large sources, whose emissions in reality are released at much higher elevations. Because of meteorological (i.e. wind direction and speed) differences throughout the various layers, revisions to the elevation from which the Canadian sources emit were required. CENRAP made these changes to the Canadian 2000 inventory. MRPO, which was in the process of switching to a 2005 base year, chose to use the Canadian 2005 inventory, and with the help of Ontario environmental staff, fixed the problems in that province. The Minnesota$_{(MRPO)}$ replaced the 2000 Canadian inventory with the Canadian 2005 inventory. A summary of annual 2005 Canada emissions totaled over the MRPO 4rpos domain is in Table 2.11.

Table 2.11 Canada Annual 2005 Emissions Total in MRPO 4rpos Region in Tons[37]

	SrcGroup	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
CANADA	**Point**	948,000	298,000	7,700	28,800	96,600	108,000
	Area	36,300	115,000	360,000	0	0	1,400,000
	Mobile (nonroad + onroad)	26,200	535,000	9,470	2	2	412,000
	Biogenics		80,200				4,650,000
	TOTAL:	**1,010,000**	**1,030,000**	**377,000**	**28,800**	**96,600**	**6,570,000**

CENRAP used model-ready projected Canada emissions for the year 2020 from the EPA to represent 2018. CENRAP notes in its TSD that the EPA did not confirm whether EPA corrected any Canadian stack parameters.

Because of the large uncertainties in the Canadian inventory, Minnesota elected to use the Canadian 2005 inventory for both the base year and the future year. Thus, no credit is taken for any possible reduction (or increase) in emissions from Canada. The previous sentence contains

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[37] These emissions are calculated from hourly CAMx model input files and reported to three significant digits. Sum totals may not add up do to rounding.

an emphasis on reduction in emissions because the 2000 and 2020 Canada emission summaries[38] for the entire Inter-RPO National Domain provided by CENRAP show annual reductions in Canadian SO_2 of -2,150,000 tons, which equates to an 88 % reduction—nearly all of which consists of point source SO_2 (-2,130,000 tons, -97%)—and in Canadian NO_X of -731,000 tons, which equates to 25% reduction, most of which consists of point source NO_X (-630,000 tons, -95%). Although the actual values may be questionable, it is safe to say the Canadian inventory predicts a reduction in emissions.

3.0: Emissions Modeling

The MRPO uses the EMS-2003 model, and CENRAP uses the SMOKE model, to develop emissions ready for import into atmospheric chemistry and transport models. The emissions inventory described in Section 2.0 is not immediately ready for input into the air quality models, (and in some cases, the emissions are calculated using the emissions models). State developed emissions are reported as total emissions over the year, whereas modeling requires hourly emissions. Although State developed inventories contain specific locational (longitude/latitude) information for industrial point sources, all other emissions are reported on a county-basis. Emissions modeling will allocate emissions as specifically to each 36km (or less) grid square as possible.

In addition to spatially and temporally allocating emissions, the models are used to speciate the emissions for each of the source categories, where applicable. For example, if the state NEI submittal reports emissions as NO_x, these emissions are speciated into NO and NO_2. Point sources are allocated to grid cells based on their locational (latitude/longitude) coordinates, and are allocated to individual hours using reported operating schedule information. County-level area source emissions are spatially allocated to grid cells using surrogates, for example population or land use, and are allocated to specific hours using hourly profiles representative of the area source. Both EMS and SMOKE directly allocate mobile and biogenic source emissions to grid cell by hour.

The MRPO generated modeling emissions estimates for a weekday, Saturday and Sunday for each month for point, mobile on-road, mobile non-road, and area sources. Biogenic emissions were developed for every day of the year. General choices in emissions modeling for both MRPO and CENRAP are shown in Table 3.1. Summaries of the methodologies are in Table 3.2.

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[38] Obtained from emis_smry_cenrap_typ02f_b18f_021407.xls

Table 3.1. General Emissions Modeling Selections by RPO.

	MRPO	CENRAP
Emissions Model Biogenics model:	EMS version 2003 BEIS3	SMOKE version 2.1 and 2.3 BEIS3
Domain Extent	4rpos	National
Grid Size	36km	36km
Emission Categories		
• **Point**	Weekday, Sat, Sun per Month	Daily
• **Mobile Onroad**	Weekday, Sat, Sun per Month	Daily
• **Nonroad**	Weekday, Sat, Sun per Month	Mon, weekday, Sat, Sun (MWSS)
• **Area**	Weekday, Sat, Sun per Month	Average weekday; MWSS
• **Biogenic**	Daily	Daily
Species	SO_2, NO_x, VOC, PM_{25}, CM and NH_3	SO_2, NO_x, VOC, PM_{25}, CM and NH_3

Emissions were generated for every hour and allocated to 36km grids over the National Inter-RPO Domain. This domain was agreed upon by all the RPOs as the basic domain from which to model. The MRPO uses a subset of the national RPO domain, called the 4rpos domain, to focus on an area that includes the United States and Canada extending east of a line dissecting the United States at the western-most tip of Texas. Both the National Inter-RPO Domain and the MRPO 4rpos domain are shown in Figure 3.1. CENRAP generated modeling emissions in a similar fashion, but encompassing the entire National Inter-RPO 36km domain. Minnesota created a 12km flexi-nested domain over Minnesota to take a closer look at Minnesota nearby source impacts.

Figure 3.1. National Inter-RPO Domain and MRPO 4rpos Domain.

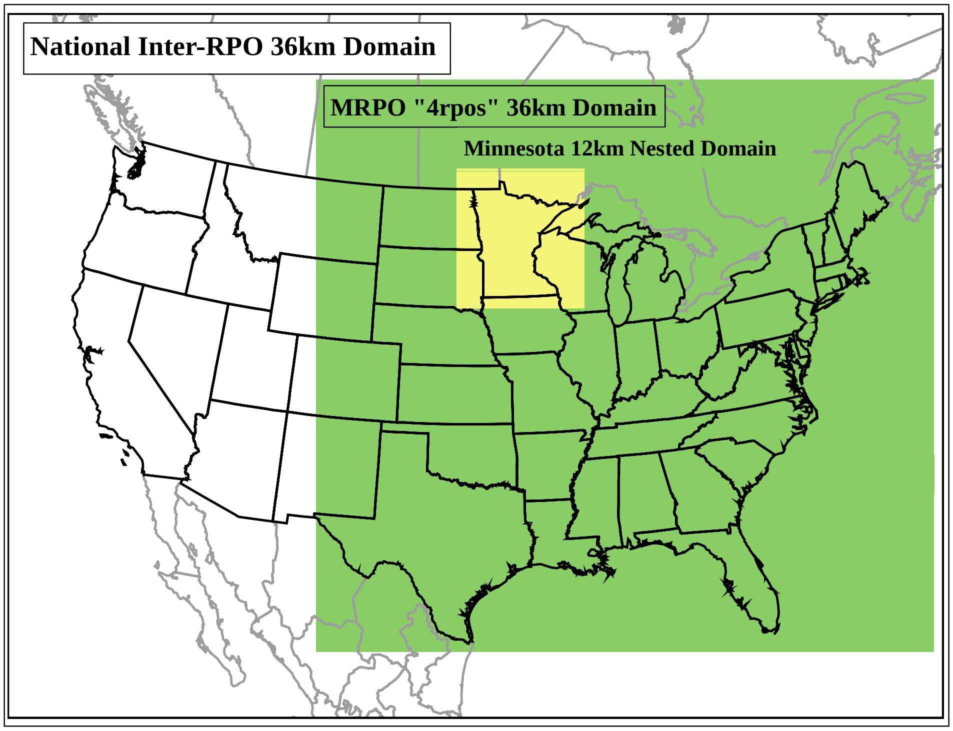

Table 3.2. Summary of Temporal and Spatial Allocation and Speciation Profile Methodology by RPO

Source Category		MRPO[39] (baseK)	CENRAP[40] (baseG)
Point	EGU Temporal Profiles:	EGU SO_2 and NO_X emissions were temporalized using heat input, in lb/MMBtu from CEM data to create temporal profiles with month-of-year and day-of-week, and hour-of-day variations by emissions unit. Three years of CEM data were obtained, and a median value for each weekday, Saturday and Sunday for each Month was used for projections to the future. The median value was used to apportion the annual (SO_2) emissions and summer/winter (NO_X) IPM results [41]	CENRAP used CEM temporal profiles for both VISTAS and CENRAP, based on 2000 – 2003 data. Data representative of Saturday, Sunday, weekday and Monday emissions were used as surrogates.
	Non-Utility Temporal Profiles:	No temporal profiles were used. Emissions allocated evenly over the year.	If CEM data available, SMOKE was configured to explicitly represent daily conditions with hourly meteorology and daily/hourly emissions. Otherwise, representative Saturday, Sunday, weekday and Monday emissions were used as surrogates.
	Spatial Allocation:	Point source locations specified in data provided by States and RPOs. Locations were quality assured and modified as recommended by States.	Revised EPA Spatial Surrogates
	Speciation Profiles	EPA's SPECIATE data base Version 3.0, augmented with EC/R developed speciation profiles for a few large non-utility sccs, specified by MRPO.[42] Applied these speciation profiles to all U.S. States.	NCOAL for lignite-burning EGUs in North Dakota and Texas CMU profile developed for MRPO for all other coal-burning EGUs

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[39] MRPO (April 2005)

[40] ENVIRON (September 2007)

[41] EGU temporalization: Both SO_2 and NO_X were temporalized using heat input, in lb/MMBtu. They correlated well (note: in 2018, the temporalization was like that of 2005 where the temporalization was not done by heat input. This is because the NOx SIP call was implemented in some States. So, they turn on their SCRs in the summer and turn them off in the winter. Thus, emissions were used for temporalization, rather than heat input).

[42] EC/R Incorporated (February 2005)

			Revised CB4 Chemical Speciation
Mobile Onroad	Temporal Profiles:	Used default EPA profiles base on the NEI.	Hourly meteorology and daily/hourly emissions were used in SMOKE.
	Spatial Allocation:	Used population for lesser roads, used fraction of road miles within a grid cell for arterials, freeway and expressways.	
	Speciation Profiles:	Updated EC/R profiles.[32]	WRAP emissions pre-speciated. SMOKE PM speciation module for other states CB4
Nonroad	Temporal Profiles:	Wisconsin DNR ran NMIM to create monthly profiles for MRPO states plus Minnesota for all categories, and added Iowa and Missouri Agricultural Equipment. Pechan developed local data for MRPO states to improve on EPA defaults for Construction. Pechan prepared local data for Ag equipment for MRPO states plus Minnesota and Iowa.[43]	Seasonal temporal coverage for WRAP non-road mobile and aircraft, with uniform monthly temporal profiles. Annual temporal coverage for WRAP locomotive, in-port and all CENRAP non-road, VISTAS and MANE-VU non-road sources with non-uniform monthly temporal profiles. Monthly temporal coverage for MRPO and MN non-road sources and IA non-road agricultural sources, with uniform monthly temporal profiles.
Marine, Locomotive Aircraft & Recreational Vehicles	Spatial Allocation:	Marine is allocated to all but winter months.	Area-like using spatial surrogates
	Speciation Profiles:	Carbon Bond IV (CB4)	CB4
Area Fire	Temporal Profiles:	Not applicable	Diurnal temporal profiles were applied to most states, and monthly and flat weekly profiles to WRAP states.
Area Ammonia		Ammonia temporal profiles specific for hogs, beef and dairy farms (hogs defined poultry) were	Uniform monthly temporal profiles used.

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[43] E.H. Pechan (September 2004)

		developed by UC-Riverside based on UC-Davis ammonia model (beta version).[44]	
Other Area Sources	Temporal Profiles:	Monthly, daily and hourly EC/R profiles.[45]	
	Spatial Allocation:	Spatial profile data from EPA; spatial surrogates.	Spatial profile data from EPA; spatial surrogates
	Speciation Profiles:	EPA's SPECIATE database Version 3.0 augmented with EC/R developed speciation profiles or various SCCs. Applied to all SCCs throughout the country.[32]	Revised CBM-IV Chemical Speciation
Biogenic	Temporal Profiles: Spatial Allocation:	MRPO used BIOME3 (BEIS3) within EMS-2003 with day-specific meteorology and hourly satellite-based photosynthetically activated radiation values. Biogenic Emissions Landcover Database version 3 (BELD3) was used for fractional land-use and vegetative speciation.	Environ used SMOKE with BEIS3.12, with day-specific meteorology from MM5. BELD3 land use data was used.

3.1 Temporal and Spatial Differences between MRPO and CENRAP 2002 Base Year Inventories

Large differences can occur between modeling studies on how the annual emissions get distributed to each month. These differences would likely vary most in the months comprising Spring and Fall because profiles are often developed for a Summer and Winter day. Depending on the category, this can be significant. For non-road sources, Minnesota found that emissions would be significantly over-estimated were monthly profiles not used. The State of Wisconsin, which was creating monthly non-road temporal profiles for MRPO states, agreed to create similar profiles for Minnesota. MRPO used the Minnesota monthly non-road profiles, and asked CENRAP to do the same.

Temporalization for ammonia can also be very important. Assigning more of the total ammonia emissions in the colder months will make it more available to interact with NO_x to form ammonium nitrate (although preferentially interacting with SO_2 to form ammonium sulfate). Assigning ammonia emissions to warmer months will make them more available to form ammonium sulfate.

MRPO and CENRAP took different approaches to compile estimates of ammonia emissions for the 2002 base year emission inventory (see Section 2.0). Not only are the CENRAP estimates of

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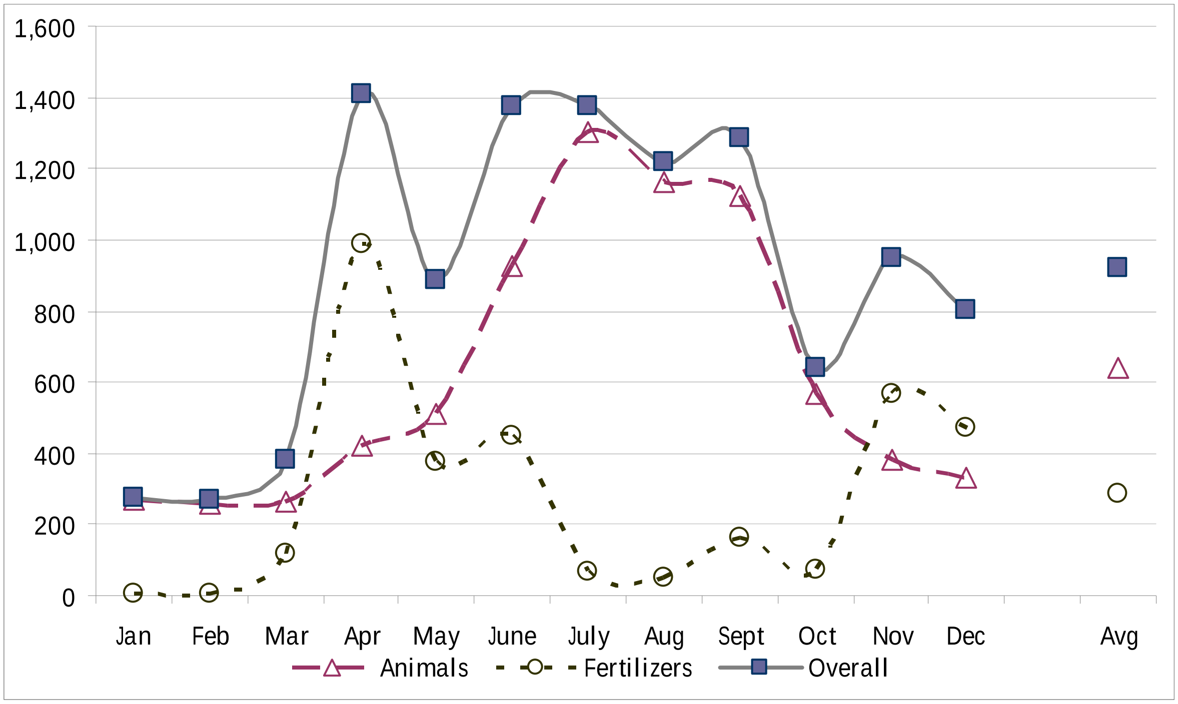
[44] MRPO (April 2005)
[45] EC/R Incorporated (February 2005)

livestock and agricultural ammonia emissions higher than MRPO estimates, the distribution of those emissions among categories of livestock and fertilization methods, and the temporal distribution, vary as well.

An example of the temporal profiles for the ammonia inventory developed by the MRPO is shown in Figure 3.2. The Figure was developed for the MRPO 2005 inventory and illustrates the profile for the combined States Minnesota, Wisconsin and Michigan. The Figure depicts the same temporal profile as the Minnesota$_{(MRPO)}$ case, however, there is more total ammonia estimated in 2005 than in 2002 (~7 % in Minnesota).

Figure 3.2: Estimated Seasonal Distribution of Ammonia Emissions from Livestock and Fertilizer in Minnesota, Michigan and Wisconsin Combined (tons per day)[46].



Although it does not provide a complete picture, emissions for one summer day and one winter day from MRPO and CENRAP were compared in order to get a sense for the temporal and spatial differences between MRPO and CENRAP. Emissions for both the CENRAP baseF[47] (the immediate predecessor of baseG) and the MRPO 2002 case for a winter and summer day in tons were obtained from CAMx model input files for each organization[48]. Thus, no differences between values from the two organizations are attributable to calculation methodology. Table 3.3 contains winter and summer day emissions of each species for Minnesota, surrounding States and Canada. Table 3.4 contains similar winter and summer day emissions from the MRPO 2005 model input files.

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[46] EC/R Incorporated (November 2007)

[47] The main difference between CENRAP baseF and baseG was updated emissions from Mexico.

[48] Although CENRAP used the CMAQ model for most applications, CAMx was used for source apportionment (see Section 8.0). Minnesota obtained one winter day and one summer day model input file from ENVIRON.

Ammonia. As shown in the tables, CENRAP has significantly more ammonia in the model system than MRPO for Minnesota, Iowa, North Dakota, South Dakota, Wisconsin and Canada combined This occurs in both winter and summer. Some of the additional ammonia in the CENRAP inventory is allocated to northern Minnesota, near the two Minnesota Class I areas, as shown in Figures 3.3 and 3.4. These figures contain total emissions from all source categories. As mentioned in Section 2, more ammonia present results in more ammonium nitrate and ammonium sulfate formation. Levels of ammonia emissions in the MRPO 2005 case are more similar to $\text{Minnesota}_{\text{(MRPO)}}$, with growth from the 2002 to 2005 base year.

Nitrogen Oxides. NO_x emissions are of greater importance in the colder months, and for a winter day, it appears that the $\text{Minnesota}_{\text{(MRPO)}}$, and CENRAP cases have similar amounts of NO_X at this time of the year for Minnesota and surrounding states combined. The spatial distribution of those emissions varies. On the winter day, CENRAP has additional Minnesota and North Dakota NO_X than $\text{Minnesota}_{\text{(MRPO)}}$. CENRAP also has significantly more Canada NO_X using the Canada 2000 inventory than $\text{Minnesota}_{\text{(MRPO)}}$ has using the 2005 Canada inventory. Spatially, some of the increased NO_X from Canada appears directly along the border shared with Minnesota, and along the northern border of North Dakota, directly North and Northwest of the Minnesota Class I areas, as shown in Figures 3.3 and 3.4. As shown in the model performance in Section 6, winds during the 20 percent worst days at Boundary Waters and Voyageurs during 2002 often come from the West/Northwest of the Class I areas.

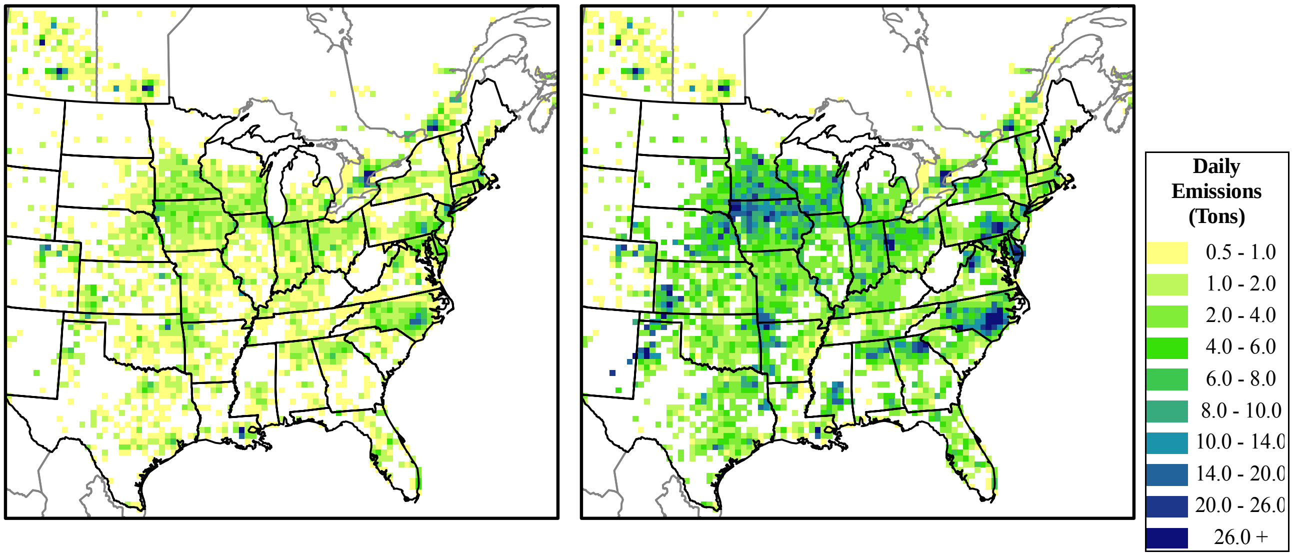
The MRPO 2005 winter day contains less NO_X in the region than both CENRAP or $\text{Minnesota}_{\text{(MRPO)}}$ mainly due to the use of a difference calculation methodology for biogenic $NO_{X,}$ and emission reductions for mobile and nonroad sources from 2002 to 2005.

Sulfur Dioxide. There are no significant differences between the winter and summer day SO_2 emissions. Between the two organizations, the emissions in the U.S are quite comparable. The exception is for Canada emissions, where CENRAP SO_2 emissions are significantly higher. However, impaired visibility due to SO_2 from the north on the 20 percent worst days are not prevalent. Thus, this emissions difference from Canada does not appear to be as relevant for those days. Some of the CENRAP increased SO_2 from Canada occurs directly north of the two Class I areas, but most of the elevated SO_2 is due to a single 1,100 ton per winter day source in Ontario, just north of Lake Huron.

Fine and Coarse Particulates, and Volatile Organic Compounds. As discussed in Section 2.0, the CENRAP case has significantly more of these components of haze than the $\text{Minnesota}_{\text{(MRPO)}}$ case. In regard to particulates, this is mainly due to MRPO excluding wind-blown dust and agricultural equipment dust because of concerns about the transportable fraction. Primary particulates are not a major component in the visibility equation for Boundary Waters and Voyageurs.

The reason for the difference in VOCs between $\text{Minnesota}_{\text{(MRPO)}}$ and CENRAP—associated with biogenics—is not readily apparent. The MRPO 2005 has somewhat more biogenic VOC than $\text{Minnesota}_{\text{(MRPO)}}$, due to the use of a different calculation methodology, and more is allocated to summer than winter. However, because control measures are not proposed for biogenic sources, the analyses can be more forgiving in differences of VOC emissions for regional haze purposes.

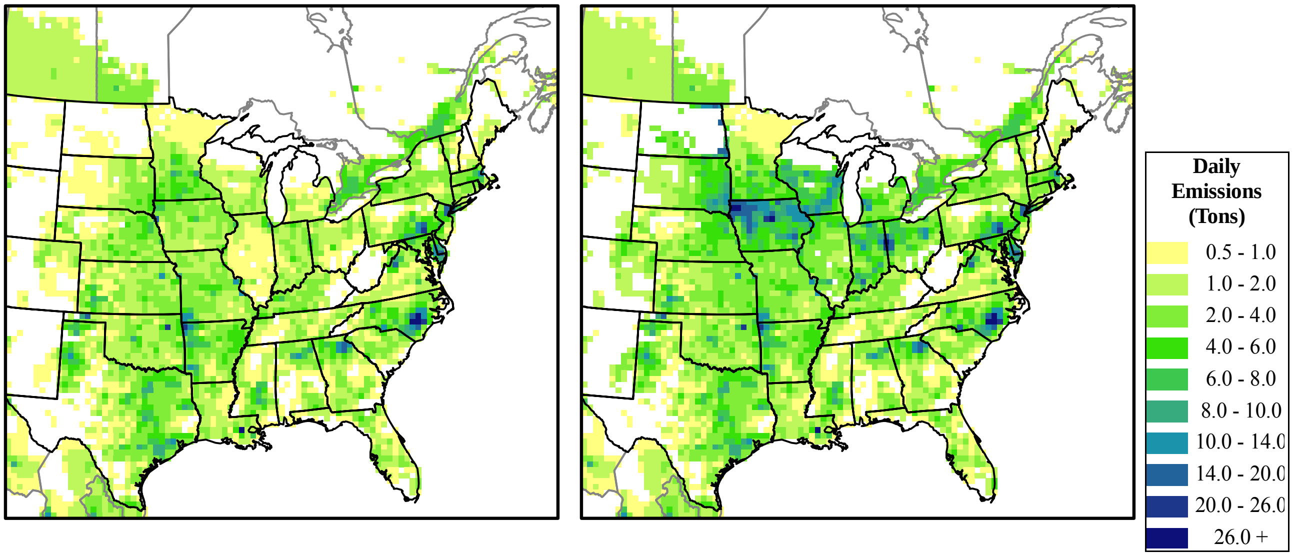
Figure 3.3. 2002 Winter Day and Summer Day <u>Ammonia</u> Emissions in Tons for Minnesota$_{\text{(MRPO)}}$ Case.



Minnesota$_{\text{(MRPO)}}$—<u>Winter Day</u>:

Minnesota$_{\text{(MRPO)}}$—<u>Summer Day</u>:

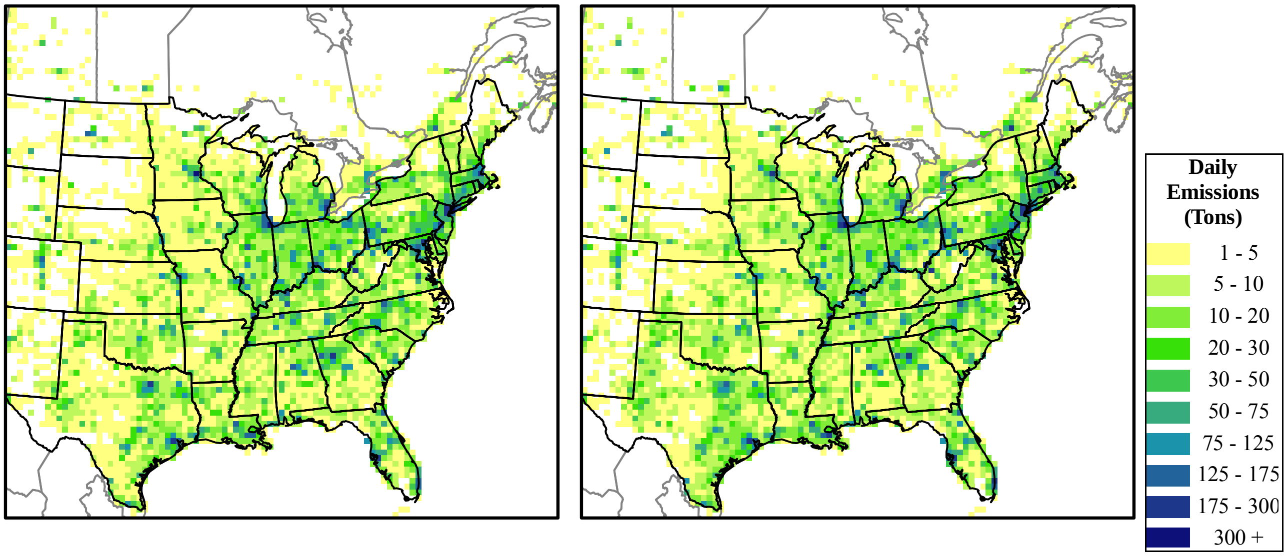
Figure 3.4 2002 Winter Day and Summer Day <u>Ammonia</u> Emissions in Tons for CENRAP Case.



CENRAP—<u>Winter Day</u>:

CENRAP—<u>Summer Day</u>:

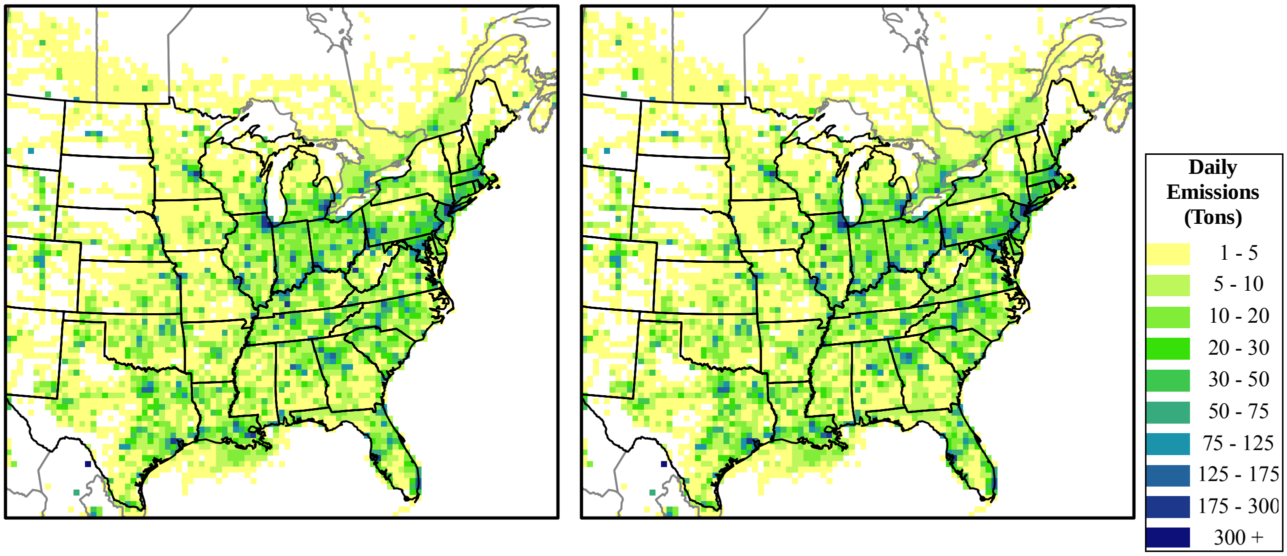
Figure 3.5. 2002 Winter Day and Summer Day $\underline{NO_X}$ Emissions in Tons for Minnesota$_{(MRPO)}$ Case.



Minnesota$_{(MRPO)}$—Winter Day:

Minnesota$_{(MRPO)}$—Summer Day:

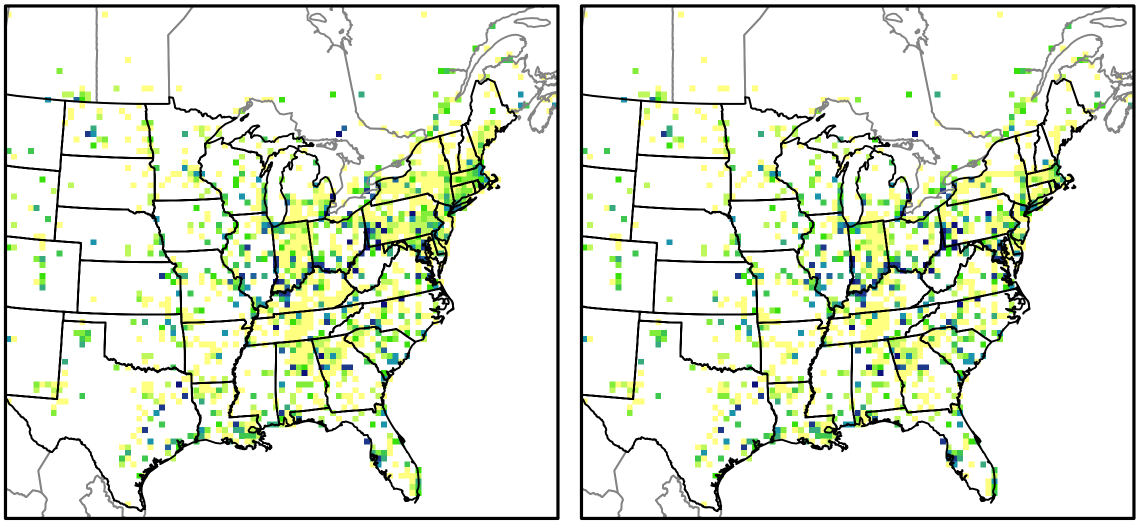
Figure 3.6 2002 Winter Day and Summer Day $\underline{NO_X}$ Emissions in Tons for CENRAP case.



CENRAP—Winter Day:

CENRAP—Summer Day:

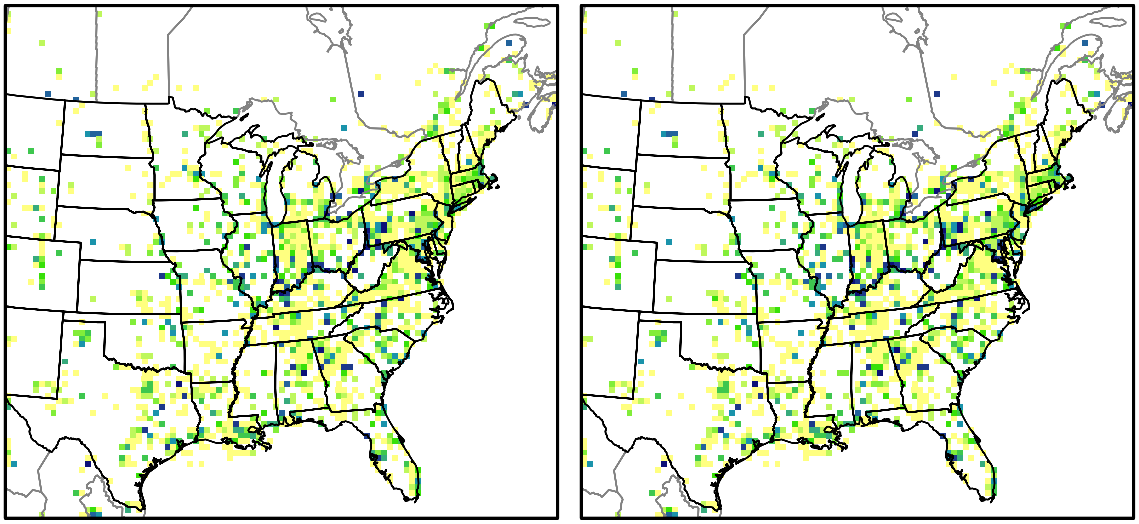
Figure 3.7. 2002 Winter Day and Summer Day SO_2 Emissions in Tons for Minnesota$_{(MRPO)}$ Case.



Minnesota$_{(MRPO)}$—Winter Day:

Minnesota$_{(MRPO)}$—Summer Day:

Figure 3.8 2002 Winter Day and Summer Day SO_2 Emissions in Tons for CENRAP case.



CENRAP—Winter Day:

CENRAP—Summer Day:

Table 3.3. 2002 Emissions for a Winter and Summer Day in Tons for Minnesota$_{(MRPO)}$ and CENRAP .

Region	Winter Day Emissions in Tons -- Base Year 2002											
	Minnesota $_{(MRPO)}$						CENRAP					
	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
Minnesota	458	1,378	158	113	304	1,552	477	1,461	345	282	1,349	1,615
Iowa	533	942	237	64	175	814	469	910	269	232	1,231	1,006
North Dakota	617	498	23	11	47	279	647	627	74	264	1,744	601
South Dakota	91	250	72	12	47	292	50	280	214	427	3,706	380
Wisconsin	785	1,298	131	68	91	1,347	675	1,093	122	74	208	1,507
Canada*	2,491	2,055	997	78	256	3,236	4,046	4,080	1,023	680	3,576	11,535
total: (only U.S)	2,484	4,365	621	269	663	4,284	2,319	4,371	1,024	1,280	8,238	5,109
total: (incl Canada)	4,975	6,421	1,618	347	919	7,520	6,365	8,451	2,047	1,960	11,814	16,644

* Canada emissions are the total included over the entire extent of the 4rpos domain; not delineated by Province. The Minnesota(MRPO) emissions include the Canada 2005 inventory, while the CENRAP emissions include the Canada 2000 inventory.

Region	Summer Day Emissions in Tons -- Base Year 2002											
	Minnesota $_{(MRPO)}$						CENRAP					
	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
Minnesota	461	1,506	666	99	296	6,483	476	1,668	437	293	1,362	8,822
Iowa	564	1,135	1,027	70	189	1,927	495	1,102	1,058	218	982	2,757
North Dakota	549	636	122	10	50	1,607	695	995	925	190	836	2,891
South Dakota	89	390	314	10	45	1,983	80	595	541	129	573	3,236
Wisconsin	797	1,237	571	33	57	3,883	796	1,144	553	63	105	5,246
Canada*	2,036	3,257	994	73	237	48,198	3,187	5,215	1,047	661	3,233	85,214
total: (only U.S)	2,460	4,904	2,700	222	638	15,883	2,542	5,505	3,514	894	3,857	22,952
total: (incl Canada)	4,496	8,161	3,694	295	875	64,082	5,729	10,720	4,561	1,555	7,091	108,166

* Canada emissions are the total included over the entire extent of the 4rpos domain; not delineated by Province. The Minnesota(MRPO) emissions include the Canada 2005 inventory, while the CENRAP emissions include the Canada 2000 inventory.

Table 3.4. 2005 Emissions in Tons for a Winter and Summer Day for MRPO BaseM

Region	Winter Day Emissions in Tons -- Base Year 2005					
	MRPO					
	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
Minnesota	494	1,303	162	83	314	1,236
Iowa	543	764	250	62	171	599
North Dakota	456	449	32	12	16	274
South Dakota	69	192	77	11	20	179
Wisconsin	765	1,023	136	84	127	1,139
Canada*	2,652	2,416	1,013	78	257	5,399
total: (only U.S)	2,327	3,730	658	252	647	3,426
total: (incl Canada)	4,485	4,843	1,509	247	590	7,590

* Canada emissions are the total included over the entire extent of the 4rpos domain; not delineated by Province.

Region	Summer Day Emissions in Tons -- Base Year 2005					
	MRPO					
	SO_2	NO_X	NH_3	PM_{25}	PM_{10}	VOC
Minnesota	463	1,711	703	65	293	10,145
Iowa	559	1,326	1,110	65	178	3,933
North Dakota	519	1,233	141	13	19	1,930
South Dakota	122	948	340	9	19	2,417
Wisconsin	748	1,227	564	20	65	8,499
Canada*	2,099	3,735	1,022	73	238	66,277
total: (only U.S)	2,411	6,445	2,858	172	574	26,923
total: (incl Canada)	4,047	8,469	3,176	180	519	83,056

3.2 MRPO Quality Assurance for Emissions Inventories

While developing the emissions inventory and conducting emissions modeling, Minnesota participated in the MRPO quality assurance for emissions inventories. MPRO assured the quality of the data through the review of emissions reports and spatial analysis[49] as follows:

- *Emission Reports*: EMS performs a number of checks and generates several reports, as documented in the EMS User's Guide[50]. The QA checks for point sources, for example, duplicate or missing keys (stid, cyid, fcid, stkid, dvid, prid, polid), missing UTM coordinates and mismatched UTM zone, missing or invalid FIPS state and county codes, missing facility name missing or invalid SIC, and missing or out-of-range stack parameters. The reports include tabular summaries of the state- and county-level emissions for point, area, and mobile sources; and various spatial plots of emissions.

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[49] MRPO (June 2004)

[50] Janssen, M., Hua, C. (1998)

- *Spatial Analysis*: A second level of quality assurance is performed by the photochemical modelers The additional checks include: evaluating spatial tile plots of total daily SO_2, NO_X, VOC, ammonia, $PM_{2.5}$, and coarse mass emissions, and evaluating plots that show the variation in emissions from month to month, and from hour to hour.

4.0: Meteorological Modeling

Meteorological data inputs were prepared using the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5). Appendix B contains a protocol titled "Meteorological Modeling Protocol for Application to PM2.5/Haze/Ozone Modeling Projects", December 2004, for conducting meteorological modeling with MM5.

Both the MRPO and CENRAP use the same 36km modeled meteorological data for their 2002 and 2018 simulations. The data was prepared by Matthew Johnson of the State of Iowa.

Appendix D contains the detail on the meteorological inputs, including the definition of the meteorological data grid, processing of input data to MM5, model execution and the model performance evaluation. There are two model performance documents. One was prepared by Kirk Baker of MRPO, titled "Meteorological Modeling Performance Summary for Application to PM2.5/Haze/Ozone Modeling Projects", February 18, 2005, and the other was prepared by Matthew Johnson of Iowa, titled "Meteorological Model Performance Evaluation of an Annual 2002 MM5 (version 3.6.3) Simulation, 2004-2007, v2.0.3. Model performance was deemed good.

5.0: Atmospheric Chemistry and Transport Modeling

Guidelines for conducting regional-scale modeling for particulate matter and visibility are provided in 40 CFR § 51, Appendix W. The EPA recommends the use of one of the three following models to simulate pollutants impairing visibility: Community Multiscale Air Quality (CMAQ), the Comprehensive Air Quality Model (CAMx), and Regional Modeling System for Aerosols and Deposition (REMSAD). These are Eulerian models that compute the numerical solution of partial differential equations of plumes on a fixed grid. The models simulate atmospheric and surface processes affecting the transport, chemical transformation and deposition of air pollutants and their precursors. CAMx also allows two-way grid nesting, a subgrid scale Plume-in-Grid (PiG) module to treat the early dispersion and chemistry of point source plumes, a fast chemistry solver, and Particulate Source Apportionment Technology (PSAT), which tracks the origin of particulate species by geographic region (i.e. States) and by source category (i.e. point sources, mobile sources)[51]

The EPA sponsored the development of CMAQ. For regional haze modeling, CENRAP contractors used CMAQ and CAMx (for PSAT), and the MRPO and its member States use CAMx. Minnesota, using MRPO model inputs, also uses CAMx. Both CENRAP and MRPO limited regional haze modeling to the 36km grid scale. Both organizations found this grid resolution sufficient for regional haze. However, Minnesota has an interest in evaluating the

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[51] ENVIRON (September 2006).

impacts of sources close in to Boundary Waters and Voyageurs. Minnesota has conducted an evaluation using the MRPO inputs, creating a 12km nested grid covering the State of Minnesota, and using PiG treatment for those sources nearest the Minnesota Class I areas. Minnesota used CAMx version 4.42.

A modeling protocol formalizes the procedures for conducting the modeling analyses. Minnesota did not prepare its own protocol, instead relying on the meteorological modeling and air quality modeling protocols prepared by the MRPO.

MRPO Modeling Protocol. Appendix E contains the MRPO protocol, "2002 Basecase Modeling Protocol: Technical Details", October 15, 2007. Minnesota conducted modeling using the MRPO inputs and defers to the MRPO modeling protocol for the technical details:

1. The methodology for conducting the regional scale modeling, including details on
   a. the geographic coverage of the modeling domain (i.e. covering an area that includes the United States and Canada extending east of a line dissecting the United States at the western-most tip of Texas) and the size of individual grid cells (i.e 36km X 36km grids);
   b. details on the meteorological data input to the CAMx modeling;
   c. a summary of the emissions inputs, landuse inputs, drought stress and snow cover, photolysis rates, initial and boundary conditions;
   d. quality assurance measures taken on the model inputs; and
   e. the configuration of the CAMx model, the gas phase chemistry, deposition, nesting, PiG treatment of point sources, and the use of probing tools (i.e. source apportionment);
2. Steps taken to evaluate the model predictions compared to observations (monitored values) at the same location over the same time period; and
3. Conversion of the data to visibility metrics; and the method for conducting the reasonable progress test (estimate of position on the uniform rate of progress toward natural visibility).

Minnesota explored answers to questions specific to Minnesota beyond the scope covered by the air quality modeling protocol prepared by the MRPO. For example, Minnesota is interested in the visibility impact of sources located near Boundary Waters and Voyageurs. This resulted in a modeling analysis using a 12km nested grid and a PiG tool for individual elevated point sources located within a certain distance of the Class I areas. PiG tracks individual plume segments from each point source, rather than immediately dispersing the individual point source emissions in the grid cell. In order to use the PiG module properly, some modifications to the air quality modeling inputs files were required. For example, stack parameter and location information has greater importance when PiG is employed. These changes are outlined in Section 2.0.

The meteorology and all emissions in the Minnesota 12km grid are "flexi-nested". This means that no emissions were developed with an emissions model to allocate emissions appropriately to each 12km grid (excluding point sources). Thus, area source emissions for a 36km grid cell were evenly distributed to each of the nine 12km grid cells contained within the 36km grid cell. However, a specific 12km landuse file was created and input to CAMx. The 12km landuse file was created with MRPO methodology. The main purpose of the 12km nest is to better locate, and concentrate emissions, from point sources to a smaller grid and to allow a better segue for invoking PiG treatment for larger point sources located near the Minnesota Class I areas. The

GREASD PiG treatment was applied to point sources with emissions greater than 100 tons per year of SO_2 or NO_x and located within the six Minnesota counties nearest the Boundary Waters and Voyageurs Class I areas.

Unlike the MRPO, who uses the Particulate Source Apportionment Tool (PSAT) to track the contributions of all the individual components of PM_{25}, Minnesota limited contribution assessment to the sulfate ion, nitrate ion, and ammonium ion because these are the components most likely to be involved in control measures. Also, MRPO PSAT results show that the excluded components—elemental carbon, and primary emissions of organic aerosol, soil and coarse mass—are not significant contributors to visibility in contrast to ammonium nitrate and ammonium sulfate, especially because fires are not included in the modeled emissions inventory. The MRPO did not employ source apportionment for secondary organic aerosols because of the long simulation run times. However, Minnesota has reported secondary organic aerosol contributions specific to biogenic and anthropogenic sources from the standard CAMx output. Separate geographic regions and source groups tracked by Minnesota are detailed in Section 8.0—Control Strategy Development.

6.0: Model Performance Evaluation

Prior to proceeding to the development of future year emissions, it is desirable to show the air quality model's ability to simulate observed measurements on the same days that are selected for evaluation. EPA guidance calls this an "operational evaluation" of regional haze model performance.

Model performance is conducted on the base model year, which was developed based on the 2002 emissions inventory and meteorology. The base case period used to evaluate model performance is the same as that applied to the baseline period in the modeled attainment test. Several iterations of the 2002 base inventory were conducted by MRPO culminating in the latest baseK inventory used as the backbone for the $\text{Minnesota}_{\text{(MRPO)}}$ modeling. Model performance evaluations of these iterations allowed for improving the emissions, meteorology and the CAMx model, resulting in improved model performance.

Both CENRAP and MRPO have evaluated model performance over the entire domains they modeled. Because Minnesota is using MRPO 2002 inputs with emissions modifications described in Section 2.0, the State focused its own model performance on Boundary Waters and Voyageurs. Particular attention was placed on the 20 percent worst days in the two Class I areas.

In addition to the more specific performance evaluation results for the $\text{Minnesota}_{\text{(MRPO)}}$ modeling, a summary of the CENRAP and MRPO model performance results are provided. All performance results provided are for the 36km grid. Minnesota also evaluated performance of the $\text{Minnesota}_{\text{(MRPO)}}$ 12km grid with PiG in this Section. The results are discussed, but corresponding plots and charts are not provided as part of this technical support document.

Model performance evaluation was conducted on the several components of fine particulate ($PM_{2.5}$)—sulfate ion (SO_4), nitrate ion (NO_3), ammonium ion (NH_4), organic carbon (OC), elemental carbon (EC) and crustal/soil material. These major components that comprise the mixture $PM_{2.5}$ are evaluated separately in order to avoid compensating errors that might indicate good model performance were the compounded $PM_{2.5}$ evaluated.

The remainder of the discussion for this Section includes a summary of the observational data available for observed/predicted comparisons, an identification of the performance tests used and their results, a description of the ability of the model to reproduce observed temporal and spatial patterns, and an overall assessment of what the performance evaluation implies.

6.1 Observed Data Available/Used for Comparison.

The speciated components used in the $\text{Minnesota}_{\text{(MRPO)}}$ evaluation are collected with monitors in the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. This network collects individual $PM_{2.5}$ components (excluding ammonium) at Class I areas, such as at Boundary Waters (BOWA1) and Voyageurs (VOYA2). The locations of these monitors in relation to Boundary Waters and Voyageurs are provided in Figure 6.1. The Isle Royale monitor is not located on the island, but further southwest, on the Upper Peninsula of Michigan. The species collected at the monitor and the corresponding species in the CAMx model are shown in Table 6.1.

Figure 6.1. Locations of IMPROVE Monitors at Boundary Waters and Voyageurs.

Table 6.1 – Performance Evaluation Monitor to Model Definition of Pollutants Evaluated at Minnesota Class I Areas[52].

Component	**IMPROVE**	**CAMx4 species**
Sulfate Aerosol	SO4f	PSO4
Nitrate Aerosol	NO3f	PNO3
Organic Aerosol	OCf * FACTOR FACTOR = 1.6 rural 2.1 urban	SOA1 + SOA2 + SOA3 + SOA4 + SOA5 + POA
Elemental Carbon	ECf	PEC
Soil/Crustal	2.2 * ALf + 2.49*SIf + 1.63*CAf + 2.42*FEf + 1.94*TIf	FCRS

Monitoring data used for model performance was obtained from the Visibility Information Exchange Web System (VIEWS), the repository of data to support the Regional Haze Rule. This data is available at http://vista.cira.colostate.edu/views/ and is maintained by the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. Performance evaluation is conducted using the raw data set. $PM_{2.5}$ and $PM_{2.5}$ component species at the two IMPROVE sites are collected over 24-hour periods once every three days.

VIEWS has a substitute data set for Boundary Waters because of a lack of complete data for a few years. An equipment malfunction in 2002, 2003 and 2004 caused the loss of the following data:

- "Module A" – $PM_{2.5}$ particle mass;
- "Module C" – Elemental and organic carbon mass, and
- "Module D" – PM_{10} particle mass.

This data loss invalidated three out of every seven samples from these modules. "Module B" has a denuder that collects nitrate, chloride, sulfate and nitrite. According to CIRA, the "Module B" data from Boundary Waters during this period are valid. In order to utilize the valid data from Boundary Waters, Scott Copeland of CIRA substituted the missing components with a linear regression analysis from corresponding valid data collected at Voyageurs. Data substitution reports are available on the VIEWS website.[53] Substituted data at Boundary Waters is identified in this Section with the acronym BOWAV.

The performance evaluation relies on a different set of 20 percent worst days at Boundary Waters than those currently available on VIEWS. The MRPO identified some days at Upper Midwest Class I areas where data was excluded from the 20 percent worst days on VIEWS because of incomplete capture of insignificant components of visibility in those Class I areas. For example, coarse mass and soil/crustal material are missing, while the remaining components—notably sulfate and nitrate—are present at levels that would cause those days to be on the list of 20 percent worst.[54] More detail on the implications of this is provided in Section 7.0.

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[52] MRPO (October 2007)

[53] http://vista.cira.colostate.edu/views/Web/Documents/SubstituteData.aspx

[54] MRPO (June 2007)

For the year 2002, the inclusion of this previously excluded data results in the displacement of two days from the 20 percent worst days in Boundary Waters. January 11 and March 27 are replaced with July 22 and September 8. The 20 percent worst days in 2002 at Voyageurs remain the same. The data for the previously excluded days are in the raw data set from VIEWS and as long as model performance programs do not hard-code which days are the 20 percent worst days, the evaluation will include days otherwise excluded because of incomplete capture of insignificant components. Table 6.2 contains the observed values of each component for the 20 percent worst days in this performance evaluation. The “v” next to the Julian date means the day is one of the 20 percent worst for Voyageurs only, the “b” means the day is one of the 20 percent worst for Boundary Waters only. Days without a letter mean the day is one of the 20 percent worst for both Class I areas. In modeling analyses, days are identified by their Julian date. Throughout the rest of this document, days modeled may be identified either based on the Gregorian or Julian Calendar. Appendix F contains a cross-reference table for Gregorian and Julian calendar days in 2002.

Table 6.2 Species Data at Minnesota Class I Area Monitor Sites for 20% Worst days in Micrograms per Cubic Meter

Station	PM2.5 component	Julian date										
		5v	11v	26b	71v	86v	104v	131	146	149b	152v	161b
BOWAV	SO4	no data	1.074	2.892	no data	1.518	1.425	2.262	1.979	3.866	no data	6.938
	NO3	no data	2.192	0.670	no data	1.721	1.207	0.636	0.413	0.216	no data	0.189
	EC	no data	0.117	0.129	0.228	0.119	0.245	0.292	0.280	0.287	no data	0.501
	OC	no data	0.522	0.687	0.822	0.597	1.169	1.586	2.523	1.523	no data	2.543
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	no data	0.256	0.275	0.437	0.442	0.673	0.740	0.766	0.454	no data	0.738
VOYA2	SO4	1.911	0.863	2.420	2.002	1.562	1.542	2.283	1.834	1.390	0.786	no data
	NO3	3.292	3.360	0.742	2.789	2.818	2.418	0.762	0.268	0.203	0.210	no data
	EC	0.224	0.204	0.202	0.258	0.187	0.309	0.228	0.256	0.183	0.818	no data
	OC	0.811	0.733	1.057	0.851	0.752	1.120	1.593	2.327	1.553	8.925	no data
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	0.217	0.114	0.159	0.378	0.477	0.404	0.385	0.508	0.384	0.552	no data

Station	PM2.5 component	Julian date										
		170	176b	179	188	197	200	203b	221	242	245	251b
BOWAV	SO4	5.287	3.658	2.140	1.850	4.829	0.857	3.415	2.200	4.415	3.054	7.839
	NO3	0.535	0.283	0.108	0.243	0.254	0.096	no data	0.174	0.177	0.094	0.208
	EC	0.560	0.278	0.575	0.221	0.331	0.713	0.225	0.266	0.365	0.229	0.443
	OC	3.299	2.445	7.394	2.435	1.543	11.436	1.492	1.312	1.820	1.314	2.981
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	0.867	0.808	0.867	1.269	0.938	0.408	0.548	0.525	0.564	0.453	no data
VOYA2	SO4	4.602	1.739	1.733	2.095	7.645	1.163	0.229	2.102	5.054	4.101	no data
	NO3	0.522	0.092	0.102	0.241	0.192	0.107	0.029	0.173	0.231	0.245	no data
	EC	0.707	0.179	0.585	0.298	0.408	0.842	0.034	0.296	0.417	0.256	no data
	OC	2.742	1.301	7.650	2.248	1.938	15.187	0.682	1.336	1.984	1.332	no data
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	0.422	0.292	0.533	0.867	1.245	0.708	0.123	0.461	0.495	0.391	no data

Station	PM2.5 component	Julian date									
		254v	260v	272v	275b	284v	299	314b	332	344	347
BOWAV	SO4	1.365	0.669	1.545	3.319	0.218	1.459	1.465	1.627	0.865	1.958
	NO3	0.080	0.065	0.158	1.025	0.024	4.197	1.482	3.372	4.023	2.816
	EC	0.137	0.305	0.066	0.471	0.350	0.363	0.191	0.242	0.294	0.316
	OC	1.312	1.659	0.523	1.738	1.475	1.493	0.955	0.791	1.194	1.334
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	0.280	1.102	0.131	0.588	0.435	0.208	0.113	0.597	0.326	0.377
VOYA2	SO4	1.045	1.959	2.510	0.306	2.496	1.771	0.819	1.459	0.694	1.458
	NO3	0.182	0.228	0.184	0.016	1.172	4.486	0.388	2.641	3.193	4.387
	EC	0.269	0.349	0.171	0.028	0.394	0.353	0.125	0.245	0.324	0.353
	OC	3.116	1.772	1.031	0.388	1.642	1.674	0.676	0.853	1.310	1.482
	NH4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
	CRUSTAL	0.232	1.000	0.230	0.060	0.412	0.228	0.017	0.299	0.297	0.351

6.2 Performance Tests Used and their Results.

EPA guidance recommends considering various statistical assessments and other techniques of modeled versus observed pairs when conducting a performance evaluation for regional haze. The other techniques include spatial plots, timeseries plots and qualitative descriptions.

6.2.a Fractional Bias and Error. Focus for the statistical assessment is on mean fractional bias and error, although MRPO also looks at mean bias and gross error. Performance goals and performance criteria for mean fractional bias and error are equal to or less than the values in Table 6.3.

Table 6.3 Performance Goals and Criteria for Fractional Bias and Error.[55]

Fractional Bias	Fractional Error	Goal/Criteria
± 30%	50%	Goal—Best that a model is expected to achieve.
± 60%	75%	Criteria—Acceptable for standard modeling applications.

The goals and criteria shown above apply to more abundant concentrations of $PM_{2.5}$ components in the atmosphere. At zero concentration, the goal and criteria range from ±200% mean fractional bias to +200% mean fractional error. The goal and criteria asymptotically approach the goals and criteria in Table 6.3. Thus, a higher percentage error and bias are allowed at low concentrations. This is because at lower concentrations the models have greater difficulty predicting concentrations.

The statistics typically look better at greater averaging times. Thus, the fractional bias and error likely will show a better fit within the goals and criteria at an annual average than a monthly average, and at a monthly average than a 24-hour average.

As mentioned in earlier sections, the MRPO 2002 case is the backbone for the $\text{Minnesota}_{(\text{MRPO})}$ case. The MRPO evaluated performance of the MRPO 2002 case encompassing a significant portion of the 4rpos domain. The analysis included monitor sites in Minnesota (most notably Boundary Waters and Voyageurs), but also extended as far East as Maine and as far South as to include some sites in South Carolina, Georgia, Alabama, Arkansas and Oklahoma. In addition to the IMPROVE sites, the MRPO evaluation also included Speciation Trends Network (STN) and CASTNet visibility sites.

Figure 6.2 depicts fractional bias and error for the monthly average concentrations in the MRPO 2002 case. These results show very good performance for sulfate and elemental carbon; good performance for soils and nitrate; and an under prediction of organic carbon.

The MRPO also conducted performance analysis[56] for 24-hour average mean bias, gross error, fractional bias and fractional error for each month of 2002 over the same domain. That analysis concludes that model performance for sulfate is good in the summer months when concentrations are highest; nitrate is best in winter when concentrations are highest; organic carbon is poor

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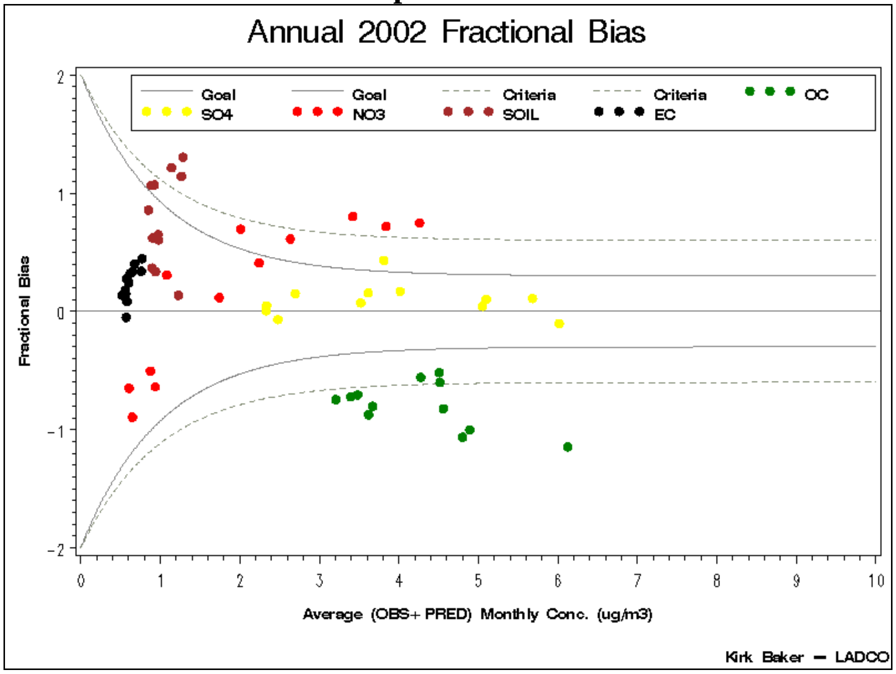
[55] Boylan, J.W. and Russell, A.G. (2006)

[56] Baker, Kirk, (undated)

especially in the summer months when concentrations are highest and in urban areas; soil (crustal material) is poor; and elemental carbon is good. Not much soil is collected on the filters at the Boundary Waters and Voyageurs IMPROVE monitors, so model performance is not as important for this specie as it is for sulfate, nitrate and organic carbon. Ammonium is not collected at the IMPROVE monitors.

Figure 6.2 MRPO Fractional Bias for 2002 Monthly Average Concentrations for 4rpos Domain



The statistical evaluation of the Minnesota$_{(MRPO)}$ modeling performance focuses attention on the IMPROVE sites at the Minnesota Class I areas (Boundary Waters and Voyageurs). Evaluation was done for 24-hour averaging times. Fractional bias and error are evaluated for 36km and 12km (w/ PiG) grid scale modeling. The evaluation compares observed and modeled values for the 20 percent worst days for one or the other (or both) Class I area. There are thirty-two 20-percent worst days total. Eight days are Boundary waters only, 10 days are Voyageurs only, and 14 days are shared between the two Class I areas.

Fractional bias and error plots for the 20 percent worst days at Boundary Waters and Voyageurs for the 36 km grid are shown in Figures 1 through 12 in Appendix G. Because Boundary Waters has substituted data for all components but sulfate and nitrate, it is appropriate to test performance only on sulfate and nitrate at Boundary Waters. However, including the substituted data in the performance provides some insight into how the substituted data aligns with modeled predictions.

Sulfate fractional bias and error fit the criteria and goals, except the four days January 26, May 11, September 17 and October 11. ***Nitrate*** fractional bias and error show poor model performance. There are nearly the same number of days not meeting the criteria as are meeting the criteria. These days are scattered throughout the year, although most of the poor performing days are at very low observed concentrations—between 0.03-0.52 µg/m³—in the summer months when modeled concentrations are zero.

Organic carbon performance is good with several days not meeting the criteria. They are May 26, June 1, June 28, July 19 and October 2. Good performance may somewhat be associated with prescribed burning emissions inadvertently included in the Minnesota non-utility point file. In a paper titled "Establishing Reasonable Progress Goals for the Northern Class I Areas: Treatment of Organic Carbon", April 2, 2007, the MRPO addresses impact from wildfire activity. MRPO identifies the days with bad organic carbon model performance as days in which the Minnesota Class I areas were impacted by Canadian wildfires.

Elemental carbon performance is good with only two days not meeting the criteria, June 1 and July 19. Elemental carbon is produced by fires, and these two days are impacted by the Canadian wildfires. ***Soil/crustal*** material performance is good. ***Coarse mass*** performs poorly, which is expected because coarser primary particles (largely composed of wind borne dust) do not travel far and are influenced by very nearby sources. The 36km grid modeling cannot account for these local influences. Also, wind borne dust was excluded from the emissions inventory, for reasons described in Section 2.0.

As mentioned earlier in this document, Minnesota has an interest in the impact of local emissions to regional haze in Boundary Waters and Voyageurs, so fractional bias and error were also evaluated for the Minnesota$_{(MRPO)}$ case with a 12km grid covering the State of Minnesota with PiG invoked for point sources in Northeast Minnesota. Fractional bias and error look very similar between the 36km and 12km(PiG) modeling results for all components except for nitrate. Poor at 36km, nitrate performance is worse at 12km(PiG), especially when concentrations are highest. Three days that are just outside the criteria for fractional bias and just within the criteria for fractional error exhibit poor performance for the 12km(PiG) run. These three days are January 5, December 10 and December 13. Table 6.4 illustrates the difference on these three days.

Table 6.4 Nitrate Fractional Bias for 36km and 12km(PiG) where Results Significantly Differ.

Date	Average Observation	Fractional Bias	
		36km	12km
January 5	3.29	-73.6	-106.8
December 10	3.61	-69.2	-104.6
December 13	3.61	-61.5	-125.8

These results suggest that nitrate either is more a local point source issue at Boundary Waters and Voyageurs and the 36km meteorology is too coarse to transport the point source plumes in the "true" direction; or dispersing the emissions from Northeast Minnesota sources immediately into 36km grid cells near the monitors is masking underlying issues in the modeling system that are causing poor nitrate performance at the two Class I areas.

6.2.b Time Series Plots. Time series plots help determine how well the model performs each day of the week over the year modeled as compared to observed for each Class I area. Appendix

G, Figures 13 through 24, contains time series plots by specie for both Boundary Waters and Voyageurs. Observed values are depicted by dots, as this data is collected on the monitor filters every three days. Modeled values are depicted as a line, as modeled estimates are continuous.

The time series plots are divided into quarters of the year. Because concentrations of species can vary significantly at different times of the year, the scales on the y-axis may differ in each plot by quarter for the same specie. For example, the timeseries plots for nitrate are on a scale of 0-10 µg/m^3 in the 4th quarter, but on a scale of 0-1 µg/m^3 in the 3rd quarter because there is so little nitrate formed during that quarter.

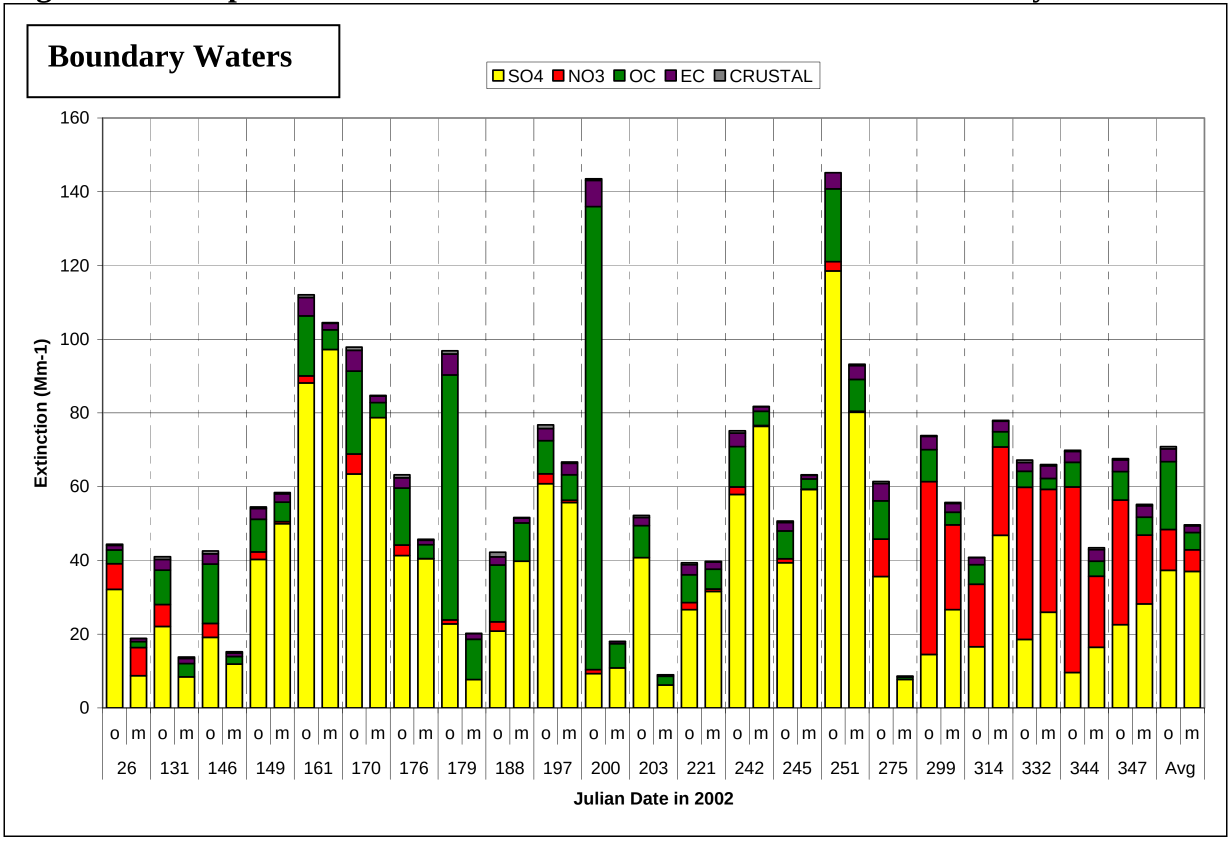
The model is following the patterns (ups and downs) of the observed peaks and valleys quite well. This means that when an observed value is higher, the modeled value also is higher. At times, the modeled estimate is not high enough. The model misses some peaks of NO_3 in the 1st quarter, specifically in January and March. The model does not predict the very low concentrations of NO_3 in the summer. The model also misses some SO_4 peaks in the first quarter and over predicts SO_4 a few days in both the 1st and 4th quarters. Some of these days with over predicted winter SO_4 correspond with days with under predicted NO_3. Ammonia preferentially reacts with SO_2 to form SO_4, so limited ammonia available to further react with NO_x to form NO_3 could explain this modeled response.

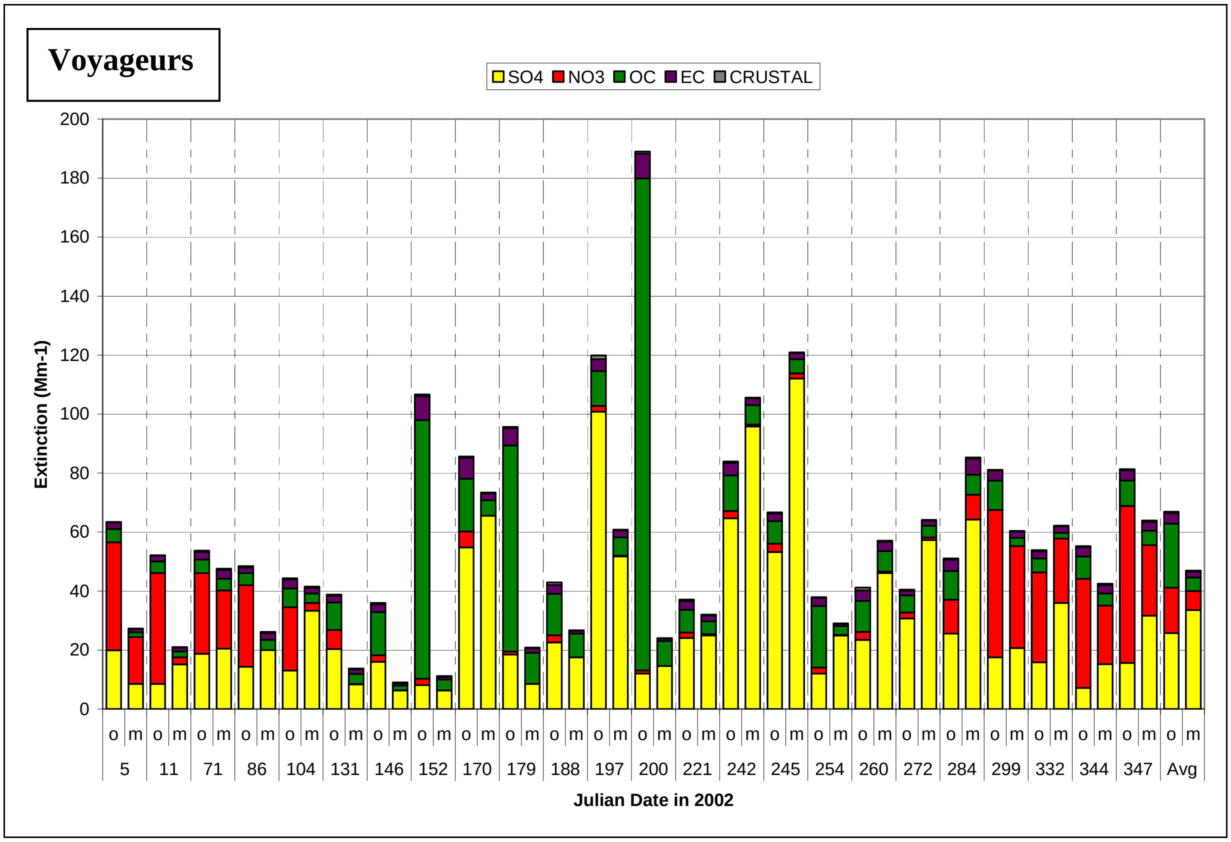
Elemental carbon looks good, organic carbon looks good except a few days attributed to fires. Crustal/soil follows the pattern of observed quite well except for the 2nd quarter. As expected, the model does not capture the patterns of observed coarse mass because coarse mass deposits out of the air very near the source, and can not be captured by 36km grid scale modeling. Also, wind-blown dust was excluded from the modeled inventory for reasons described in Section 2.0.

6.2.c Observation and Prediction Comparison Bar Charts. The bar charts in Figure 6.3 compare each of the 20 percent worst day $\text{Minnesota}_{(MRPO)}$ modeled predicted values to observed values for each Class I area in terms of extinction, as calculated with the IMPROVE algorithm. The column labeled “o” is the observed value. The column labeled “m” is the model predicted value.

The bar charts illustrate that elemental carbon and crustal material are not significant components of light extinction in either the observed or the modeled values. Organic carbon (shown as a green bar) is a significant component in extinction at Boundary Waters and Voyageurs as illustrated in the observed. The model does not show appreciable amounts of organic carbon on days where fire influences the level of organic carbon, because wild fires were excluded from the model inventory as further discussed in other sections of this document. The charts also illustrate the significant roles nitrate and sulfate have in the extinction equation, and the times of the year when nitrate and sulfate claim greater importance. In 2002, nitrate has greater importance from the end of October to the end of the year.

Figure 6.3 Comparison of Observed and Modeled Pairs for 20% Worst Days as Extinction





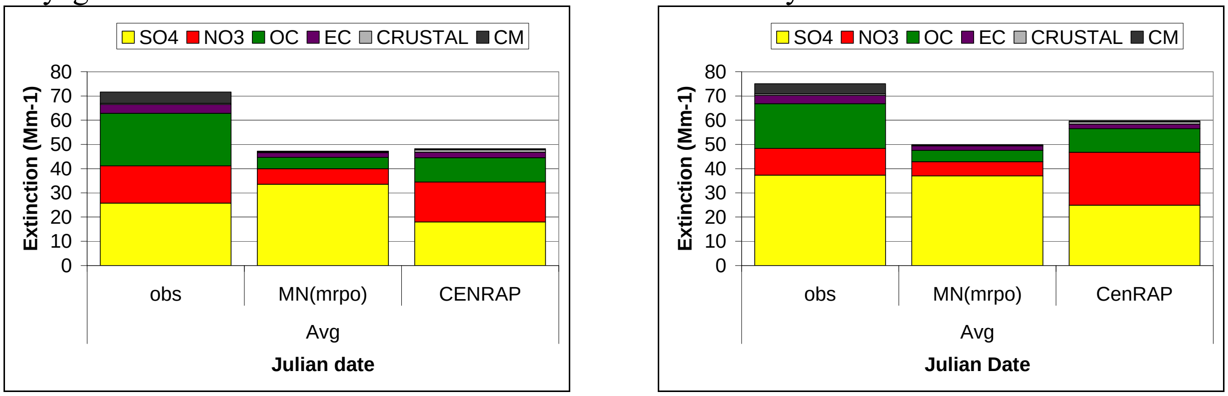
6.3 Comparison of Minnesota$_{(MRPO)}$ and CENRAP Model Performance Evaluation on Specific Individual Days.

CENRAP conducted its performance evaluation as described in its Technical Support Document[57]. The evaluation was conducted on the CENRAP baseF and over a different domain than the MRPO. The CENRAP performance evaluation was conducted at monitor locations throughout the CENRAP region. Because the coverages do not overlap it is not possible to directly compare MRPO and CENRAP model performance evaluation. Also, CENRAP focused its performance on four months of 2002; January, April, July and October.

Except for nitrate, the general conclusions for both organizations are very similar. Both the MRPO 2002 and CENRAP cases generally show good performance for sulfate and elemental carbon and poor performance for soil and coarse mass. Both studies have passable nitrate performance. The MRPO 2002 case found nitrate to be under predicted, but best in the winter months when the concentrations are highest. The CENRAP case found nitrate performance was variable over their domain with under estimation in the summer and over estimation in the winter. CENRAP organic carbon mass performance was variable, but better than MRPO over its domain. This could be attributed to an updated secondary organic aerosol module in CMAQ that was not available in the version of CAMx used in the MRPO 2002 and Minnesota$_{(MRPO)}$ cases. It is more likely attributed to a fire inventory included in the CENRAP modeling, which was not included in the MRPO and Minnesota$_{(MRPO)}$ modeling. Because organic carbon performance at Boundary Waters and Voyageurs is okay except for a few days likely influenced by fire it does not appear that the secondary organic aerosol modifications would make much difference at the two Minnesota Class I areas.

Nitrate at Boundary Waters and Voyageurs. On average—over the 20 percent worst days at each Class I area—the Minnesota$_{(MRPO)}$ case under predicts nitrate by 5 Mm^{-1} at Boundary Waters and 9 Mm^{-1} at Voyageurs; while the CENRAP case over predicts nitrate by 10 Mm^{-1} at Boundary Waters and 1 Mm^{-1} at Voyageurs. Minnesota$_{(MRPO)}$ matches observed for sulfate at Boundary Waters and over predicts sulfate at Voyageurs by 8 Mm^{-1}. The CENRAP case under predicts sulfate by 14 Mm^{-1} at Boundary Waters and by 8 Mm^{-1} at Voyageurs. The 20 percent worst day average for the observed, Minnesota$_{(MRPO)}$ and CENRAP predictions are shown in Figure 6.4.

Figure 6.4 Observations and Predictions in Minnesota$_{(MRPO)}$ and CENRAP Cases—Extinction by Species Averaged Over 20 Percent Worst Days.



Voyageurs:

Boundary Waters:

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[57] ENVIRON (September 2007)

Minnesota has compared observed and predicted results from the CENRAP and Minnesota$_{(MRPO)}$ modeling studies for nitrate and sulfate in order to get a clearer picture on the differences between the results on individual 20 percent worst days at Boundary Waters and Voyageurs. Back trajectories are included along with the results in order to provide some evidence of the direction winds originated on the days with large differences between the two studies. Back trajectories are not assumed to mimic the MM5 wind flows. Some back trajectories were difficult to interpret, so only observed/modeled pairs where backtrajectories indicate air parcels travel in a clear path are presented here.

The backtrajectories were created using HYSPLIT4 (September 2007), with EDAS meteorological data and a starting level of 500 meters. Four trajectory end times were chosen, tracking air parcels arriving at the Minnesota Class I areas at midnight, 6 am, noon, and 6 pm. Trajectories extend backward in time for 48 hours, but were truncated if they extended beyond the northern limit of the EDAS data (approximately 400 kilometers north of the United States border).

On most individual days, the CENRAP and Minnesota$_{(MRPO)}$ cases similarly predict observed nitrate. Days of similarity are in the warmer months when nitrate concentrations are low. Differences occur in the colder months, when nitrate concentrations are highest. The day of greatest difference is at Boundary Waters on October 26, when the Minnesota$_{(MRPO)}$ case under predicts nitrate by 24 Mm^{-1}, while the CENRAP case over predicts nitrate by 46 Mm^{-1}. Other days with significant differences between the studies for nitrate are January 5, January 11, December 10 and December 13. All the air parcels on these days distinctly originate and end in northern Minnesota and surrounding states and Canada.

On days such as January 5 and 11 where the Minnesota$_{(MRPO)}$ case under predicts nitrate and the CENRAP case either simulates observed quite well or under predicts less, the air parcels appear to originate in western Canada and do not travel across the United States. The trajectories do get truncated at the northern boundary of the EDAS domain, so it is not possible to see the entire path of the air parcels. However, the performance difference could be interpreted to suggest that the Minnesota$_{(MRPO)}$ case is missing emission sources in Alberta Canada that the greater western extent of the CENRAP domain (see Figure 3.1) captures.

Although similar data from CENRAP is not available (for the 2000 Canada inventory), Table 6.5 contains the difference in Canada 2005 elevated point source emissions between the 4rpos and inter-RPO national domain. To provide some perspective on the level of “missing” Canada NO_x emissions, they are relatively close to the combined point source NO_x emissions from Minnesota and South Dakota (see Table 2.2), but from much further away. The emissions in Alberta are at a distance of about 1,600 kilometers from Boundary Waters and Voyageurs; about the same distance as to the lower third of Missouri.

Table 6.5. Canada Elevated Point Source Emissions in 2005 Inventory—Domain Differences

Domain	Source Sector	SO_2	NO_X	PM_{25}	PM_{10}	VOC
National	Elevated Point	1,790,000	406,000	24,000	80,500	38,300
4rpos	Elevated Point	881,000	227,000	16,100	51,700	13,700
difference:		909,000	179,000	7,900	28,800	24,600

A look at other days suggests the answer may be closer to home. On all days where the CENRAP case over predicts nitrate, air parcels originate from the west/northwest. The more time the air parcel appears to spend just northwest of the Minnesota border and in northern Minnesota, the greater the over prediction in the CENRAP case. The CENRAP inventory has more wintertime NO_x and ammonia in those regions than the Minnesota$_{(MRPO).}$ case. Section 3.0 contains plots demonstrating the spatial difference between CENRAP and Minnesota$_{(MRPO)}$ case emissions for a January and July weekday.

The more time the air parcel originating in the west/northwest appears to spend in the United States, the closer the Minnesota$_{(MRPO)}$ results compare with the observed. In these cases, the under prediction of nitrate is likely due to insufficient ammonia available in the model in the winter to react with NO_x to form ammonium nitrate.

Figure 6.5 EndPoint VOYA, January 5, 2002

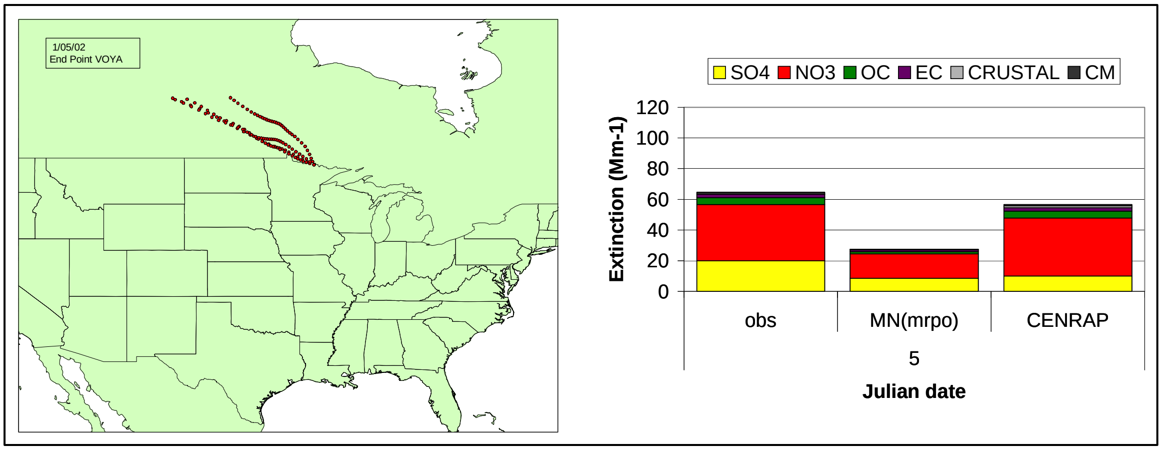


Figure 6.6 EndPoint VOYA, January 11, 2002

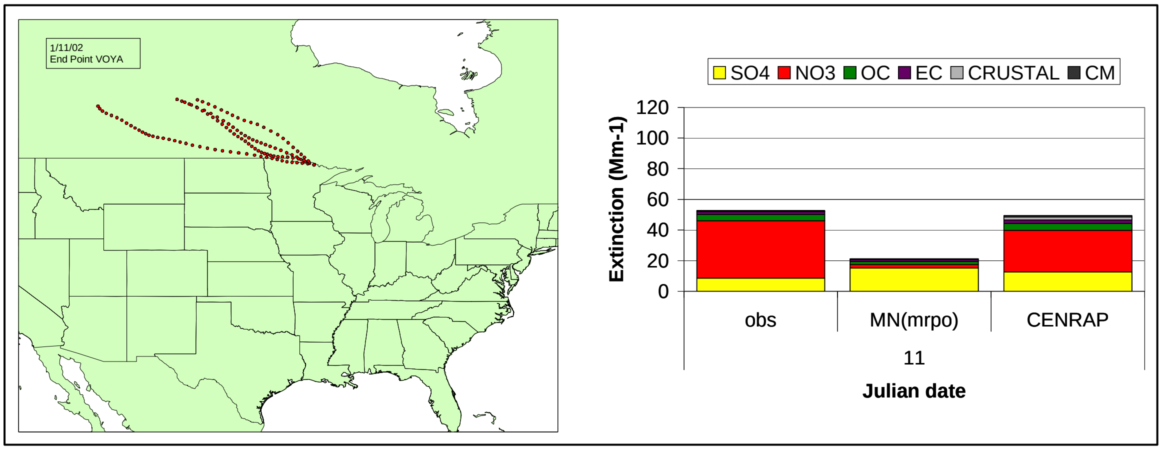


Figure 6.7 EndPoint VOYA, October 26, 2002

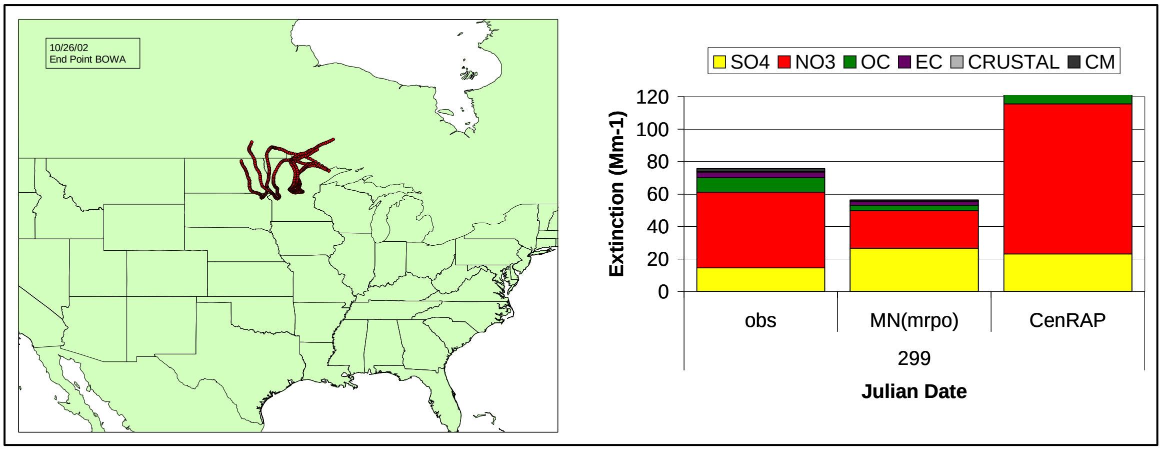


Figure 6.8 EndPoint BOWA, December 10, 2002

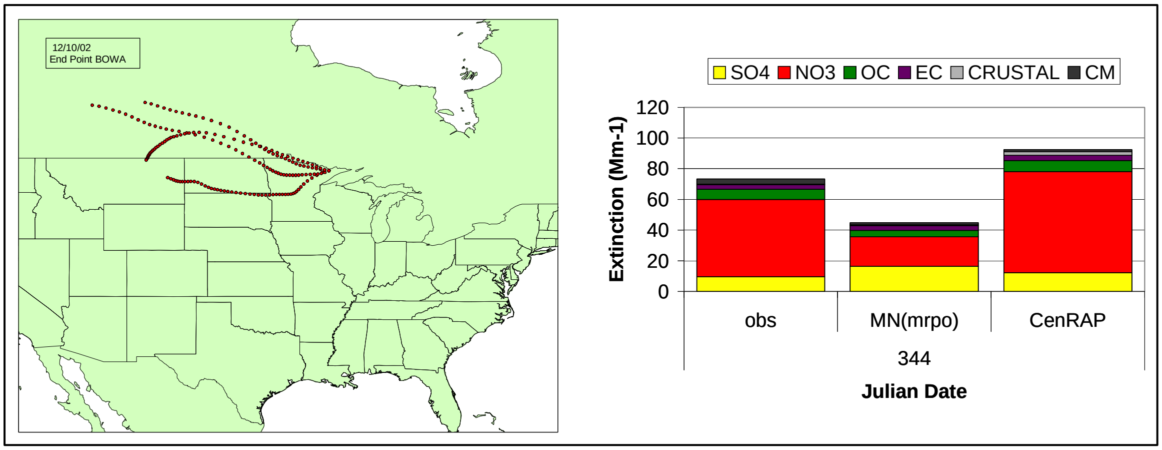
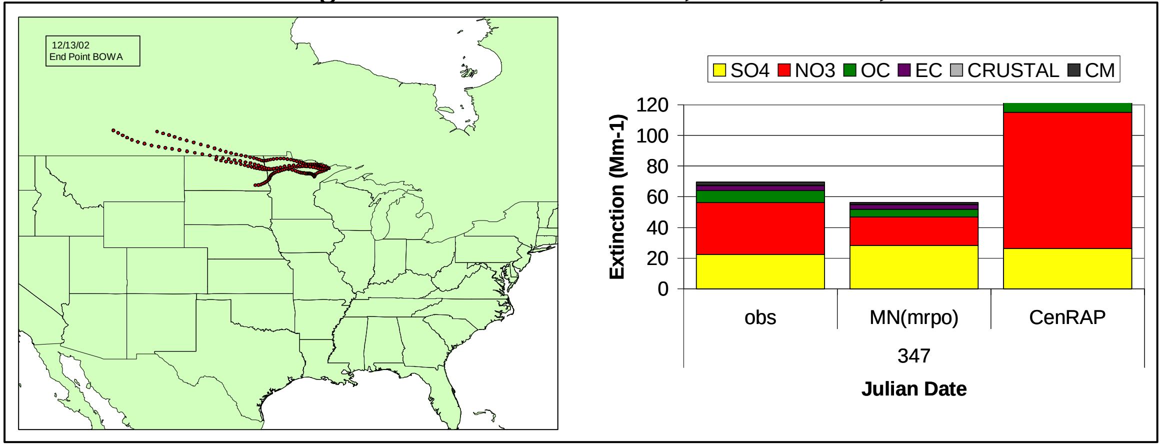


Figure 6.9 EndPoint BOWA, December 13, 2002.



For sulfate, the day of greatest difference is at Voyageurs on September 2, when the Minnesota$_{(MRPO)}$ case over predicts sulfate by 59 Mm^{-1}, while the CENRAP case under predicts sulfate by 43 Mm^{-1}. On that day, air parcels originated to the west, northwest and in the Midwest (starting at Chicago/Gary area and looping down through Missouri and up through Iowa and Minnesota). On other days where the Minnesota$_{\text{(MRPO)}}$ case over predicts, and the CENRAP case under predicts sulfate, there is a strong southerly component where air parcels spend time in southern Minnesota. All the back trajectories are difficult to interpret. It appears that the Minnesota$_{\text{(MRPO)}}$ over prediction and CENRAP under prediction may be due to higher point source SO$_2$ emissions estimates for the MRPO states in the Minnesota$_{\text{(MRPO)}}$ case and greater summer ammonia emissions estimates for Minnesota (i.e. +200 tons/day in July) in the Minnesota$_{\text{(MRPO)}}$ modeling.

Figure 6.10 EndPoint VOYA, April 14, 2002

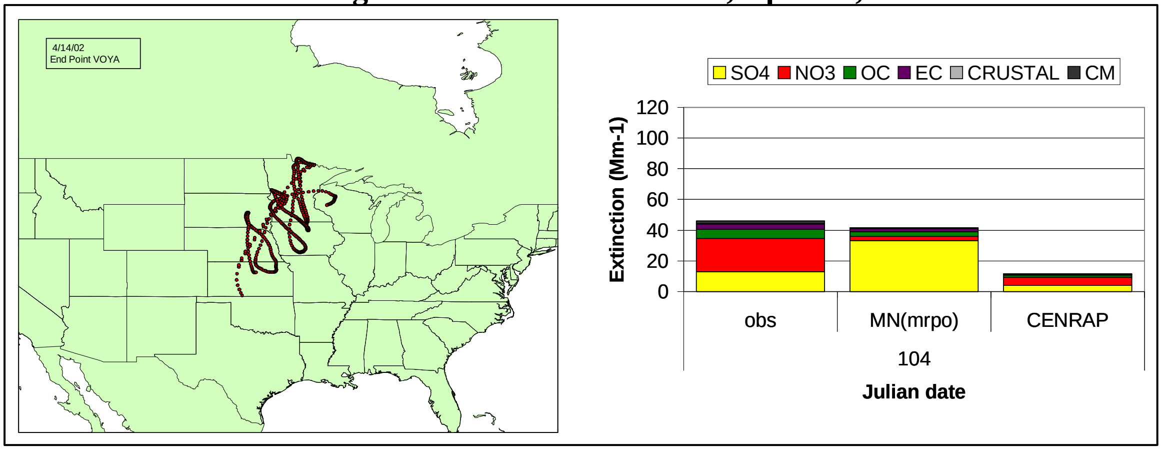


Figure 6.11 EndPoint VOYA, August 30, 2002

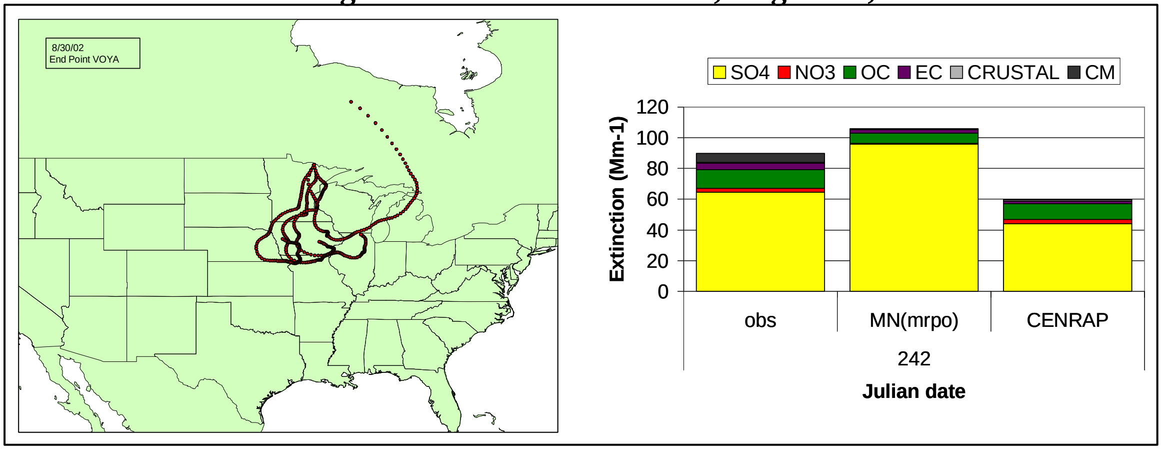
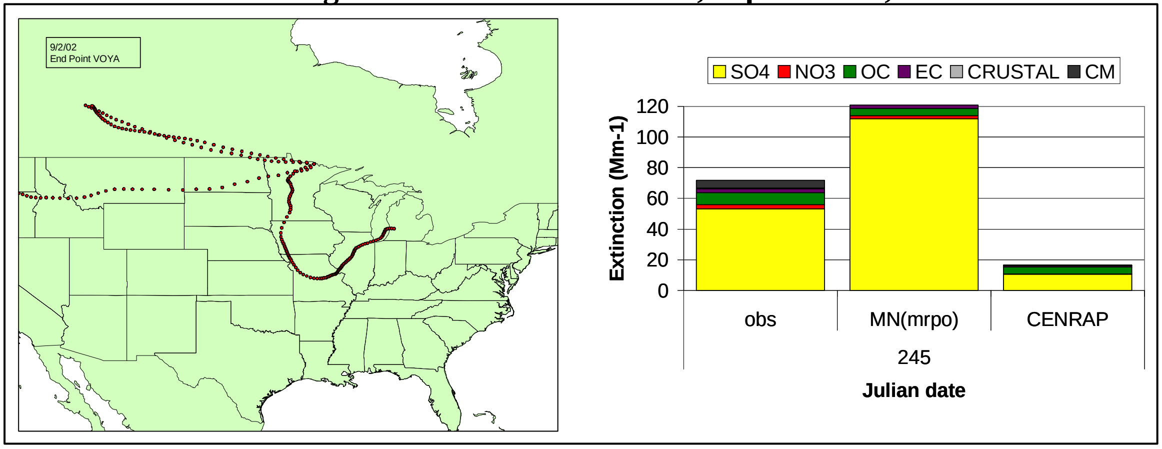
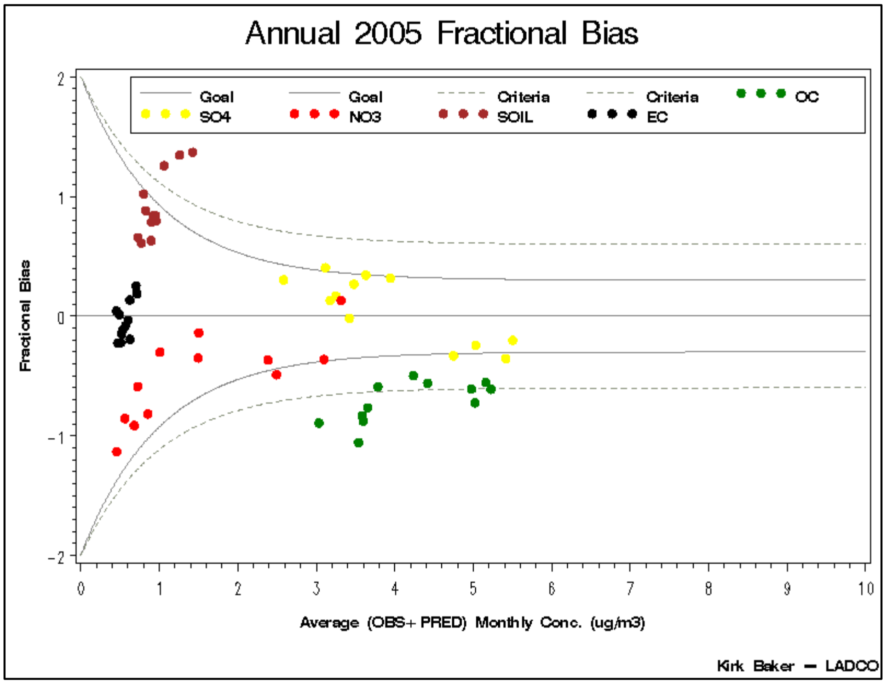


Figure 6.12 EndPoint VOYA, September 2, 2002



The performance evaluation of the MRPO 2005 case shows similar performance with improved performance for nitrate. The MRPO 2005 case has more ammonia in the model system with similar profiles as the MRPO 2002 and Minnesota$_{(MRPO)}$ cases. It is difficult to conclude whether the improved performance is due to the increased ammonia, because the MRPO 2005 case was conducted using different meteorology—culminating in a different set of 20 percent worst days—than the Minnesota$_{(MRPO)}$ and CENRAP cases. Figure 6.13 shows the MRPO 2005 case model performance results.

Figure 6.13. MRPO Fractional Bias for 2005 Monthly Average Concentrations for 4rpos Domain.



6.4 Implications of the Performance Evaluation.

The model performance among the different cases at Boundary Waters and Voyageurs varies significantly on individual 20 percent worst days. The EPA guidance attempts to mitigate uncertainties in model performance by using the model results in a "relative" sense, meaning that the future concentrations are anchored to an observed measurement value. Thus, problems posed by less than ideal model performance—as shown for individual days above—are reduced. However, these differences do appear to affect how the model responds to reductions in emissions, which is described in Section 7.0.

6.4.a Grid Scale Needs. The performance evaluation at the monitor locations is slightly better at 36km than for the Minnesota$_{(MRPO)}$ 12km(PiG) grid for nitrate. As discussed above, these results suggest that nitrate either is more a local point source issue at Boundary Waters and Voyageurs and the 36km meteorology is too coarse to transport the point source plumes in the "true" direction; or dispersing the emissions from Northeast Minnesota sources immediately into 36km grid cells near the monitors is masking underlying issues in the modeling system that are causing poor nitrate performance at the two Class I areas. However, as shown in Section 7.0, the 12km grid (with PiG) and the 36km grid modeling result in the same future visibility estimate.

6.4.b Horizontal Extent of Domain. Minnesota$_{(MRPO)}$ modeling performance for nitrate suggests the modeling could benefit from extending the domain further west to encompass additional sources in Canada. However, there is enough uncertainty in Canada emissions and the model response to ammonia levels, that this conclusion is not substantiated. Minnesota has elected to keep Canada emissions constant between the base and future year. Effectively, Canada emissions (whether increases or decreases) have no relevance in developing the RPG at Boundary Waters and Voyageurs. Further discussion on Canada contributions to regional haze are discussed in Section 8.5.

6.4.c Improvements to Emissions Inventory. Continued emissions/modeling and corresponding performance evaluations conducted by the RPOs has resulted in the best emissions inventory possible to date. Efforts continue to improve the inventory, including the ammonia emissions inventory. Section 8.5 provides information on the models sensitivity to ammonia emissions in establishing the RPG.

6.4.d Modifications of Models. Model performance evaluations over entire domains have resulted in changes to models, but were made for some reason other than achieving regional haze goals in Boundary Waters and Voyageurs. An example would be the secondary organic aerosol module improvements in CMAQ, and more recently in CAMx version 4.5. Although overall model performance for organic carbon may improve, model results without those improvements are acceptable in Boundary Waters and Voyageurs. Also, improved secondary formed organic carbon will not affect reasonable progress in Boundary Waters and Voyageurs as natural biogenic emissions—which are the main contributor to SOA formation at the Class I areas—remain constant in the baseline and future year. Obviously, no controls are proposed for trees, thus they are not accounted for in development of the relative reduction factors. MRPO sensitivity tests show between 1-2 $\mu g/m^3$ difference in organic carbon mass in northern Minnesota occurring in the summer months between CAMx 4.2 (without SOA module improvements) and the beta version of CAMx 4.5.

6.5 Diagnostic tests: Accuracy of the model in characterizing the sensitivity of $PM_{2.5}$ to changes in emissions. Simulations can be performed to determine the sensitivity of model predictions to various inputs to the model. The purpose for diagnostic tests is to assess how various changes to the model inputs affect $PM_{2.5}$ concentrations. It may be that reductions in one input component may still result in similar overall $PM_{2.5}$ concentrations because reduction of one precursor may free up another for additional chemical reactions formulating $PM_{2.5}$ concentrations. An example might be an examination of the extent to which sulfate concentration reductions might increase nitrate concentrations by freeing-up ammonia. No specific diagnostic tests were conducted to test performance of the models for this analysis. However, sensitivity to changes in ammonia emissions in the base and future year and their impact on the RPG is documented in Section 8.0

7.0: Uniform Rate of Progress Analysis

The Regional Haze Rule, promulgated by the EPA July 1, 1999, requires states to "establish goals (expressed in deciviews) that provide for reasonable progress towards achieving natural visibility conditions for each Class I area within a State"; improving visibility on the most impaired days and not degrading visibility on the least impaired days[58]. The ultimate goal of natural visibility is to be met in 2064, and reasonable progress goals are interim goals representing progress toward that end. The year 2018 is the initial year for developing a reasonable progress goal.

EPA guidance describes the method for determining the reasonable rate of progress goal for each Class I area. There are several steps, summarized as follows:

1. Calculate average **baseline visibility conditions** for the 20 percent worst and 20 percent best visibility days at each Class I area using five years—2000 through 2004—of observed values that straddle the modeled base year (i.e. 2002);
2. Calculate **natural conditions** using observed values;
3. Model a **base year ambient air concentration**, in micrograms per cubic meter ($\mu g/m^3$), with modeled values that meet performance goals and criteria;
4. Project **future ambient air concentration** in $\mu g/m^3$;
5. Calculate **relative response factors** for the main components of $PM_{2.5}$ from the modeled base year and projected future year concentrations and apply them to the observed concentration data (by individual component) for the 20 percent worst and 20 percent best days;
6. Calculate projected **future year visibility** in terms of extinction in inverse megameters (Mm^{-1}) using the IMPROVE algorithm; and
7. Convert extinction to **deciviews (dv).**

The core of the visibility assessment is the baseline and natural visibility conditions based on observed data collected at IMPROVE monitors and made available through VIEWS. The **baseline visibility conditions** are developed from five years of monitoring data and represent the starting point from which reasonable progress is measured. The Regional Haze Rule prescribes the baseline period as the years 2000-2004, and defines baseline visibility conditions as the average of the 20 percent worst visibility impaired days, calculated from the monitoring data for each year of the baseline, and then averaged over the 5-year baseline period.

The monitoring data used in the baseline visibility conditions is the regulatory version obtained from VIEWS, including the substituted values for Boundary Waters described in Section 6.0. The 20 percent worst days in Boundary Waters and Voyageurs used here differ from those currently available on VIEWS. The MRPO identified some days at Upper Mid-West Class I areas that were excluded from the 20 percent worst days on VIEWS because of incomplete capture of insignificant components of visibility. For example, coarse mass and soil/crustal material are missing, while the remaining components—notably sulfate and nitrate—are present

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[58] (40 CFR 51.308(d)(1))

at levels that would cause those days to be on the list of 20 percent worst.[59] Over the five-year period used to calculate the baseline visibility conditions, this affects six days at Boundary Waters and three days at Voyageurs. The baseline increases by 0.3 dv at Boundary Waters and 0.2 dv at Voyageurs. The MRPO treatment does not affect the 20 percent best days.

Using the monitored data over the 5-year baseline period, the baseline visibility for each day is ranked for each day based on the extinction coefficient. Extinction was calculated using PM_{10} and speciated $PM_{2.5}$ measurements at Boundary Waters and at Voyageurs in the IMPROVE equation adopted by the IMPROVE Steering Committee in December 2005[60]:

$$\begin{aligned} b_{ext} = {} & 2.2 * f_S(RH) * [\text{small sulfate}] + 4.8 * f_L(RH) * [\text{large sulfate}] \\ & + 2.4 * f_S(RH) * [\text{small nitrate}] + 5.1 * f_L(RH) * [\text{large nitrate}] \\ & + 2.8 * [\text{small organic mass}] + 6.1 * [\text{large organic mass}] \\ & + 10 * [\text{elemental carbon}] \\ & + 1 * [\text{fine soil}] \\ & + 1.7 * f_{SS}(RH) * [\text{sea salt}] \\ & + 0.6 * [\text{coarse mass}] \\ & + \text{Rayleigh scattering (site specific—BOWA1= 11, VOYA2 = 12)} \\ & + 0.33 * [NO_2\ (\text{ppb})] \end{aligned}$$

where: b_{ext} is calculated total light extinction in inverse megameters
$f_S(RH)$ is the relative humidity adjustment factor for small particles;
$f_L(RH)$ is the relative humidity adjustment factor for large particles;
$f_{SS}(RH)$ is the relative humidity adjustment factor for sea salt; and

The apportionment of the total concentration of sulfate compounds into the concentrations of the small and large size fractions is accomplished using the following equations:

[large sulfate] = ([total sulfate]/20$\mu g/m^3$) * [total sulfate], for [total sulfate] < 20 $\mu g/m^3$;

[large sulfate] = [total sulfate], for [total sulfate] ≥ 20 $\mu g/m^3$; and

[small sulfate] = [total sulfate] – [large sulfate]

The same equations above for large sulfate, are also used to apportion total nitrate and total organic mass concentrations into the large and small size fractions.

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[59] MRPO (June 2007)

[60] VIEWs web site. http://vista.cira.colostate.edu/views/Web/RHR/RHR_Planning.aspx

NO_2 is not currently measured at the IMPROVE monitors[61], so this factor is not included. The IMPROVE equation assumes sulfate is in the form of ammonium sulfate and nitrate is in the form of ammonium nitrate.

Monthly f_S(RH) and f_L(RH) values are presented in Table 7.1[62],[63].

Table 7.1. Monthly f_S(RH) and f_L(RH) values for Boundary Waters and Voyageurs

ClassI	f(RH)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BOWA1	f_S(RH)	3.24	2.84	2.99	2.64	2.93	3.21	3.44	3.67	3.80	3.07	3.50	3.49
	f_L(RH)	2.50	2.26	2.32	2.09	2.22	2.42	2.57	2.69	2.76	2.37	2.65	2.65
	f_{SS}(RH)	3.74	3.37	3.34	2.92	3.03	3.43	3.68	3.85	3.95	3.44	3.89	3.92
VOYA2	f_S(RH)	3.16	2.77	2.82	2.59	2.65	3.28	3.25	3.48	3.66	3.02	3.37	3.32
	f_L(RH)	2.46	2.22	2.22	2.07	2.09	2.46	2.46	2.59	2.70	2.35	2.58	2.55
	f_{SS}(RH)	3.69	3.31	3.20	2.90	2.89	3.46	3.55	3.71	3.87	3.42	3.83	3.80

The solution to this equation is in the form extinction (b_{ext}). The Regional Haze rule requires visibility to be expressed in deciviews (dv). The following equation converts b_{ext} to deciviews (dv):

Haze Index (dv) = $10\, ln(b_{ext}/10)$

Where: b_{ext} and light scattering due to Rayleigh scattering (i.e. the "10" in the denominator) are both expressed in inverse megameters (Mm^{-1}). In order to be consistent across all Class I areas, the EPA prescribed that the Rayleigh scattering in the denominator should always be 10 instead of using site-specific Rayleigh scattering values.[64]

Values for **natural conditions—**visibility conditions that would exist in the absence of man-made impairment—were obtained from CIRA.[65] The missing data described above are not included in the natural conditions due to the relatively late discovery of these data in the regional haze process (early 2007) and the workload and staff shortage at CIRA for updating VIEWS . The resulting change in natural conditions will be small due to the fact that natural conditions in deciviews are small and the changes due to the addition of these days had a relatively small effect on the 20 percent best and worst days in the baseline period. A proportionate change to natural visibility would be less. According to Scott Copeland of CIRA, "Including the (missing) days has a demonstrable effect on the baseline values, but the natural conditions two values are normalized to the Trijonis annual mean estimate. So, for example, adding a few extra high sulfate days increases the annual sulfate mean, which increases the sulfate scaling factor which reduces all the values in the distribution, somewhat offsetting the larger values. In the specific case of (Boundary Waters) and (Voyageurs), only 6 and 3 sample dates respectively are added to

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[61] According to Scott Copeland of CIRA, "NO_2 is not a normal part of the IMPROVE program. [He] would expect slight changes to both natural and baseline conditions, perhaps adding very roughly 1-3 Mm^{-1} to the 20% worst baseline and 0.5-1.5 Mm^{-1} to the 20% worst natural. This would have a small effect on glide path calculations."

[62] VIEWs web site. http://vista.cira.colostate.edu/views

[63] Hand, et al. (March 2006)

[64] EPA (April 2007).

[65] Copeland, Scott (April 2008)

the distribution of roughly 120 observations that are in the 5 years' worth of 20 (percent) worst days, so there is …no way to move the mean very much."

A straight line connecting the baseline visibility average (2000-2004) and natural conditions (2064) form the uniform rate of progress or "glidepath". Placement relative to the line determines whether estimated future visibility (i.e. 2018) moves in a downward direction at a rate that natural conditions are likely reached in 2064. Voyageurs would be on the glidepath in 2018 if visibility impairment on the 20 percent worst visibility days were reduced by 1.7 dv ([19.5 – 12.1]*[(2018-2004)/(2064-2004)]) from baseline conditions. Boundary Waters would be on the glidepath in 2018 if visibility impairment on the 20 percent worst days were reduced by 2.0 deciviews from baseline conditions.

Base year and future year ambient air concentrations were modeled using emissions and meteorology inputs as described in Sections 1.0 through 5.0. The **Relative Response Factors (RRF)** are the ratio of the future year and base year ambient air concentrations, calculated as follows:

$$RRF_{[X]} = \text{Modeled Future Mean}_{[X]} / \text{Modeled Base Year Mean}_{[X]}$$

Where: RRF is the relative response factor (unitless);
Future Mean and Base Year Mean are the modeled base year (2002) and the future year (2018) concentrations at the Class I area monitor location averaged for the 20 percent worst days (and 20 percent best days) as determined by the base year (2002) monitor data; and
[X] is the species concentration (i.e. sulfate, nitrate, organic carbon, elemental carbon, fine soil and coarse particulate matter).

Applying the RRFs to baseline monitoring conditions, for each species comprising $PM_{2.5}$, provides the estimate of **future year visibility** conditions, described below:

A. Multiply each species specific RRF, developed from the 2002 and 2018 modeling data, by the corresponding measured species concentration for all of the 20 percent worst (and 20 percent best) days over the 5-year baseline period;

$$[X]\text{future} = RRF_{(X)} * [X]\text{baseline (daily value)}$$

B. Estimate extinction coefficient for each of the 20 percent worst (and 20 percent best) days using the IMPROVE equation, convert to deciviews; and

C. Calculate the average future year deciview for the 20 percent worst (and 20 percent best) days.
    1. Calculate the arithmetic mean deciview value for the 20 percent worst and best visibility values for each year in the baseline period; and
    2. Average the resulting 5-year mean deciview values (for the 20 percent worst, and for the 20 percent best).

Applying the above methodology with future emission estimates that reflect reasonable controls provides the RPG based on modeling.

The final **deciview** value represents the reasonable progress goal, which is established using a projected future ambient concentration resulting from emissions that reflect a four-factor analysis. The Clean Air Act requires states to consider:

- Costs of compliance;
- Time necessary for compliance;
- Energy and non-air quality environmental impacts of compliance; and
- Remaining useful life of existing sources that contribute to visibility impairment.

Minnesota used the EPA Modeled Attainment Test Software (MATS) program, version 1.1.2, to calculate the baseline for the average 20 percent worst days, the RRFs using the modeling work from each organization, the resulting projected future year visibility conditions in extinction, and to convert extinction to deciviews. Section 8.0 discusses the development of Minnesota's RPG.

8.0: Control Strategy Development

The MRPO, CENRAP and Minnesota$_{(MRPO)}$ cases all initially considered on-the-books controls, meaning controls expected due to other programs despite the Regional Haze Rule, to evaluate future year placement relative to the glidepath. On-the-books controls are summarized in Section 2.0. Position relative to the glidepath in 2018, estimated with on-the-books controls in the Minnesota$_{(MRPO)}$ case, is illustrated in Figures 8.1 and 8.2 for Boundary Waters and Voyageurs, respectively. These results indicate that future year visibility is on a path toward natural visibility conditions, however, above the glidepath.

Tables 8.1 and 8.2 contain the Minnesota$_{(MRPO)}$ deciview values for the 20 percent worst and best days at Boundary Waters and Voyageurs along with the results of other modeling work conducted by CENRAP, and by MRPO (2002 and 2005 cases). In order to do an equitable comparison, the visibility conditions and the future year values for each organization were calculated using the same monitoring data establishing the baseline (2000-2004) and ran through MATS. The only difference lies with the modeled base year and future year concentrations, which are used to calculate RRFs applied to the baseline monitoring data.

The results among the modeling analyses differ by tenths of a deciview. Plotting the various results on Figure 8.1 and 8.2 would show a very tight overlapped grouping, thus they are not shown. The CENRAP case shows a future projected visibility 0.1 dv closer to the glidepath at Boundary Waters and 0.4 dv closer to the glidepath at Voyageurs than the Minnesota$_{(MRPO)}$ case. This is somewhat unexpected because the Minnesota$_{(MRPO)}$ case uses improved future emissions projections for the EGU sector, which the CENRAP case does not. See Section 2.0 for details on the EGU emissions.

The MRPO 2002 case shows future projected visibility 0.2 dv further from the glidepath at Boundary Waters and at Voyageurs than the Minnesota$_{(MRPO)}$ case. This is expected and due to the improved future emissions projections for EGU sector in the Minnesota$_{(MRPO)}$ case.

Figure 8.1. Boundary Waters 36-km Minnesota$_{(MRPO)}$ Position on Glide Path with On-the-Books Controls

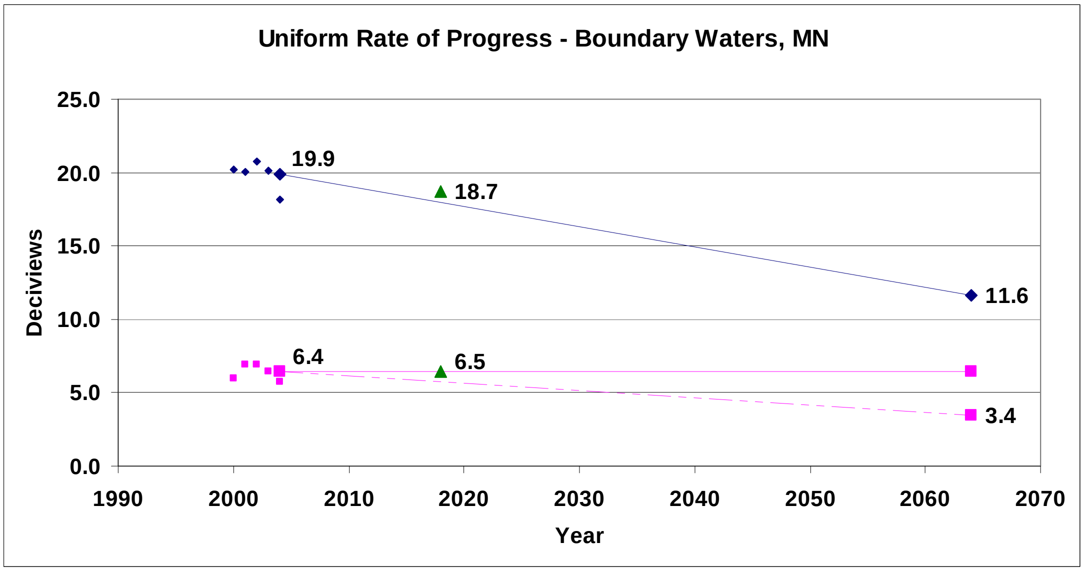
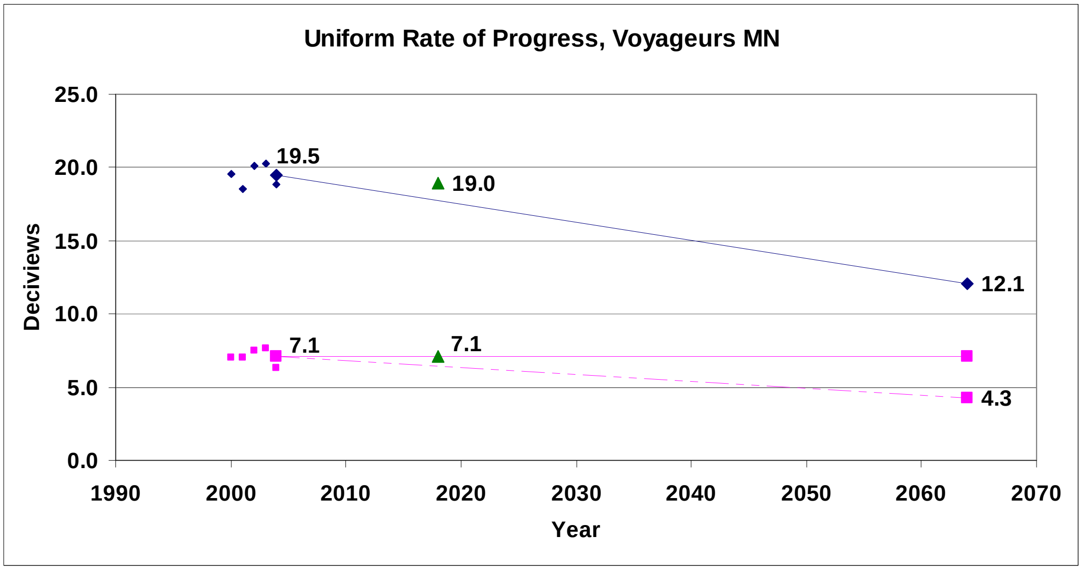


Figure 8.2. Voyageurs 36-km Minnesota$_{(MRPO)}$ Position on Glide Path with On-the-Books Controls



The MRPO 2005 results for the 20 percent worst days, in Table 8.1, are on the glidepath at Boundary Waters, and below the glidepath at Voyageurs. These results show 0.8 dv less visibility impact at Boundary Waters and 1.3 dv less visibility impact at Voyageurs than the Minnesota$_{(MRPO)}$ case.

Table 8.1 Uniform Rate of Progress Analysis for 20% Worst Days with On-the-Books Controls.

				Baseline	2018 URP	2018 Projected	
Class I Area Name	**Organization**	**Grid Resolution**	**Base Year**	**(dv)**	**(dv)**	**(dv)**	**difference (dv)**
Boundary Waters	CENRAP	36	2002	19.9	17.9	18.6	0.7
Boundary Waters	**Minnesota**	**36**	**2002**	**19.9**	**17.9**	**18.7**	**0.8**
Boundary Waters	MRPO	36	2002	19.9	17.9	18.9	1.0
Boundary Waters	MRPO	36	2005	19.9	17.9	17.9	0.0
Voyageurs	CENRAP	36	2002	19.5	17.8	18.6	0.8
Voyageurs	**Minnesota**	**36**	**2002**	**19.5**	**17.8**	**19.0**	**1.2**
Voyageurs	MRPO	36	2002	19.5	17.8	19.2	1.4
Voyageurs	MRPO	36	2005	19.5	17.8	17.7	-0.1

Table 8.2—Uniform Rate of Progress Analysis for 20% Best Days with On-the-Books Controls.

				Baseline	2018 URP	2018 Projected	
Class I Area Name	**Organization**	**Grid Resolution**	**Base Year**	**(dv)**	**(dv)**	**(dv)**	**difference (dv)**
Boundary Waters	CENRAP	36	2002	6.4	6.4	6.4	0.0
Boundary Waters	**Minnesota**	**36**	**2002**	**6.4**	**6.4**	**6.5**	**0.1**
Boundary Waters	MRPO	36	2002	6.4	6.4	6.9	0.5
Boundary Waters	MRPO	36	2005	6.4	6.4	6.1	-0.3
Voyageurs	CENRAP	36	2002	7.1	7.1	7.0	-0.1
Voyageurs	**Minnesota**	**36**	**2002**	**7.1**	**7.1**	**7.1**	**0.0**
Voyageurs	MRPO	36	2002	7.1	7.1	7.3	0.2
Voyageurs	MRPO	36	2005	7.1	7.1	6.8	-0.3

Before proceeding with the evaluation of additional control strategies, it is prudent to better understand the reasons behind the varying results between the organizations which all presumed essentially the same on-the-books controls. This includes the sensitivity of the model to varying emissions and meteorology and the resulting affect on the RPG.

Because the baseline and natural visibility conditions are the same among the various analyses, the modeled RRFs can help explain the difference. Tables 8.3 and 8.4 contain the RRFs by visibility component, or species, for each modeling study for the 20 percent worst and best days, respectively. An RRF above 1.000 means the modeled concentration increases from 2002 to 2018. A factor below 1.000 means the modeled concentration decreases from 2002 to 2018.

Evaluation of the RRFs for Boundary Waters and Voyageurs focuses on sulfate and nitrate. Both of these components figure prominently in the extinction calculation described in Section 7.0. Crustal/soil and coarse mass are not prominent components in the extinction calculation, nor are they significant in the extinction calculated at Boundary Waters and Voyageurs on the 20 percent worst days, so changes in these components will not affect the resulting future year projection. Elemental carbon has low measured values at the two Class I areas; even though the extinction calculation multiplies the observed concentration of elemental carbon by a factor of 10, it still does not feature prominently in the future year projections at Boundary Waters and Voyageurs. The RRFs for organic carbon are similar between the various analyses, so no further discussion is warranted for that component.

Table 8.3 Relative Response Factors for 20% Worst Days with On-the-Books Controls.

Class I Area Name	Organiza-tion	Grid	Base Year	Relative Response Factors					
				sulfate	nitrate	organic carbon	elemental carbon	crustal/ soil	coarse mass
Boundary Waters	CenRAP	36	2002	0.870	0.790	0.947	0.756	1.102	1.062
Boundary Waters	**Minnesota**	**36**	**2002**	**0.798**	**0.936**	**0.945**	**0.786**	**1.402**	**1.127**
Boundary Waters	MRPO	36	2002	0.877	0.929	0.949	0.788	1.265	1.112
Boundary Waters	MRPO	36	2005	0.746	0.849	0.990	0.800	1.269	0.596
Voyageurs	CenRAP	36	2002	0.932	0.817	0.954	0.796	1.101	1.091
Voyageurs	**Minnesota**	**36**	**2002**	**0.855**	**1.035**	**0.956**	**0.834**	**1.275**	**1.069**
Voyageurs	MRPO	36	2002	0.949	1.054	0.956	0.830	1.200	1.064
Voyageurs	MRPO	36	2005	0.761	0.822	0.976	0.772	1.239	0.637

Table 8.4—Relative Response Factors for 20% Best Days with On-the-Books Controls.

Class I Area Name	Organiza-tion	Grid	Base Year	Relative Response Factors					
				sulfate	nitrate	organic carbon	elemental carbon	crustal/ soil	coarse mass
Boundary Waters	CenRAP	36	2002	1.006	0.855	0.961	0.950	1.157	1.082
Boundary Waters	**Minnesota**	**36**	**2002**	**0.995**	**1.171**	**0.989**	**0.971**	**1.091**	**1.038**
Boundary Waters	MRPO	36	2002	1.022	2.181	0.991	0.972	1.046	1.039
Boundary Waters	MRPO	36	2005	0.937	0.964	0.977	0.922	1.024	0.730
Voyageurs	CenRAP	36	2002	1.001	0.854	0.973	0.859	1.175	1.139
Voyageurs	**Minnesota**	**36**	**2002**	**0.989**	**1.100**	**0.989**	**0.956**	**1.078**	**1.027**
Voyageurs	MRPO	36	2002	1.015	1.639	0.993	0.954	1.060	1.030
Voyageurs	MRPO	36	2005	0.942	0.848	0.986	0.901	0.965	0.724

Because the MRPO 2002 case is the basis for the Minnesota$_{(\text{MRPO})}$ case, it is easier to compare these two analyses. According to the RRFs, the most noticeable difference between the MRPO 2002 and Minnesota$_{(\text{MRPO})}$ cases is the response to sulfate reductions. As expected, the Minnesota$_{(\text{MRPO})}$ case shows greater reductions due to the updated EGU emission projections associated with IPM version 3.0 “will do”. The MRPO 2002 case incorporates IPM version 2.1.9 VISTAS.

The noticeable difference in the RRFs for sulfate between the CENRAP and Minnesota$_{(\text{MRPO})}$ cases are also mainly due to the differences in future year EGU emission estimates. This conclusion is drawn from the similarity in the MRPO 2002 case and CENRAP 2002 case sulfate RRFs; both cases incorporate IPM version 2.1.9VISTAS.

Even more noticeable than the differences in sulfate RRFs are the differences in RRFs for nitrate between the CENRAP, MRPO 2002 and Minnesota$_{(\text{MRPO})}$ cases. The RRFs for the 20 percent worst days, show that the CENRAP case estimates a greater reduction in nitrate than the Minnesota$_{(\text{MRPO})}$ case. In fact, Minnesota$_{(\text{MRPO})}$ case RRFs show a slight increase in nitrate at Voyageurs from 2002 to 2018. MRPO 2005 case shows the largest decrease in nitrate from 2002 to 2018. These differences in nitrate RRFs overcome the sulfate decreases in the Minnesota$_{(\text{MRPO})}$ case attributable to the change from IPM2.1.9 to IPM3.0. This explains why the position of the CENRAP case in relation to the glidepath is the same as the Minnesota$_{(MRPO)}$ case at Boundary Waters and is closer to the glidepath than the Minnesota$_{(MRPO)}$ case at Voyageurs, which would see greater influence from NO_X reductions in Canada.

To elaborate further, Section 6.0 of this document shows that the CENRAP case over predicts nitrate formation in 2002 at Boundary Waters and Voyageurs compared to observed values collected at monitoring stations. This is likely caused by additional NO_X and a significant amount of available ammonia with which to react. This information, along with the greater projected decrease in NO_X emissions (i.e. Canada), and the RRFs for nitrate, suggests that the excess free ammonia in the CENRAP inventory allows for the model to respond well to future projected reductions in NO_x emissions, possibly even over-stating them. Conversely, the lack of free ammonia in the Minnesota$_{(MRPO)}$ case for winter months in the base year combined with a significant increase in available ammonia in the future year might under-state the effects of reducing the nitrate ion due to reductions of NO_x emissions.

Tables 8.5 and 8.6 summarize the winter day NO_X and NH_3 changes in emissions for the Minnesota$_{(MRPO)}$ and CENRAP cases from 2002 to 2018 for Minnesota, North Dakota, South Dakota and Canada. These Tables focus on Minnesota and areas to the West only because winds appear to originate in that direction on the days with a discrepancy on model performance between the CENRAP and Minnesota$_{(MRPO)}$ cases (see Section 6.0). The emissions summary for Canada in Tables 8.5 and 8.6 encompasses the entire portion of that Country within the 4rpos domain. While the Minnesota$_{(MRPO)}$ case does not contain a change in Canada NO_X emissions, the CENRAP case does, by about 44 percent on a winter day over the portion of Canada covered by the 4rpos domain. However, the emissions summary can not detect where these emission reductions because the emissions summary tools used do not separate Canada emissions by province. The spatial plot in Figure 8.3 illustrates that the reduction in NO_X is distributed throughout the country within the domain, but mostly in the East, rather than the West. The Tables and the Figure also do not address the additional Canada emissions further West, outside the 4rpos domain, included in the CENRAP case.

Results from modeling conducted with the PSAT tool in CAMx supports the above interpretation on the model response to nitrate changes in the CENRAP and Minnesota$_{(MRPO)}$ cases. This tool tracks the original source of particulate species by geographic region and source category. CENRAP, MRPO and Minnesota all used this tool to assess the main contributors to visibility at the Class I areas in 2002 and 2018 for 36km modeling. The description of the PSAT analyses is provided in Section 8.1.

Table 8.5. Winter Day NO_X and NH_3 Emissions in Tons from Base Year 2002 for CENRAP and Minnesota$_{(MRPO)}$

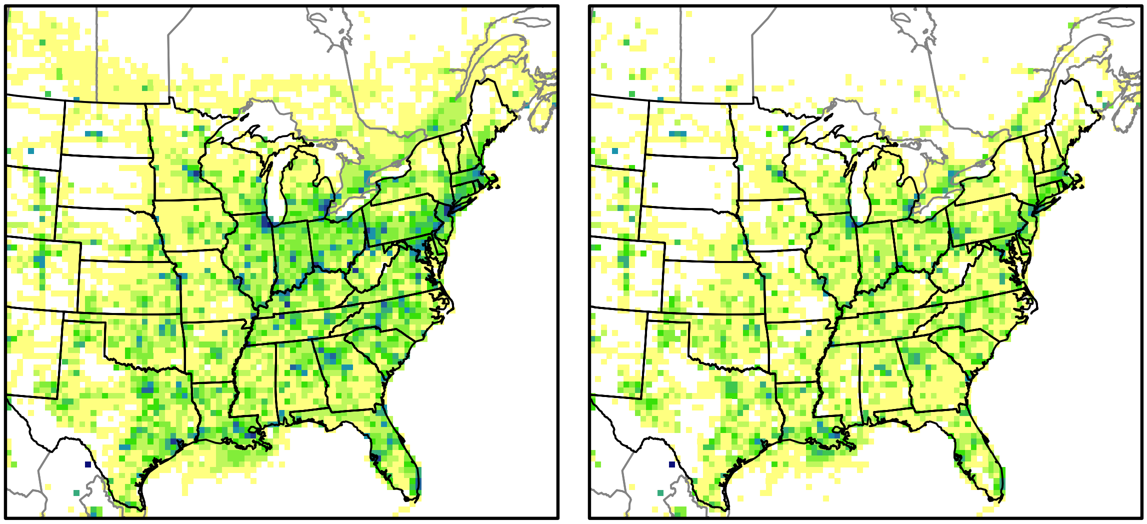
Region	Winter Day Emissions in Tons -- Base Year 2002					
	CENRAP		Minnesota (MRPO)		Difference (CENRAP - Minnesota (MRPO))	
	NO_X	NH_3	NO_X	NH_3	NO_X	NH_3
Minnesota	1,461	345	1,378	158	83	187
North Dakota	627	74	498	23	129	51
South Dakota	280	214	250	72	31	143
Canada*	4,080	1,023	2,055	997	2,025	26
total: (only U.S)	2,368	633	2,125	253	242	381
total: (incl Canada)	6,448	1,656	4,181	1,250	2,267	407

Table 8.6. Winter Day NO_X and NH_3 Emissions in Tons from Base Year 2018, and Difference from 2002 to 2018, for CENRAP and Minnesota$_{(MRPO)}$

Region	Winter Day Emissions in Tons -- Base Year 2018						CENRAP 2018 - 2002		Minnesota (MRPO) 2018 - 2002	
	CENRAP		Minnesota (MRPO)		Difference (CENRAP - Minnesota (MRPO))					
	NO_X	NH_3	NO_X	NH_3	NO_X	NH_3	NO_X	NH_3	NO_X	NH_3
Minnesota	849	431	768	208	81	223	-42%	25%	-44%	32%
North Dakota	558	75	345	33	213	42	-11%	1%	-31%	43%
South Dakota	207	218	139	102	68	116	-26%	2%	-44%	42%
Canada*	2,286	991	*2,219*	*1,016*	*67*	*(24)*	-44%	-3%	*8%*	*2%*
total: (only U.S)	1,613	724	1,251	343	362	381	-32%	14%	-41%	36%
total: (incl Canada)	3,899	1,715	3,470	1,359	429	356	-40%	4%	-17%	9%

* Minnesota (MRPO) modeling used the same 2005 Canada inventory to reflect the base year (2002) and the future year (2018). The difference in emissions shown in the above tables reflects that Canada area sources (other than ammonia sources) were inadvertently excluded from the base year files.

Figure 8.3. CENRAP Winter Day NO_X Emissions in Tons



2002:

2018:

The MRPO 2005 case uses 2005 meteorology rather than the 2002 meteorology used in the CENRAP and Minnesota$_{(MRPO)}$ cases. Thus, the MRPO 2005 projections for future visibility are based on different worst visibility days, different visibility components that contribute to those days, and the predominant wind direction from which emission reductions occur. There are also the rather significant differences in ammonia emissions. Section 6 describes improved model performance for nitrate in the MRPO 2005 base year.

Overall, the MRPO 2005 case contains more ammonia in the base year (~24% domain-wide; ~7% in Minnesota) than the 2002 Minnesota$_{(MRPO)}$ case. The MRPO 2005 case also projects significantly less ammonia in 2018 than the Minnesota$_{(MRPO)}$ case, as described in Section 2, and shown in Table 8.7 for Minnesota This combination may counter-balance the model response to NO_x emission reductions seen in the Minnesota$_{(MRPO)}$ case.

The following exercise supports this hypothesis. The ammonia inventory in the Minnesota$_{(MRPO)}$ case was replaced with the ammonia inventory in the MRPO 2005 case and modeled. Adding more ammonia in just the Minnesota$_{(MRPO)}$ base case and keeping the future year the same, resulted in a 6 percent change in the nitrate RRF at Boundary Waters and a 2 percent change at Voyageurs. Estimating less of an increase in ammonia in the future case using the MRPO 2005 case future year emissions results in an 8 percent change in the nitrate RRF at Boundary Waters, and 9 percent at Voyageurs. Ultimately, this results in a more optimistic projected RPG in 2018 by 0.2 dv at Boundary Waters and by 0.3 dv at Voyageurs.

Because the Minnesota$_{(MRPO)}$ case under predicts ammonia in the base year (see Section 2.0), and because of improvements made by MRPO to the future year ammonia inventory since the inventory used in the Minnesota$_{(MRPO)}$ case, the model sensitivity test also suggests that the RPG established in the Minnesota$_{(MRPO)}$ case may be a slightly conservative estimate.

Table 8.7 Minnesota Annual Emissions Change in Tons of NO_X and NH_3 from All Source Categories in Minnesota$_{(MRPO)}$, and MRPO 2005 Case

Specie	Minnesota$_{(MRPO)}$			MRPO 2005 Case		
	2002	2018	Difference	2005	2018	difference
NO_X	516,000	317,000	-199,000	464,000	278,000	-186,000
NH_3	185,000	253,000	+68,000	196,000	227,000	+31,000

More important is the difference in the model sensitivity to meteorology. Even though the EPA methodology for establishing the RPG attempts to take into account the year-to-year variability of the meteorology in the monitored 5-year baseline, the RPG still is sensitive to meteorology. In this case, use of 2005 meteorology provides a more optimistic RPG. Modifying the Minnesota$_{(MRPO)}$ case with only the 2005 meteorology results in a more optimistic projected RPG in 2018 by 0.4 dv at Boundary Waters and by 0.8 dv at Voyageurs.

Results from modeling using PSAT in CAMx also supports the above interpretation on how the model responds to changes in ammonia in the formation of nitrate, and the meteorology, between the MRPO 2005 and Minnesota$_{(MRPO)}$ cases. See section 8.1 for more discussion.

Another factor to take into account when comparing RRFs among organizations are the modifications made to the Minnesota$_{(MRPO)}$ case to, for example, revise inappropriate growth factors and include additional sources in northeastern Minnesota. These changes were only made to the Minnesota$_{(MRPO)}$ case and likely result in future projections further from the glidepath than were the corrections not made.

Uniform Rate of Progress Analysis with 12km(PiG) model results. In addition to the 36km results, Minnesota assessed placement relative to the uniform rate of progress line using 12km(PiG) results. Various 12km grid cells were evaluated, as pseudo monitors, throughout the Class I areas using the baseline monitoring values from the monitor within the Class I area being evaluated. Although the monitor location for Isle Royale is not on the Island but in the upper peninsula of Michigan, the observed values were still used as surrogates.

Minnesota$_{(MRPO)}$ values for the 12km grid assessed for several receptors throughout the Class I areas, indicated a range of projected values from 18.3 – 19.0 dv, with an average value of 18.7 dv in Boundary Waters—the largest Class I area—for the 20 percent worst days. The average value is the same as the 36km result at the monitor location. The same is true for the 20 percent best days. It does not appear necessary to set separate goals for various locations across the Class I area based on the 12km results. Only one receptor was placed at Isle Royale and the two Voyageurs receptors showed the same result, so separate goals for these areas are not needed either.

8.1 Particulate Source Apportionment to Assess Contributions to Visibility Impairment.

As mentioned above, PSAT in CAMx tracks the original source of particulate species by geographic region and source category. CENRAP, MRPO and Minnesota all used this tool to assess the main contributors to visibility at the Class I areas in 2002 and 2018 36km modeling. The geographical and source category groupings were somewhat different among the PSAT analyses conducted by the three organizations, depending on the purpose of each.

Geographical groupings in the Minnesota$_{(MRPO)}$ case were designed by breaking out smaller regions nearest Boundary Waters and Voyageurs that may have the greatest contributions to impaired visibility. The geographical groupings are shown in Figure 8.4 and described as follows:

- **Individual States** Arkansas, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Oklahoma, South Dakota, Texas and Wisconsin; the
- **Northeast States** consolidated as one geographic region comprised of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania and Rhode Island; the
- **Southeast States** consolidated as one geographic region comprised of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia; the
- **West States** consolidated as one geographic region comprised of Eastern portions of Colorado, Montana, New Mexico and Wyoming; and
- **Canada** all provinces consolidated as one geographic region.

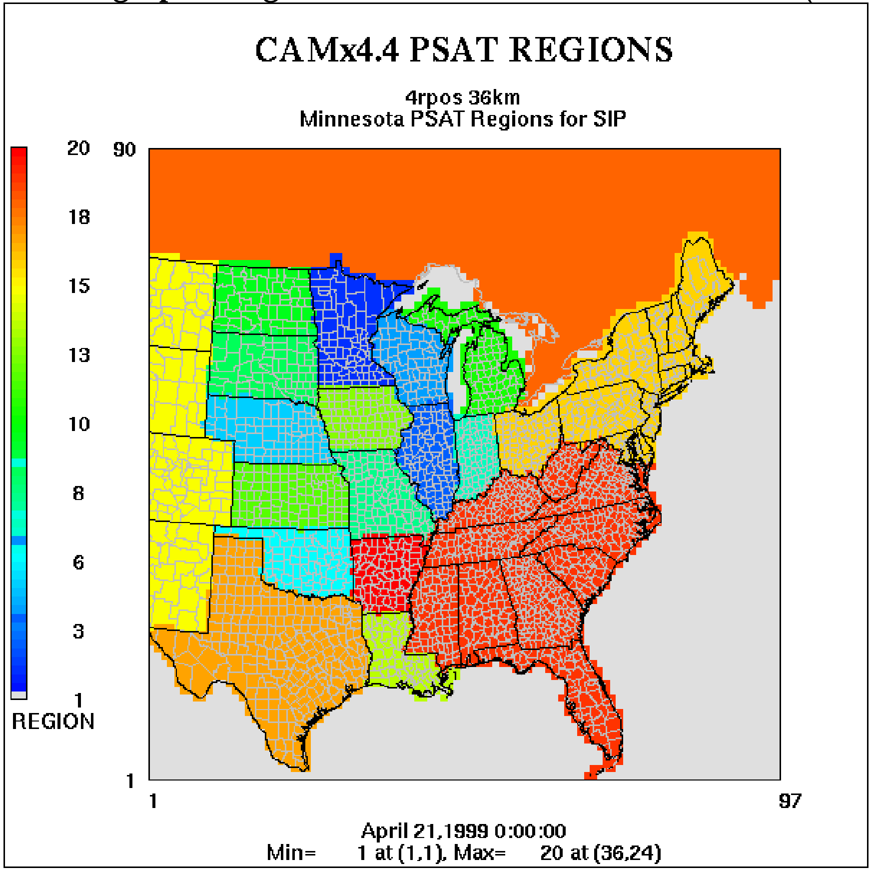
The remainder of the western United States and Canada is outside the modeling domain.

Source category groupings in the Minnesota$_{(MRPO)}$ case are described as follows:

- Electric Generating Units (**EGU**)
- Point sources that are not EGUs (**nonEGU**);
- Onroad mobile (**onroad**);
- Nonroad mobile including commercial marine, airport and recreational vehicles (**nonrd_mar**);
- Agricultural ammonia sources (**nh3**);
- Other area sources (**other**); and
- Initial and boundary conditions (**ICBC**). Boundary Conditions are air concentrations coming into the domain from the East, West, North, South and above—over the top—of the domain (i.e. intrusion of stratospheric ozone). Initial conditions are the inputs at the start-up of the model run and should not appear in the results if the model run accounts for appropriate spin-up time. For example, the Minnesota$_{(MRPO)}$ case has a spin-up period of two weeks prior to the date for which usable model results are desired.

In order to compare the PSAT results among the Minnesota$_{(MRPO)}$, CENRAP and MRPO 2005 cases, Minnesota grouped and plotted the results from each organization so they all appear on the same scale, order and color scheme as the Minnesota$_{(MRPO)}$ case. The plots for the Minnesota$_{(MRPO)}$ case are in Figures 8.5 through 8.16. The plots for the CENRAP and MRPO 2005 cases are in Appendix H.

Figure 8.4 Geographic Regions Modeled with PSAT in Minnesota$_{(MRPO)}$ Case.



The CENRAP and MRPO 2005 cases include PSAT results for the species, ammonium nitrate, ammonium sulfate, organic aerosols, elemental carbon, soil and coarse matter. The $\text{Minnesota}_{\text{(MRPO)}}$ case only includes ammonium nitrate and ammonium sulfate because it was determined that monitored and modeled extinction values for the 20 percent worst days at Boundary Waters and Voyageurs were predominantly associated with ammonium nitrate and ammonium sulfate on days not impacted by wildfires (see Section 6.0). Other considerations include the additional computational times associated with modeling the other species, coupled with their relative unimportance for the development of control strategies. The exclusion of organic aerosol, elemental carbon, soil and coarse matter led to the use of a variation of the IMPROVE equation in the $\text{Minnesota}_{\text{(MRPO)}}$ case PSAT analysis from that used for model performance and the attainment test.

The IMPROVE equation does not contain ammonium, assuming sulfate and nitrate are fully neutralized. The PSAT results in the $\text{Minnesota}_{\text{(MRPO)}}$ and MRPO 2005 cases both include ammonium as a separate species in the extinction equation, indicating that ammonia sources are viable targets for control measure consideration. Without ammonia, no ammonium sulfate and no ammonium nitrate are formed. PSAT can provide source and geographic location where the ammonia that forms ammonium originates. The inclusion of ammonium calls for an additional modification to the IMPROVE equation. The modified IMPROVE equation for sulfate, nitrate and ammonium for use in the PSAT analysis is as follows:

$$\begin{aligned}
\text{Extinction}_{(\text{Mm}^{-1})} = {} & (2.2 * f_S(RH) * [\text{small sulfate}]) + (4.8 * f_L(RH) * [\text{large sulfate}]) \\
& + (2.4 * f_S(RH) * [\text{small nitrate}]) + (5.1 * f_L(RH) * [\text{large nitrate}]) \\
& + (2.2 * f_S(RH) * [\text{small ammonium}_{\text{assoc. sulfate}}]) + \\
& \quad (4.8 * f_L(RH) * [\text{large ammonium}_{\text{assoc. sulfate}}]) \\
& + (2.4 * f_S(RH) * [\text{small ammonium}_{\text{assoc. nitrate}}]) + \\
& \quad (5.1 * f_L(RH) * [\text{small ammonium}_{\text{assoc. nitrate}}])
\end{aligned}$$

Where: $f_S(RH)$ = water growth factor as a function of relative humidity for small particles;
$f_L(RH)$ = water growth factor as a function of relative humidity for large particles; and
[nitrate], [sulfate] and [ammonium] = concentration of these components in $\mu g/m^3$.

Although reasonable progress goals are depicted in deciviews, contributions of individual species, source sectors and source regions are only evaluated in terms of extinction. An extinction value less than 10 Mm^{-1} will produce a negative value in deciviews. An extinction coefficient of $B_{ext} = 10\ \text{Mm}^{-1}$ will result in a deciview value of 0 dv ($10 * ln(B_{ext}/10)$). Assessing contributions to visibility with negative values would be confusing.

Figures 8.5 through 8.8 illustrate the geographic contribution assessment, in extinction, on the 20 percent days at Boundary Waters in the $\text{Minnesota}_{\text{(MRPO)}}$ case. Figures 8.9 through 8.12 illustrate the geographic contribution assessment at Voyageurs. In 2018 with on-the-books controls implemented, the greatest contributors to ammonium sulfate and ammonium nitrate at both Class I areas are Minnesota, Wisconsin, Iowa, Illinois, Missouri, North Dakota and Canada. Ammonium sulfate contributes most of the visibility impairment on the 20 percent days at both Class I areas.

Figures 8.6, 8.8, 8.10 and 8.12 illustrate the difference in contribution between the 2002 and 2018 PSAT analyses. These Figures show very little modeled contribution change in nitrate from the base year to the future year. This further supports the conclusion that a lack of ammonia in the base year and excess ammonia in the future year can dampen the effect of NO_X controls.

Caution should be taken when drawing conclusions from the difference charts in these Figures. PSAT does not provide answers to model response; meaning if emissions are reduced in a particular sector or region, PSAT can not tell what effect that change will have on the results. In other words, it would be inappropriate to conclude that total emission reductions in Minnesota equates to about 0.8 Mm^{-1} contribution reductions from Minnesota to visibility impairment. Instead, one can simply see how the 2018 PSAT results compare with the 2002 PSAT results on what species, regions and sectors are contributing to extinction.

Much less visibility impairment is attributed to EGUs in 2018 than in 2002. Between 2002 and 2018, the contribution from EGUs decreases from nearly all geographic regions. The contribution to nitrate formation from mobile sources also decreases in Minnesota, and to a lesser extent, Wisconsin and North Dakota. These decreases in contribution from EGUs and mobile sources cause a shift in contribution to nonEGU point sources in Minnesota, and somewhat to area sources, in 2018.

Figures 8.13 through 8.16 illustrate the source category contribution assessment for the entire domain on the 20 percent worst days at Boundary Waters and Voyageurs in the $\text{Minnesota}_{(\text{MRPO})}$ case in 2018 with on-the-books controls implemented. Overall, point sources are the greatest contributors to extinction due to sulfate and nitrate. While in Boundary Waters EGUs contribute more than nonEGU sources, in Voyageurs EGU and nonEGU sources are nearly equal contributors. As expected, the largest contributor to ammonium is agricultural operations.

After point sources, boundary conditions are the next greatest contributor to extinction in 2018 at Boundary Waters and Voyageurs. Boundary conditions are source contributions that originate outside, and transfer into and out, of the modeling domain. Source apportionment techniques can only account for the total contribution of boundary conditions to the overall visibility conditions, accounting for conservation of mass in the modeling apportionment. Although it is not possible to specifically attribute the boundary condition contribution to a specific source grouping, the domain used in the $\text{Minnesota}_{(\text{MRPO})}$ case extends far enough from Boundary Waters and Voyageurs to fully account for the contributions from the most significant States (listed above). If the emissions originating in Alberta Canada—which is outside the modeling domain—are accurate, more contribution may be attributed to Canada than depicted in the $\text{Minnesota}_{(\text{MRPO})}$ case. However, the CENRAP domain extends beyond Alberta Canada, and yet has a similar contribution level attributed to boundary conditions as the $\text{Minnesota}_{(\text{MRPO})}$ case.

Appendix H contains the 2018 PSAT results for geographic contribution in the CENRAP case. Results for Boundary Waters are in Figures H.1 through H.4, and for Voyageurs are in Figures H.5 through H.8. In comparison, the CENRAP case shows overall more light extinction (+11 Mm^{-1} at Boundary Waters, +6 Mm^{-1} at Voyageurs) due to ammonium sulfate and ammonium nitrate than Minnesota$_{(MRPO)}$ case. The relative contribution by State is quite comparable. As expected, the CENRAP case has significantly more contribution attributed to Canada. Only Minnesota contributes more than Canada in the CENRAP case, whereas in the Minnesota$_{(MRPO)}$ case Canada barely fits criteria for a main geographic source contributor (i.e. ~5% or more). The Figures also show that the CENRAP case has more nitrate formation relative to sulfate formation than the Minnesota$_{(MRPO)}$ case.

The Figures also show how extinction contribution changes between the base year and 2018. In the Minnesota$_{(MRPO)}$ case, overall extinction of ammonium nitrate and ammonium sulfate decreased by 8 Mm^{-1} at Boundary Waters and 5 Mm^{-1} at Voyageurs with nearly all of the reduction associated with ammonium sulfate. In the CENRAP case, overall extinction of ammonium nitrate and ammonium sulfate decreased by 10 Mm^{-1} at Boundary Waters and 6 Mm^{-1} at Voyageurs, with a large portion of the reduction associated with ammonium nitrate, especially from Minnesota and Canada. This supports earlier conclusions that the excess free ammonia in the CENRAP case allows for the model to respond well to future projected reductions in NO_x emissions, possibly even over-stating them. The very large contribution shift between 2002 and 2018 associated with mobile source NO_X in the CENRAP case appears to support this conclusion.

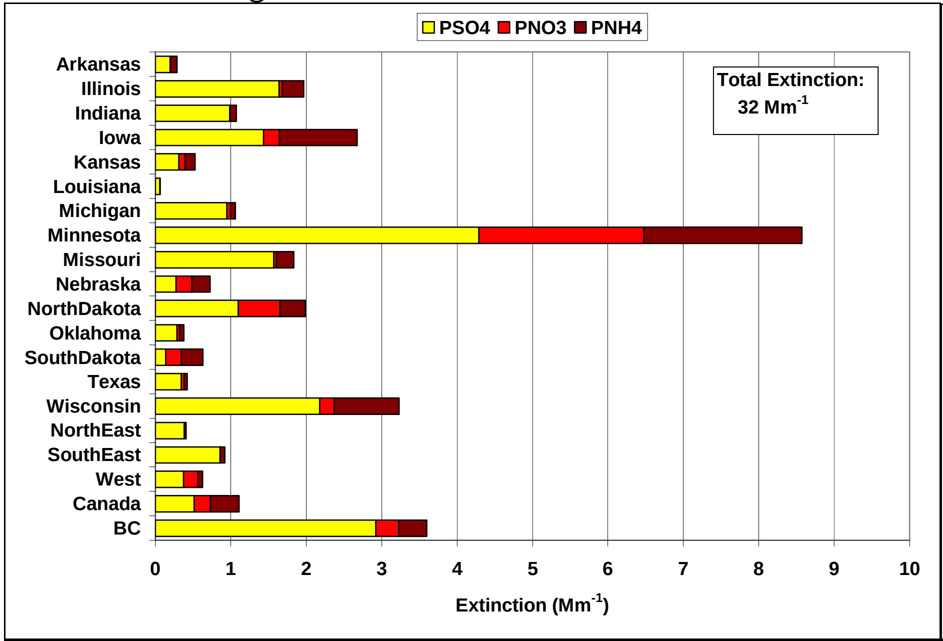
Appendix H also contains the 2018 PSAT results for geographic contribution in the MRPO case. Results for Boundary Waters are in Figures H.9 through H.12, and for Voyageurs are in Figures H.13 through H.16. In comparison, the MRPO 2005 case shows overall nearly the same extinction at Boundary Waters (+2 Mm^{-1}) and Voyageurs (-1 Mm^{-1}) in 2018 due to ammonium sulfate and ammonium nitrate as the Minnesota$_{(MRPO)}$ case. The relative contribution by State is quite comparable at Boundary Waters, however, Voyageurs is more influenced by States located to the East and Southeast of the Class I area than in the Minnesota$_{(MRPO)}$ case. As discussed above, this difference in the geographic contribution to Voyageurs is associated with the use of 2005 meteorology and hence a different set of 20 percent worst days.

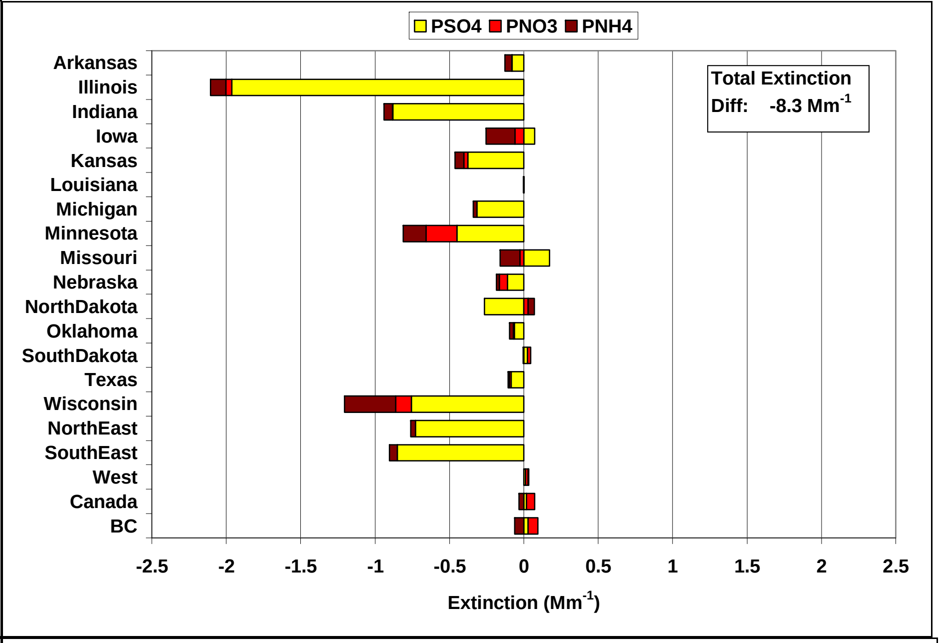
Comparing contributions between 2018 and 2005, the MRPO 2005 case shows much less contribution from States to the East and Southeast of both Class I areas, than in the Minnesota$_{(MRPO)}$ case (2018-2002). This supports the conclusion that the MRPO 2005 modeling shows more influence from emission changes that occur in those geographic regions. Boundary Waters and Voyageurs experience much less contribution to sulfate in 2018 than 2005. The MRPO 2005 case also shows less contribution to extinction from nitrate in 2018 than 2005, which also supports the conclusion that the model is responding more to NO_X reductions. The MRPO 2005 case has less contribution from point, mobile and ammonia source categories from Minnesota in 2018 than in 2005, as well. The MRPO 2005 case does not include the modifications made to nonEGU point source growth, and it inadvertently excludes the mining operations at Northshore Mining-Silver Bay, that are included in the Minnesota$_{(MRPO)}$ case. It is not possible to tell how the MRPO 2005 PSAT results might change were these modifications made.

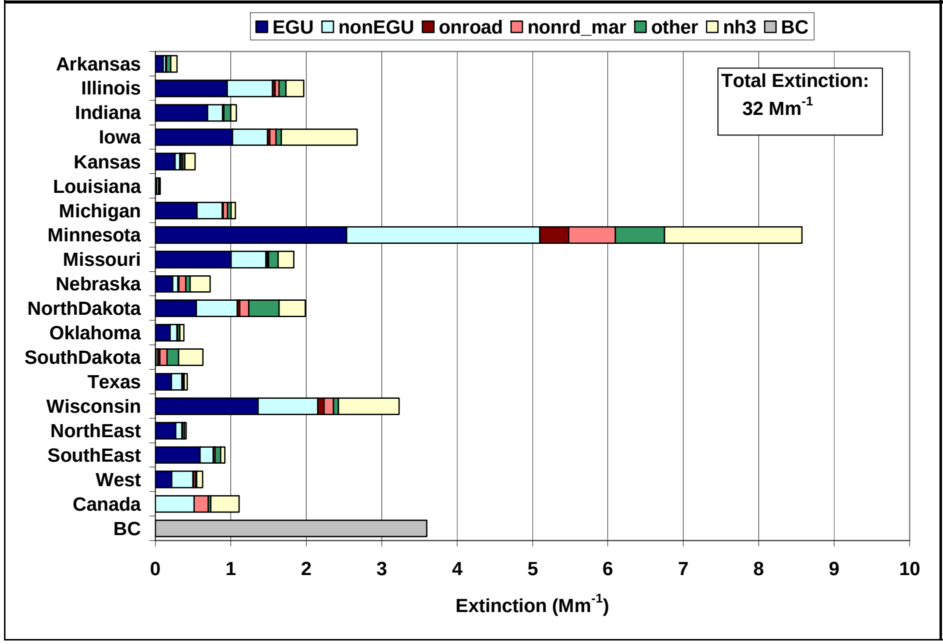
Boundary Waters: Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days

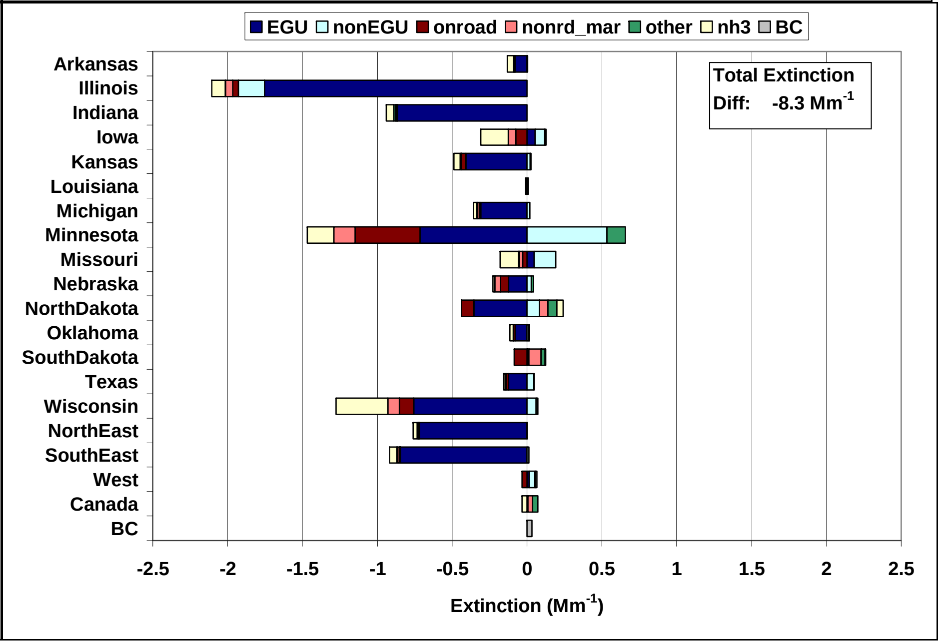
Figures 8.5 and 8.7: 2018

Figures 8.6 and 8.8: 2018 minus 2002





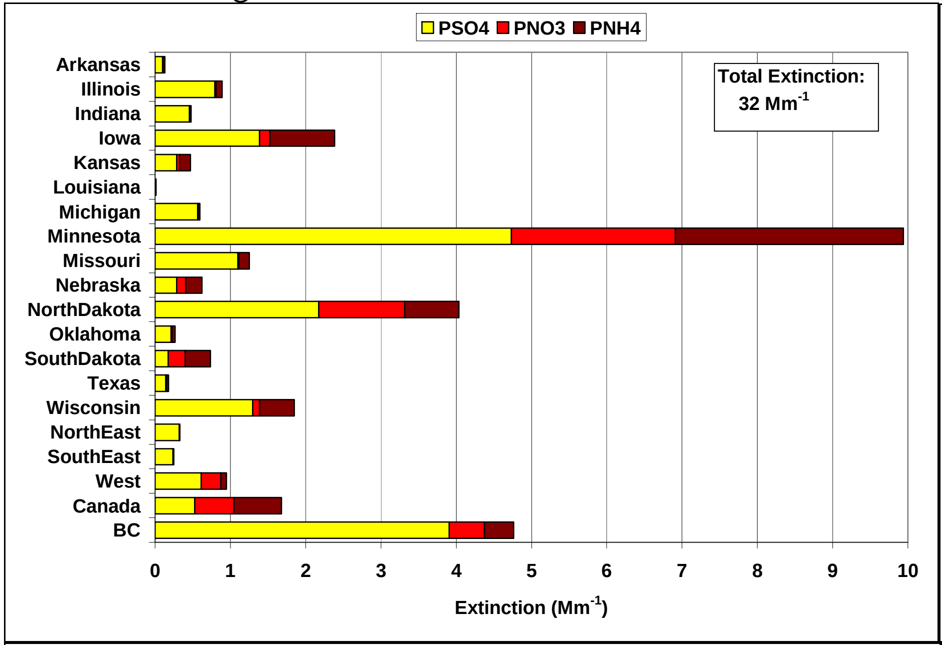


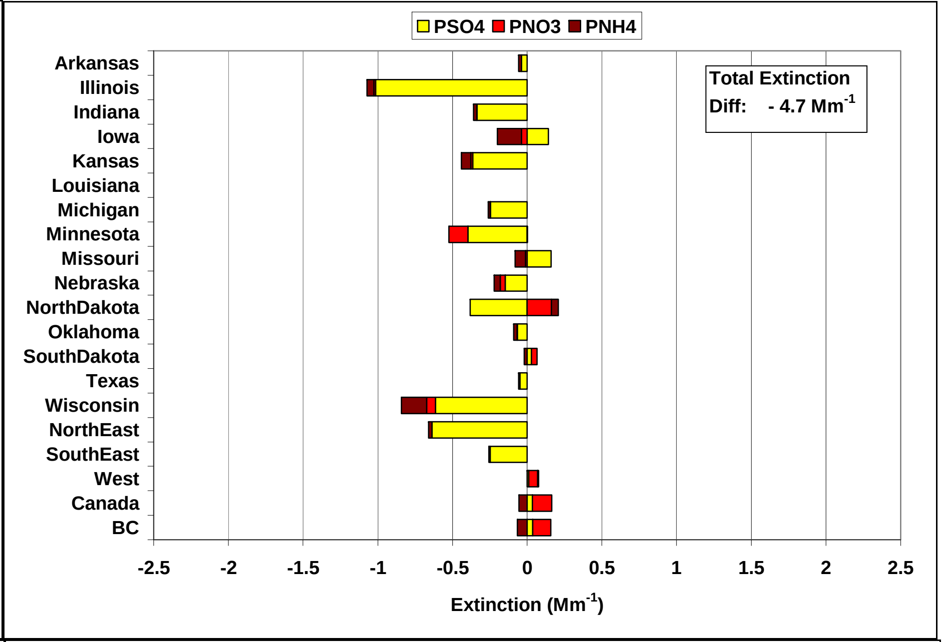


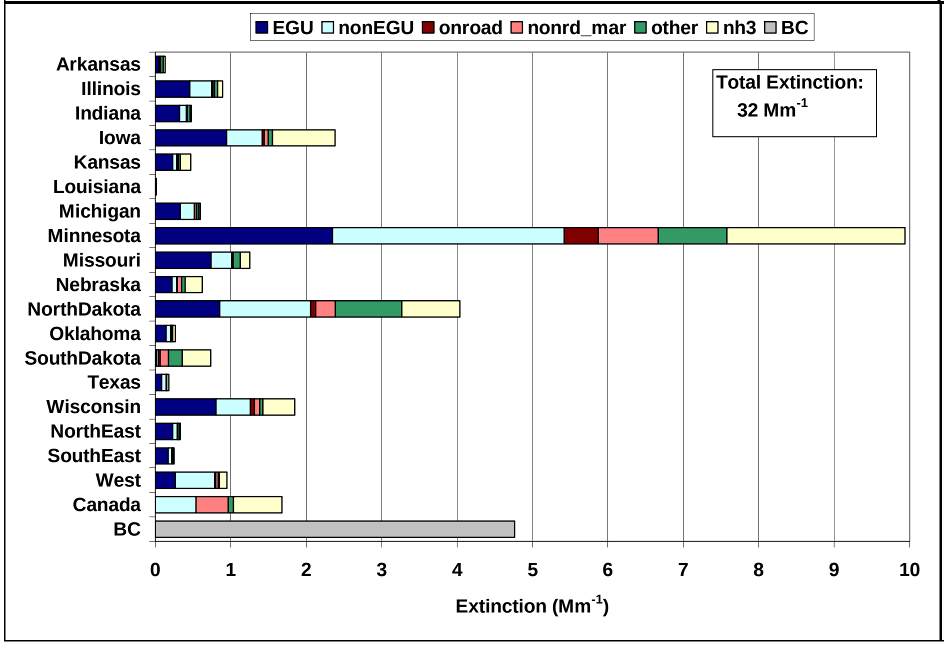
Voyageurs: Extinction Contribution by Specie and Sector for Each Region on the 20 Percent Worst Days

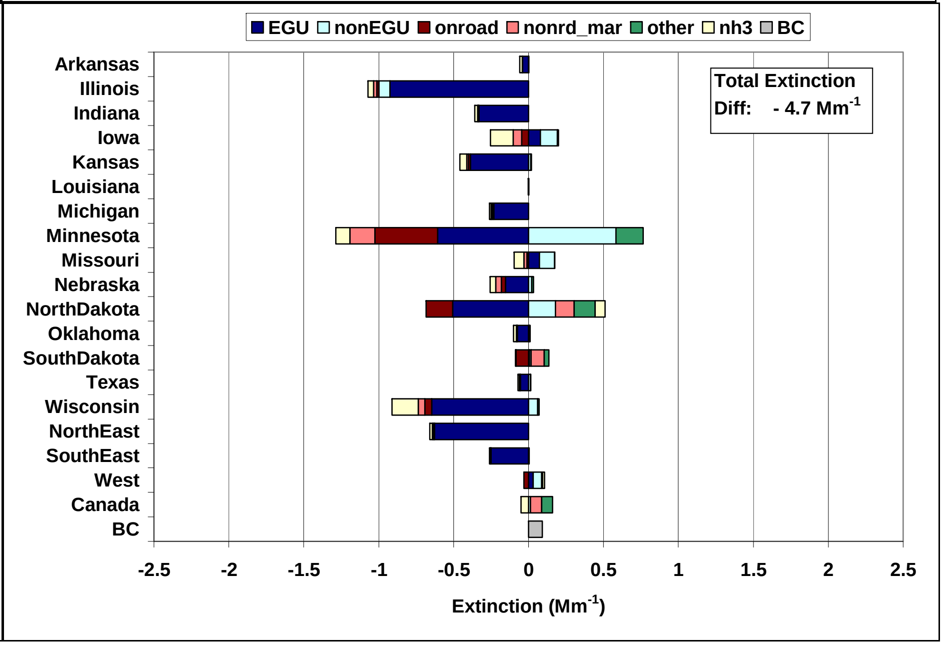
Figures 8.9 and 8.11: 2018

Figures 8.10 and 8.12: 2018 minus 2002

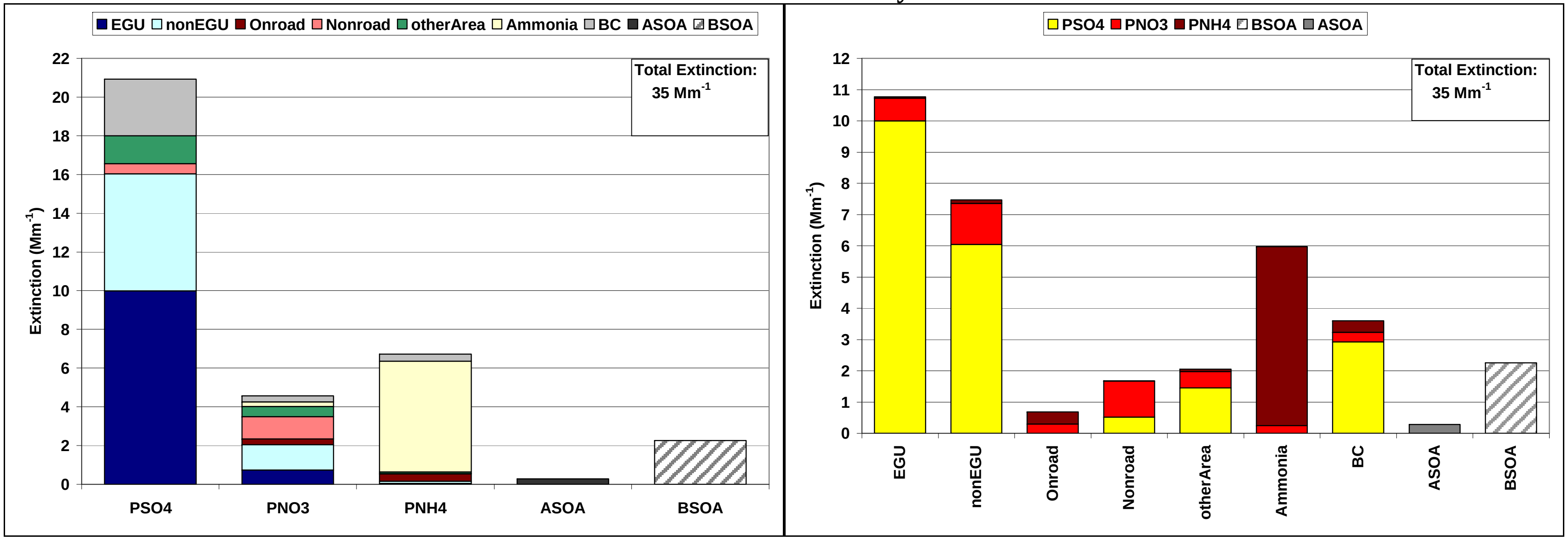




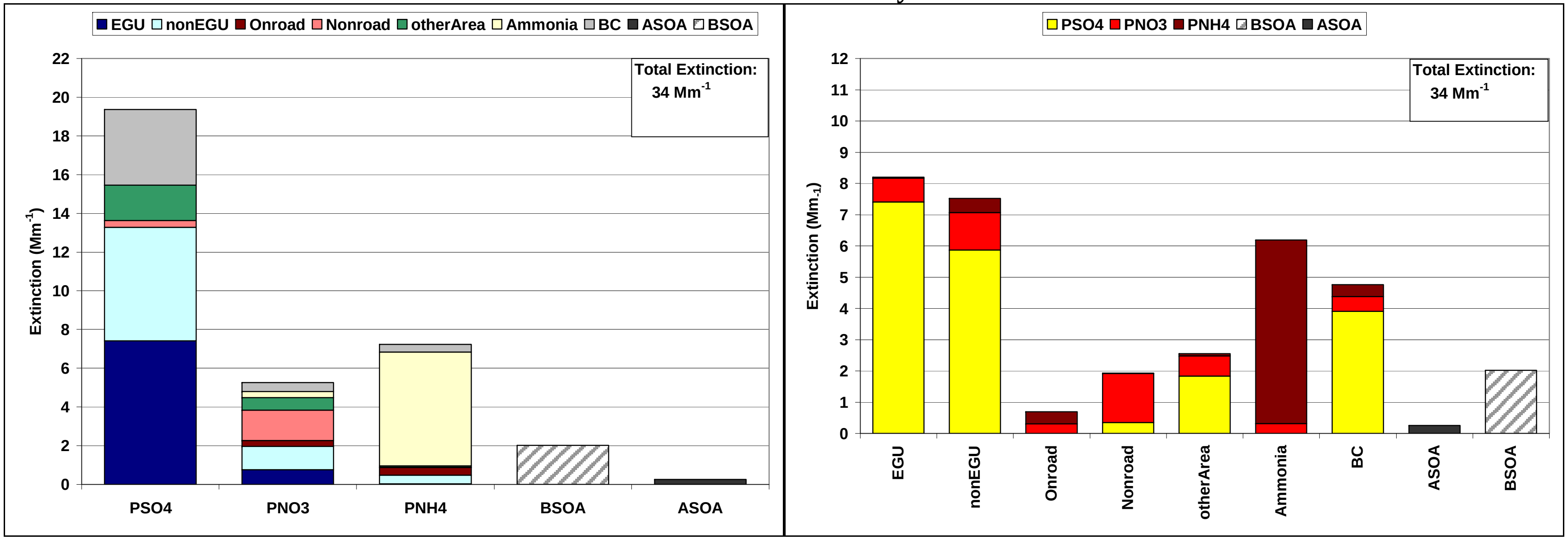




Figures 8.13 and 8.14 Boundary Waters 2018 Extinction Contribution by Sector for each Specie & by Specie for each Sector on the 20 Percent Worst Days.



Figures 8.15 and 8.16 Voyageurs 2018 Extinction Contribution by Sector for each Specie & by Specie for each Sector on the 20 Percent Worst Days.



8.2 Beyond On-the-Books Controls.

The PSAT results provide guidance to what geographic regions and source categories to target for emission reductions in 2018 beyond those associated with on-the-books controls. While the model does not respond as well as envisioned to changes in NO_X in the Minnesota$_{(MRPO)}$ case, it is sufficient for providing guidance on exploring control measures, understanding its uncertainties. The response to changes in NO_X emissions has been shown to rely on the amount of ammonia in the system. Sensitivity of the model response to improvements in ammonia emission forecasts (less ammonia in 2018 than projected in the Minnesota$_{(MRPO)}$ case) shows that visibility in the Class I areas will benefit with NO_X emission reductions. Also, as ammonium sulfate levels decline due to reductions in SO_2 emissions, more ammonia is free to react with NO_X to form ammonium nitrate. Thus, reductions in NO_X emissions should be explored as well as for SO_2 emissions.

The model response to NO_X changes in the Minnesota$_{(MRPO)}$ case does not impact the source regions and categories on which to focus for additional controls. The model was also found to be sensitive to meteorology. When Boundary Waters and Voyageurs are more impacted by sources to the Southeast and East—as is the case using 2005 meteorology—the model responds better to emission changes in those regions; the RPG reaches the glidepath. Use of 2002 meteorology in the Minnesota$_{(MRPO)}$ case may be preferred then, to explore model response to emissions changes in other regions.

In developing the RH SIP, Minnesota decided to focus attention on States that contribute 5 percent or more to either Boundary Waters or Voyageurs in 2018. The percentage breakdown contribution to ammonium nitrate and ammonium sulfate projected for 2018 by geographic region are shown in Figures 8.17 and 8.18. Minnesota contributes 28 percent (8.6 Mm^{-1}), at Boundary Waters and 31 percent (9.9 Mm^{-1}) at Voyageurs. The next largest individual state contributors at Boundary Waters are Wisconsin (10 percent, 3.2 Mm^{-1}), Iowa (8 percent, 2.7 Mm^{-1}), Illinois (6 percent, 2.0 Mm^{-1}), Missouri (6 percent, 2.0 Mm^{-1}) and North Dakota (6 percent, 2.0 Mm^{-1})[66]. The next largest individual state contributors at Voyageurs are North Dakota (13 percent, 4.0 Mm^{-1})[48], Iowa (7 percent, 2.4 Mm^{-1}), Wisconsin (6 percent, 1.8 Mm^{-1}) and Canada (5 percent, 1.7 Mm^{-1}). Recall that Canada emissions in the Minnesota$_{(MRPO)}$ case remain constant between the base year and 2018.

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[66] The state "mask" files that tell the model how to assign geographic regions for PSAT to track (see Figure 8.1) were made such that about 65,000 tpy SO_2 and 25,000 tpy NO_x from grid cells in Canada at the Canada/North Dakota border were inadvertently assigned to North Dakota. Thus, less contribution should be attributed to North Dakota, and more to Canada. In 2018, the total U.S. total North Dakota point source emissions were 77,200 SO_2 and 70,500 NO_x.

Figure 8.17. State Contributions to Ammonium Nitrate and Ammonium Sulfate Light Extinction at Boundary Waters for the Year 2018 after Implementation of On-the-Books Controls

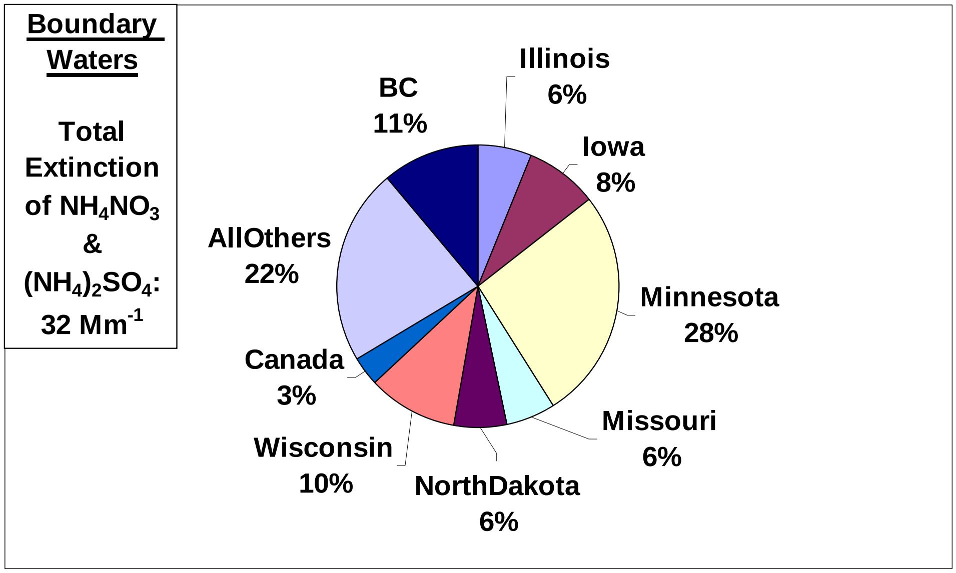
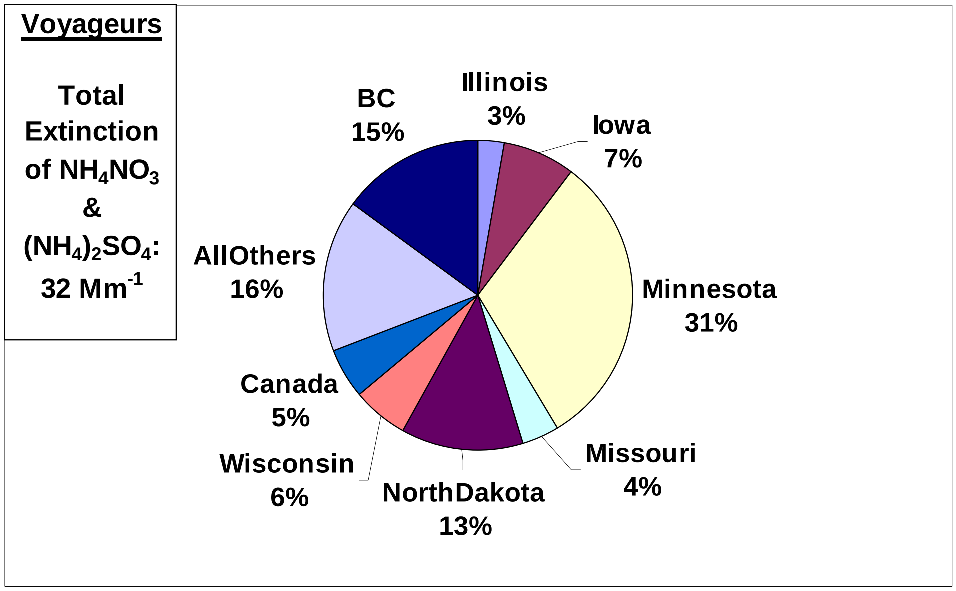
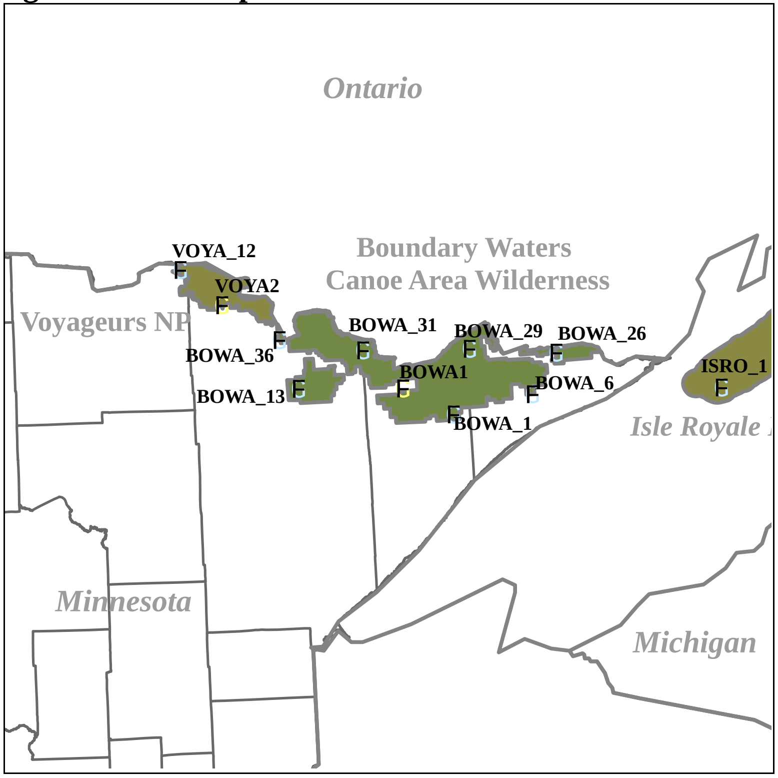


Figure 8.18. State Contributions to Ammonium Nitrate and Ammonium Sulfate Light Extinction at Voyageurs for the Year 2018 after Implementation of On-the-Books Controls



8.2.a Minnesota Controls. In order to determine where to focus potential control strategies in Minnesota, PSAT model runs were conducted to better understand contributions of the Northeast part of Minnesota (near Boundary Waters and Voyageurs) where a significant amount of point source NO_x and SO_2 is emitted, as compared to the contribution from the rest of the State. The size of Boundary Waters, 1.3 million acres stretching nearly 150 miles along the international boundary adjacent to Canada's Quetico Provincial Park,[67] and the proximity of large point source NO_X and SO_2 emitters in Northeast Minnesota, compelled Minnesota to model the $\text{Minnesota}_{(MRPO)}$ case with a 12km flexi-nested grid and apply PiG treatment to point sources of interest. For the same reasons, Minnesota chose to evaluate contributions to various receptor points within Boundary Waters and Voyageurs in addition to the monitor location used in the establishment of reasonable progress goals. Minnesota also added a receptor point on Isle Royale, as the monitor for that Class I area is not physically located on the Island. Figure 8.19 shows the location of the receptors evaluated.

Figure 8.19. Receptor Locations for 12km Grid with PiG.



The 12km PSAT results show that Northeast Minnesota contributes 14 percent and the rest-of-Minnesota contributes 12 percent of total ammonium nitrate and ammonium sulfate extinction at the Boundary Waters monitor location. Northeast Minnesota contributes 15 percent and the rest-of-Minnesota contributes 17 percent of total extinction at the Voyageurs monitor location.

At the receptors placed at various points throughout the Class I areas, Northeast Minnesota contributions range from 3 – 19 percent of total extinction. The 3 percent is at the western tip of Isle Royale, and the 19 percent contribution is at a receptor within Boundary Waters. The rest-of-Minnesota contributions range from 9 – 17 percent. The 9 percent is at the western tip of Isle Royale and the 17 percent is at a receptor within Voyageurs. Figure 8.20 illustrates the extinction contribution between Northeast Minnesota and the rest-of-Minnesota relative to contributions from all other geographic areas. Figure 8.21 shows results at the receptor with the

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[67] www.bwcaw.org

maximum (Boundary Waters, receptor 13) and the minimum (Western tip of Isle Royale) impact from Northeast Minnesota

Figure 8.20 Percentage Contribution of Northeast and Rest of Minnesota to Boundary Waters (BOWA1) and Voyageurs (VOYA2) on the 20 Percent Worst Days

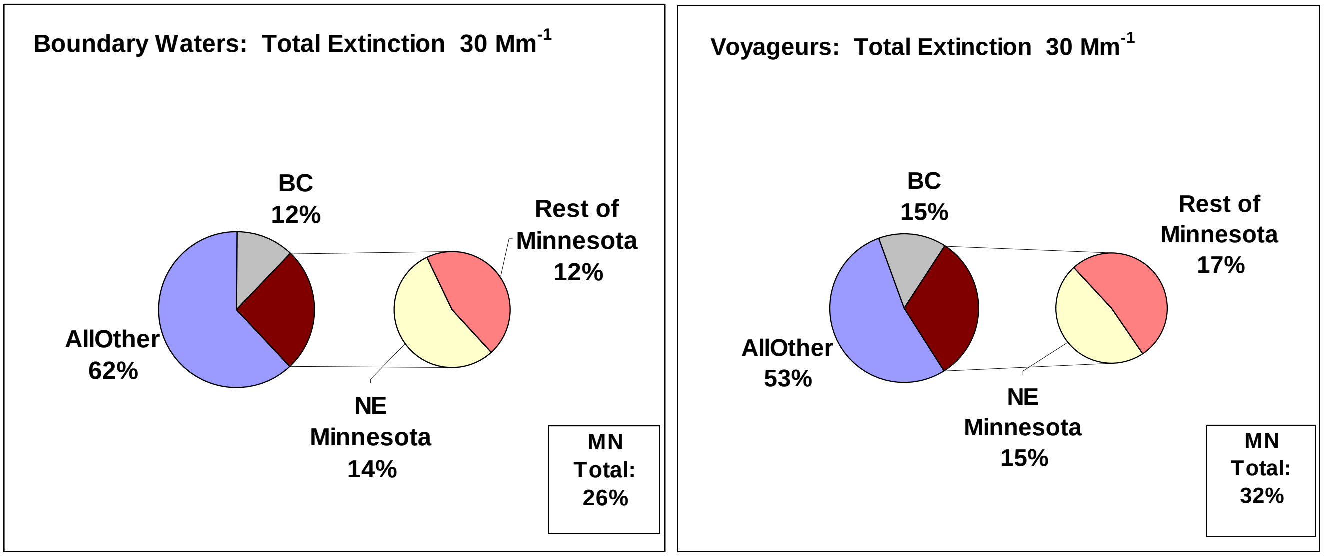
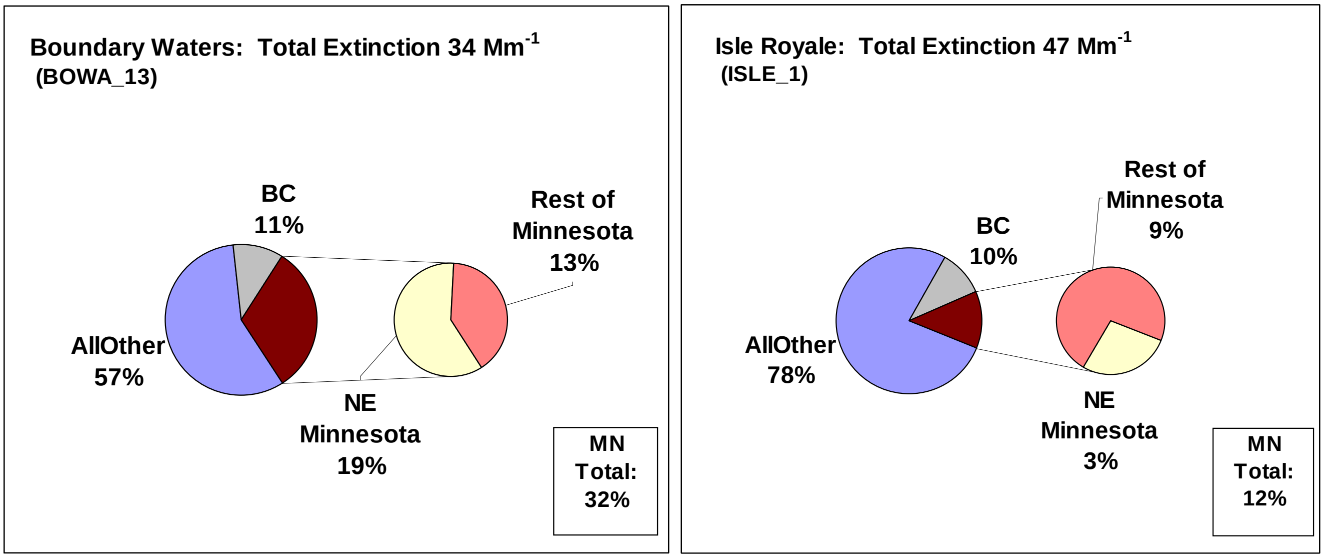


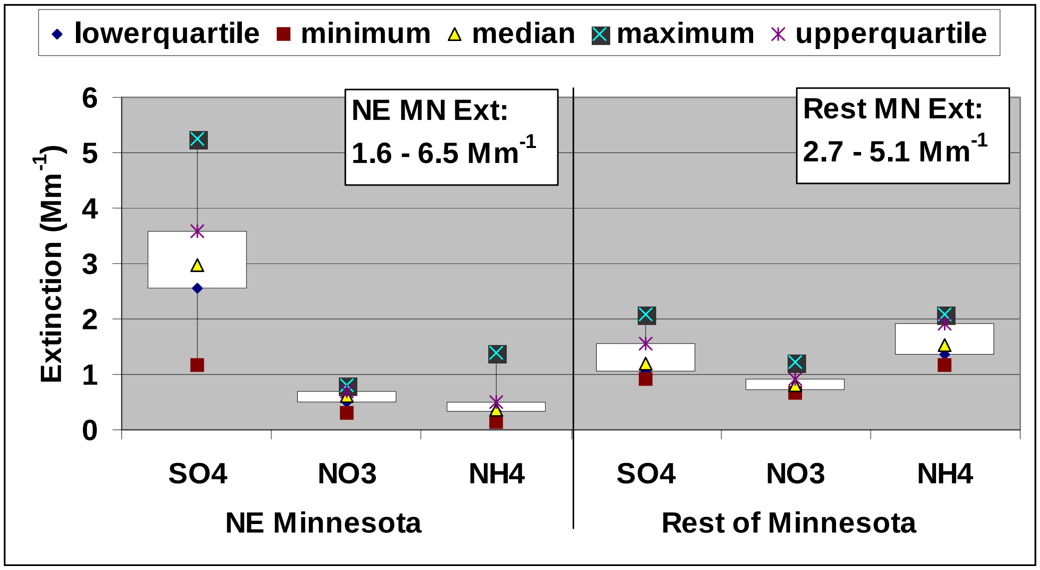
Figure 8.21 Percentage Contribution of Northeast and Rest-of-Minnesota to Maximum (BOWA_13) and Minimum (ISLE)Receptors in the Class I Areas on the 20 Percent Worst Days



Furthermore, the PSAT results indicate sulfate as the major component contributed by Northeast Minnesota point sources, while the rest of the state is more evenly divided between sulfate from point sources and ammonium from agricultural sources. Figure 8.22 illustrates the species contributions across the Class I areas. Emissions of NO_X in Northeast Minnesota are much higher than SO_2. Point source emissions of NO_X in Northeast Minnesota are estimated at 37,500 tons per year, while SO_2 emissions are 8,000 tons per year.

One explanation for this discrepancy in contribution of SO_2 and NO_X to the 20 percent worst days is that nitrate is an issue on fewer days and is formed in the colder months. Viewing animated spatial plots of the source apportionment results on days with high nitrate show that winds on several of the 20 percent worst days during this period appear to be coming from the West and Northwest of Minnesota. Thus, the NO_X emissions are not moving North toward the Class I areas to form ammonium nitrate, but are moving to the East, Southeast and South.

Figure 8.22: Minnesota Contributions at Receptors Placed throughout Boundary Waters, Voyageurs and the tip of Isle Royale in 2018 by Species and Geographic Region on the 20 Percent Worst Days



The contribution of select individual Minnesota point sources, listed in Table 8.8, was evaluated with PSAT. The sources identified as located in Northeast Minnesota were further evaluated with PiG due to their proximity to the Class I areas. In Northeast Minnesota, the point sources in the list account for nearly all the SO_2 and NO_X emissions in that part of the state. This is not the case for the individual point sources listed above for the rest-of-Minnesota. The Minnesota point sources listed above for the rest-of-Minnesota where chosen because they are some of the largest emitters in the State. The locations of the sources are shown in Figure 8.23.

Table 8.8 Minnesota Point Sources Evaluated with PSAT.

2002		2018	
Northeast Minnesota	**Other Minnesota**	**Northeast Minnesota**	**Other Minnesota**
Blandin Paper/Rapids Energy	Austin Utilities - NE Power St	Blandin Paper/Rapids Energy	Austin Utilities - NE Power St
Boise Cascade Corp - Intl	Flint Hills Resources LP - Pine Bend	Boise Cascade Corp - Intl	Flint Hills Resources LP - Pine Bend
Duluth Steam Cooperative Assoc	International Paper - Sartell	Duluth Steam Cooperative Assoc	International Paper - Sartell
EVTAC Mining - Fairlane Plant	Marathon Ashland Petroleum LLC	EVTAC Mining - Fairlane Plant	Marathon Ashland Petroleum LLC
Georgia-Pacific - Duluth Hardboard	Otter Tail Power Co - Hoot Lake	Georgia-Pacific - Duluth Hardboard	Otter Tail Power Co - Hoot Lake
Hibbing Public Utilities Commission	Rochester Public Utilities	Hibbing Public Utilities Commission	Rochester Public Utilities
Hibbing Taconite Co	Xcel - Sherburne Generating Plant	Hibbing Taconite Co	Xcel - Sherburne Generating Plant
Ispat Inland Mining Co	Xcel Energy - Allen S King	Ispat Inland Mining Co	Xcel Energy - Allen S King
Keewatin Taconite Operations	Xcel Energy - Black Dog	Keewatin Taconite Operations	Xcel Energy - Black Dog
Minnesota Power - Taconite Harbor	Xcel Energy - High Bridge	Minnesota Power - Taconite Harbor	Xcel Energy - High Bridge
Minnesota Power Inc - Boswell	Xcel Energy - Riverside	Minnesota Power Inc - Boswell	Xcel Energy - Riverside
Minnesota Power Inc - Laskin		Minnesota Power Inc - Laskin	
Minnesota Power Inc - ML Hibbard		Minnesota Power Inc - ML Hibbard	
Northshore Mining Co - Silver Bay		Northshore Mining Co - Silver Bay	
Potlatch - Cook		Potlatch - Cook	
Potlatch - Grand Rapids		Potlatch - Grand Rapids	
Sappi Cloquet LLC		Sappi Cloquet LLC	
US Steel Corp - Minntac		US Steel Corp - Minntac	
Virginia Dept of Public Utilities		Virginia Dept of Public Utilities	
		East Mine projected	
		Mesabi Nugget	
		West Mine projected	

* The Northeast Minnesota sources were modeled using PiG.

Overall, the point sources listed in Table 8.8 contribute a range of 2.5-6.7 Mm^{-1} in 2002 to 1.8-6.3 Mm^{-1} in 2018 at all receptors. Figure 8.24 illustrates the contribution for the base year and the future year for all the listed point sources, the Northeast Minnesota sources and the other Minnesota sources. Clearly the list of other-Minnesota point sources does not encompass the entire impact from the rest-of-Minnesota. However, the impact from the individual Northeast Minnesota sources listed in Table 8.8 does account for nearly all of the contribution from Northeast Minnesota.

Figures 8.25 through 8.28 illustrate the contribution break-out by individual point source modeled for both 2002 and 2018. Figures 8.25 and 8.26 show the contributions of the Other Minnesota point sources. Decreases in individual point source contributions from 2002 to 2018 for Xcel Energy—A.S. King, —High Bridge and —Riverside plants are due to implementation of the Metropolitan Reduction Project (MERP).

Figures 8.27 and 8.28 illustrate the contribution break-out for the Northeast Minnesota point sources. Reduced contribution from Minnesota Power –Boswell, and –Taconite Harbor, are due to projects reflected in the IPM3.0 "will do" scenario, described in Section 2.2. The IPM model projected increased emissions from Virginia Public Utilities and Hibbing Public Utilities. For both these facilities, IPM allowed emissions to rise to 4 lbs/MMBtu permitted rate when actuals are less than 1 lb/MMBtu. Most of the other contributions from existing sources remained the same from the base year to the future year, with very slight increases in contribution from EVTAC startup of line 1, and also some EGAS predicted growth at non-mine facilities such as Boise Cascade. Additional contributions are associated with the three new taconite mines.

Figure 8.23 Locations of Individual Point sources evaluated with PSAT and Plume-in-Grid

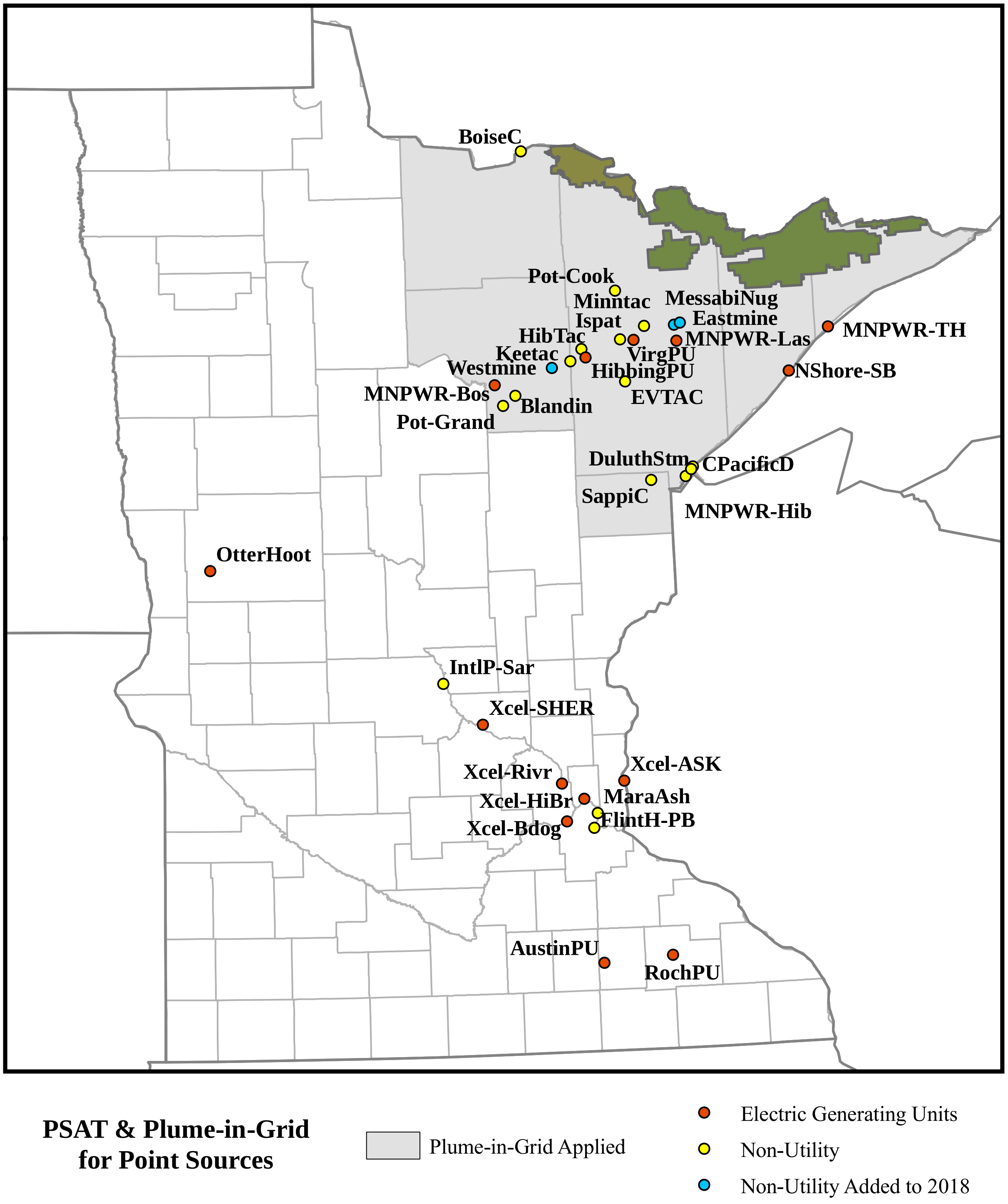


Figure 8.24 Minnesota Point Source Contributions to Nitrate, Sulfate and Ammonium Extinction at Receptors Placed Throughout Boundary Waters, Voyageurs and the Tip of Isle Royale in 2018 on the 20 Percent Worst Days

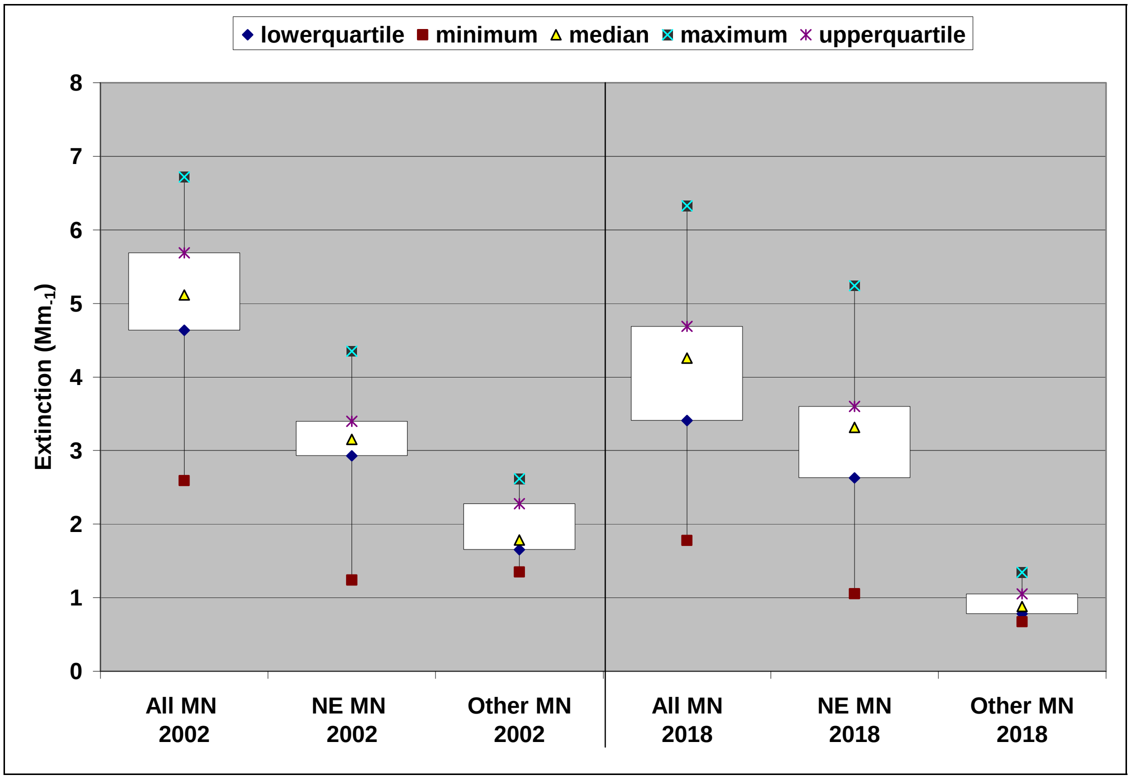


Figure 8.25 Other Minnesota Individual Point Source Contributions in 2002 on the 20 Percent Worst Days

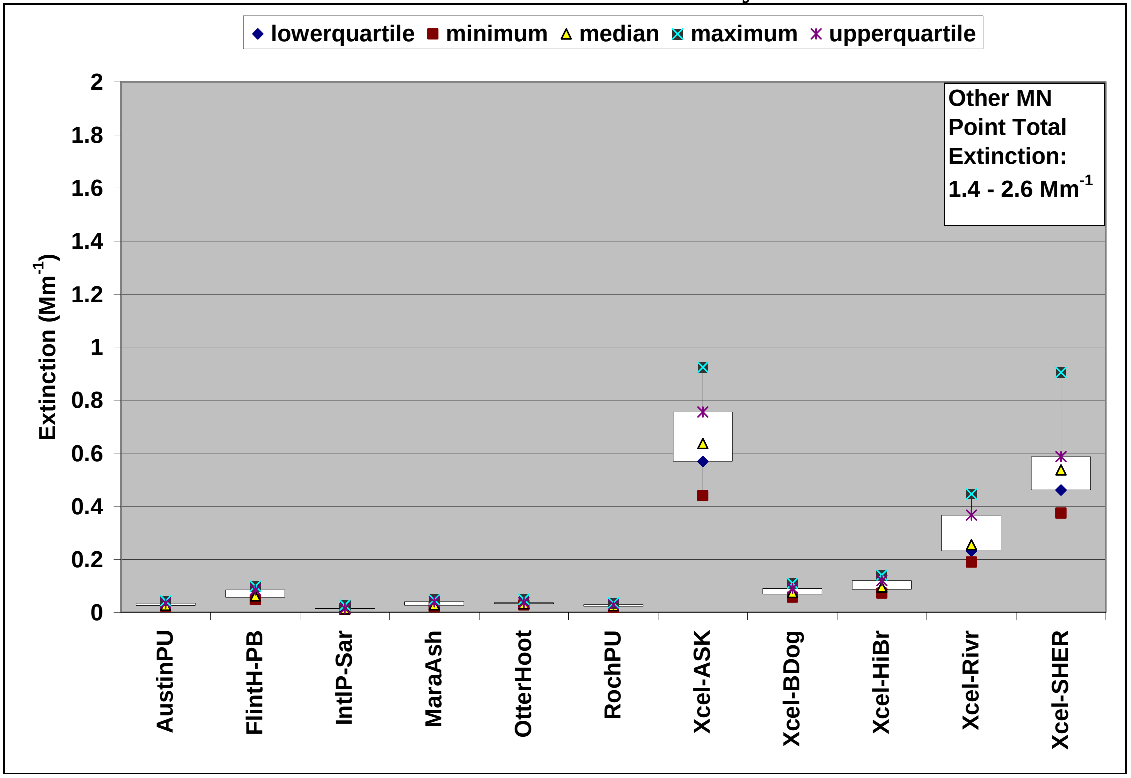


Figure 8.26 Other Minnesota Individual Point Source Contributions in 2018 on the 20 Percent Worst Days

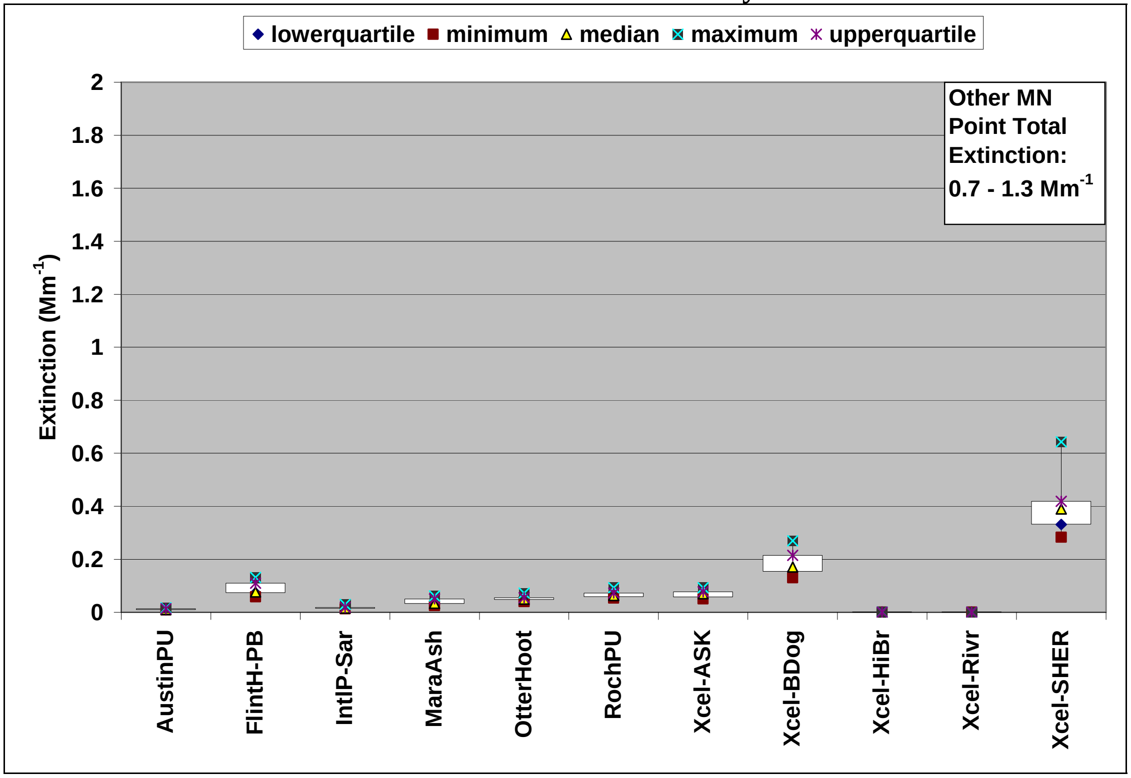


Figure 8.27 Northeast Minnesota Individual Point Source Contributions in 2002 on the 20 Percent Worst Days

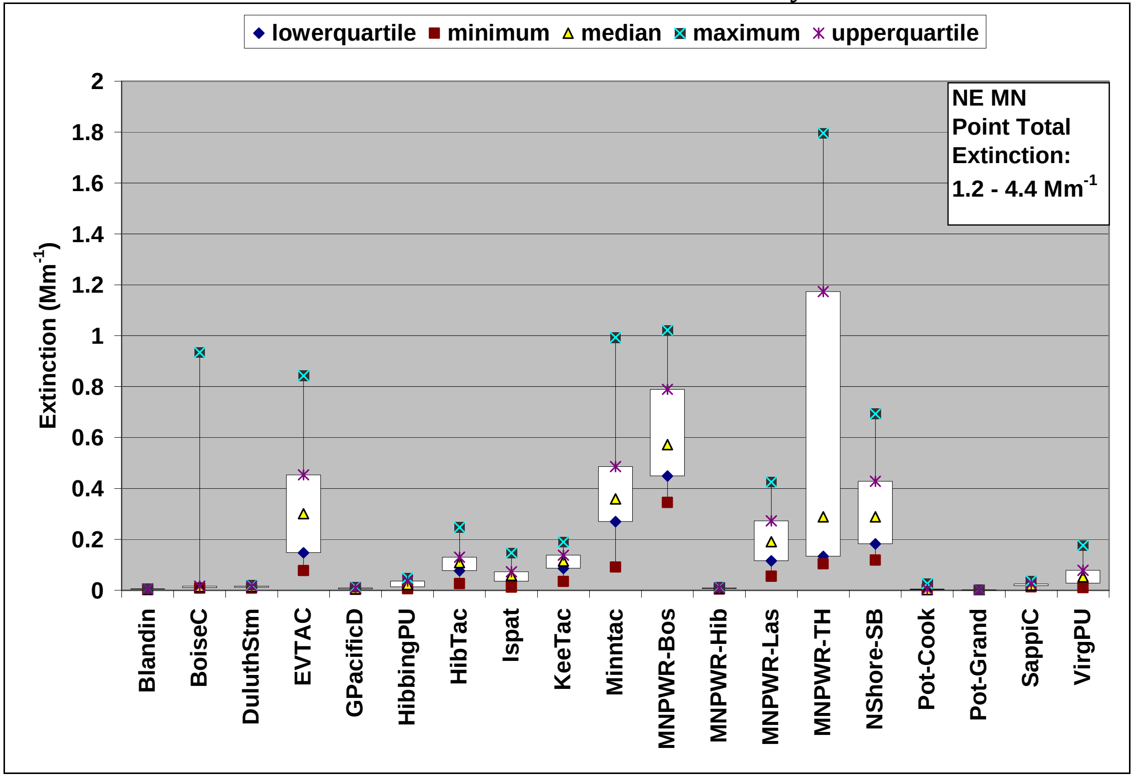
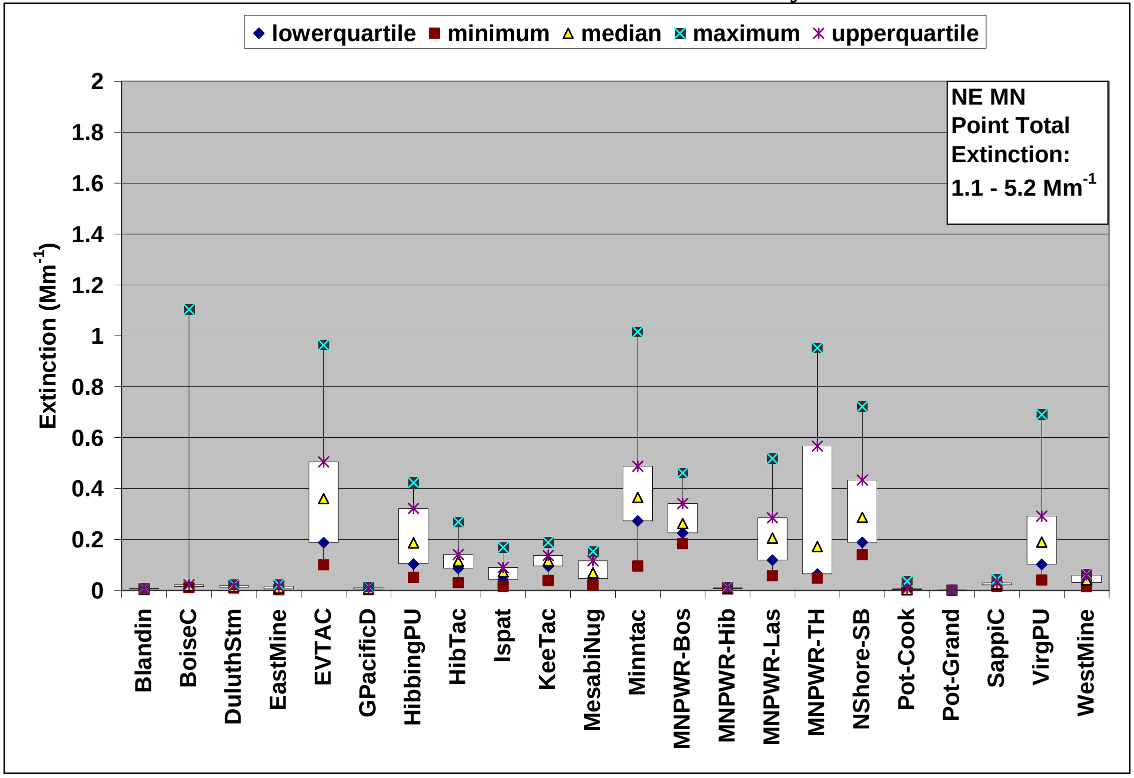


Figure 8.28 Northeast Minnesota Individual Point Source Contributions in 2018 on the 20 Percent Worst Days



The above information supports consideration of a control strategy that focuses on point sources in Northeast Minnesota. Planning staff determined that a 30 percent reduction in SO_2 and NO_X emissions from 2002 levels for the six counties comprising “Northeast Minnesota” would be reasonable. The plan is coined the “Northeast Minnesota Plan”.

Northeast Minnesota Plan. In this plan, the six counties in northeast Minnesota would maintain a 30 percent reduction in NO_x and SO_2 from 2002 emissions levels. About 21 percent of that reduction is already associated with the Minnesota Power—Boswell and –Taconite Harbor projects described above and included in the on-the-books controls. In order to model this plan in the uniform rate of progress analysis, the remaining approximately 10 percent was applied to taconite industry sources. The emission reductions were based on permit limits, furnace modifications in 2006 and 2007, fuel switching, a new scrubber, newer rate information, and some reductions due to BART.

The CAMx input files for the Minnesota$_{(MRPO)}$ case were modified to reflect the 10 percent reduction from 2002 emission levels by applying factors to unit/stack specific emissions at the taconite facilities. Table 8.9 lists the affected facility, the affected stack, the factors applied and the resulting emissions. All these controls, except those associated with BART, are in place.

Table 8.9 Northeast Minnesota Plan Reductions to Non-EGU Point Sources

Facility Name	Facility ID	Stack ID	2018 NO_x Emissions	NO_x factor	NE MN Plan Emissions	2018 SO_2 Emissions	SO_2 Factor	NE MN Plan Emissions	Comments
US Steel Minntac	2713700005	SV103	2,195	0.81	1,778	324	1.00	324	PSD permit limit
		SV118	2,521	0.81	2,042	380	1.00	380	
		SV127	2,015	0.81	1,632	380	1.00	380	
		SV144	2,557	0.81	2,071	380	1.00	380	
		SV151	1,767	0.81	1,431	343	1.00	343	
Hibbing Taconite	2713700061	SV024	1,797	0.80	1,438	197	1.00	197	Furnace Mod. in ‘06/’07
		SV028	1,682	0.80	1,345	185	1.00	185	
		SV029	1,916	0.80	1,533	211	1.00	211	
Ispat Inland Mining	2713700062	SV017	3,254	0.70	2,278	155	1.00	155	Furnace Mod. in Fall ‘07
Keewatin Taconite	2713700063	SV030	6,049	0.70	4,234	464	1.00	464	Switched from NG to NG/coal blend + New Scrubber
EVTAC Mining – Fairlane Plant	2713700113	SV049	1,764	0.86	1,517	3,222	0.41	1,321	’05 Rate for 1 and 2, BART on line 2
		SV046	2,626	0.86	2,258	53	1.00	53	

Including the changes to the Northeast Minnesota EGUs and the taconite adjustment factors, the overall percent reduction from Northeast Minnesota point sources is about 31 percent. A uniform progress analysis was developed for this scenario, and Minnesota chose the resulting deciview values at Boundary Waters (18.6 dv worst days, 6.5 dv best days) and at Voyageurs (18.9 dv worst days, 7.1 best days) for the RPG, shown in Figures 8.29 and 8.30.

Figure 8.29. RPG at Boundary Waters
36-km Minnesota$_{(MRPO)}$ with On-the-Books Controls + the Northeast Minnesota Plan

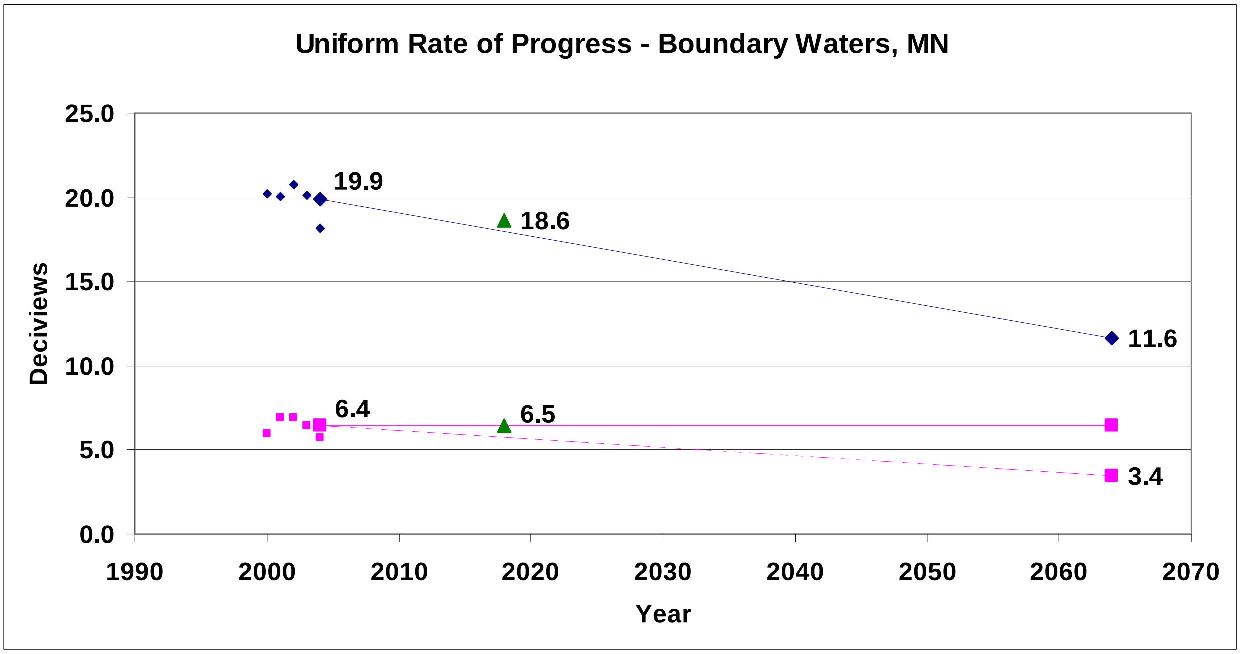
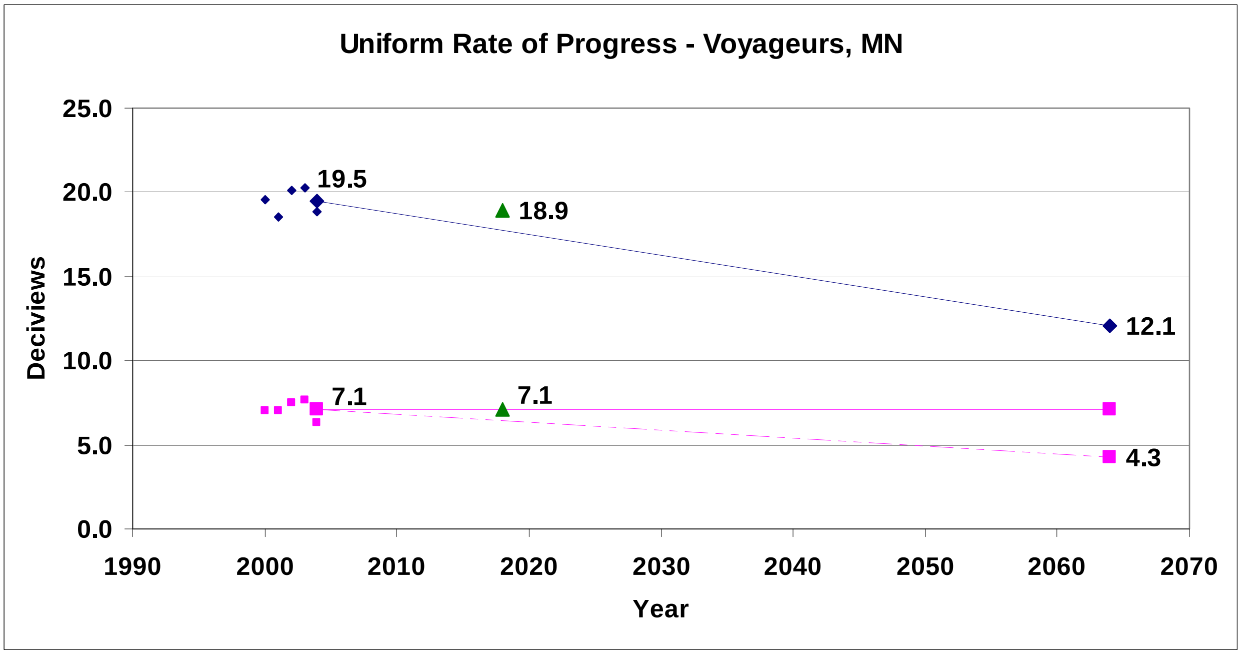


Figure 8.30. RPG at Voyageurs
36-km Minnesota$_{(MRPO)}$ with On-the-Books Controls + the Northeast Minnesota Plan



Northshore Mining – Silver Bay. Other recent controls finalized after establishment of the RPG are those associated with the BART determination for the power boilers (EGUs) at Northshore

Mining—Silver Bay. The controls are LNB on Power Boilers 1 & 2 (emission unit i.d. EU001 & EU002) to control NO_X, and co-firing of biomass to displace coal on Power Boilers 1 & 2 to control SO_2. These controls were not explicitly included in IPM, however, the IPM model projected low annual emissions for these units in 2018. Effectively, these controls are accounted for in the RPG in Figures 8.29 and 8.30.

Xcel Energy – Sherburne County. During the time controls were evaluated for the $\text{Minnesota}_{\text{(MRPO)}}$ case, other proposed control measures were considered, including Xcel Energy—Sherburne County. Xcel energy had submitted a potential project that involved retrofit SCRs, fabric filters and dry scrubbers on Units 1 and 2, and SCR on Unit 3, as shown in Table 8.10. However, Xcel Energy later withdrew the proposal for SCR on all three units due to cost concerns. Instead, they committed to low NO_X burners (LNB) on Units 1, 2 and 3[68]. The new proposal (in Table 8.11) projects less SO_2 emitted than IPM base total emissions based on a change in projected fuel use. The LNB results in more projected NO_X than the original proposal with SCR. Units 1 & 2 are subject to BART, and the new proposal has since been determined to be BART. The RPG in Figures 8.29 and 8.30 does not reflect the controls in either proposal because the modeling was completed before the project was finalized. LNB was installed 2008/2009; scrubber upgrade (retrofitting sparger tubes and installing limestone injection) is expected to occur upon EPA approval of the SIP. The original proposal was included in an analysis of potential controls explored for Minnesota and other significant contributing States. That analysis is described further in Section 8.2.b.

Table 8.10. Xcel Energy –Sherburne Plant Original Proposal

Facility Name	**Basis for Correction/Adjustment**	**Unit #**	**IPM base Total Emissions (Mton)**		**Original Proposal Total Emissions (Mton)**	
			NO_x	**SO_2**	**NO_x**	**SO_2**
Xcel—Sherburne Co	SCR+Fabric Filter+Dry Scrubber on Units 1 and 2; SCR on unit 3.	1	4.58	4.82	2.78	3.05
		2	6.99	4.87	2.80	3.08
		3	8.31	--	3.55	--

Table 8.11. Xcel Energy –Sherburne Plant Final Proposal

Facility Name	**Basis for Correction/Adjustment**	**Unit #**	**IPM base Total Emissions (Mton)**		**New Proposal Total Emissions (Mton)**	
			NO_x	**SO_2**	**NO_x**	**SO_2**
Xcel—Sherburne Co	LNB+Upgraded Venturi Scrubber and Lime Injection+Wet ESP on Units 1, 2;	1	4.58	4.82	4.16	3.33
		2	6.99	4.87	4.20	3.36
	LNB+Fabric Filter+Dry Scrubber on Unit 3	3	8.31	--	8.17	--

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[68] Letter to Anne Jackson (MPCA) from Jim Alders (Xcel Energy), "Request for Withdrawal in the Matter of the Other Environmental Improvements Plan at the Sherburne County and A.S. King Generating Plants", MPUC Docket No. E002/M-08-739, November 24, 2008.

8.2.b Other Contributing State Controls. Control measures thought to be potentially reasonable—based on initial cost estimates by CENRAP and initial four-factor analyses results from MRPO—were applied to the Minnesota$_{(MRPO)}$ case in order to evaluate what additional improvements to visibility might result. The regions and source categories targeted are those believed to be contributing most to the 20 percent worst visibility days.

The potentially reasonable control measures are a 0.25 lb/MMBtu emission rate from Iowa, Missouri, North Dakota and Wisconsin. These rates were applied to EGUs in those states that did not already have additional controls in place. The MRPO assisted in developing this scenario by adjusting the IPM "will do" emissions used to establish the RPG in Figures 8.29 and 8.30. This emissions scenario also included the original Xcel Energy—Sherburne County proposal described above, and emission reduction requests from MANE-VU for all five MRPO states (Illinois, Indiana, Michigan, Ohio and Wisconsin). The MANE-VU reduction request involves scaling EGU SO_2 emissions for non-scrubbed units on a list of 167 emission units by 0.10 (90% control), and scaling nonEGU point (and nonroad, MAR, and on-road) SO_2 emissions by 0.72.

In response to the Minnesota 0.25 lb/MMBtu emission rate request from neighboring states and Missouri, MRPO applied the emissions rate to the IPM3.0 "will do" by scaling SO_2 and NO_X emissions for the top emitting power plants by 0.10 (90% control). In establishing an emissions target, MRPO used the emissions summary for each specified state from the "will do" and applied ratios to the emissions in the respective States modeling inventory to estimate a "target" value. Table 8.12 contains the state-wide ratios.

Table 8.12 Statewide Emissions Ratios for EGU IPM3.0 "will do" Scenario

State	SO_2 (tons/year)	SO_2 (lb/MMBtu)	NO_X (tons/year)	NO_X (lb/MMBtu)	Statewide Ratio SO_2	Statewide Ratio NO_X
Iowa	116,000	0.434	60,000	0.224	0.58	n/a
Missouri	238,000	0.532	73,000	0.163	0.47	n/a
North Dakota	56,200	0.328	58,900	0.343	0.76	0.73
Wisconsin	150,000	0.445	55,000	0.163	0.56	n/a

The ratios were applied to the largest emitting facilities using MRPO emissions-over-distance "Q/d" lists for 2002 emissions. MRPO determined that 90% control (scaling SO_2 and NO_X emissions by 0.10) would get close to the "target". The facilities chosen, the targets, and emission reductions should 2018 "will do" emissions get scaled are shown in Table 8.13.

Table 8.13 Adjustments Made to Contributing States to Reflect 0.25 lb/MMBtu Emissions Rate

State	Pollutant	Facility Name	2018 Total (tons/day)	Reduction (tons/day)	New 2018 Total (tons/day)
Iowa	SO_2	George Neal North	60.28	-54.25	6.03
		Ottumwa	48.97	-44.07	4.90
		George Neal South	41.15	-37.04	4.12
Missouri	SO_2	Labadie	153.51	-138.16	15.35
		AE Hill	70.73	-63.66	7.07
		Rush Island	76.63	-68.97	7.66
		Meramac	49.06	-44.16	4.91
North Dakota	SO_2	Antelope Valley	38.91	-35.02	3.89
	NO_X	Antelope Valley	36.58	-33.28	3.30
		Coal Creek	23.85	-20.80	3.05
Wisconsin	SO_2	Dairyland	37.22	-13.94	23.28
		Stoneman	17.58	-15.82	1.76
		Alliant	78.39	-71.30	7.10
		WP & L Alliant	44.87	-40.39	4.49

Table 8.14 summarizes the resulting 2018 emissions projections for point sources associated with the potentially reasonable control measures and the emissions change from the 2018 Minnesota$_{(MRPO)}$ emissions projections used for establishing the reasonable progress goal. The emission reductions associated with Minnesota point sources in Table 8.14 reflects the original Xcel Energy—Sherburne County proposal.

Table 8.14 Annual 2018 Potentially Reasonable Control Measures Emissions for Point Sources in Tons

Region	Potentially Reasonable Control Measure Emission (ton/year)		Reduction from 2018 RPG Emissions (ton/year)		Reduction from 2018 RPG Emissions (percent)	
	SO_2	NO_X	SO_2	NO_X	SO_2	NO_X
Iowa	66,700	58,500	-47,200	0	-41%	
Minnesota	51,000	38,200	0	0		
Missouri	127,000	72,700	-2,980	-10,700	-1%	
North Dakota	46,000	39,900	-1,900	-6,550	-3%	-11%
Wisconsin	96,300	51,900	-111,000	0	-77%	

The resulting position on the glidepath at Boundary Waters and Voyageurs, due to the emissions reductions summarized above, is shown in Figures 8.31 and 8.32. The results show an additional 0.3 dv reduction at Boundary Waters and an additional 0.2 dv reduction at Voyageurs than in the RPG (see Figures 8.29 and 8.30), but still above the glidepath. As mentioned above, these results are not the RPG because none of the control measures from other states, nor the original Xcel Energy—Sherburne County proposal, have been determined reasonable at the time of RH SIP development.

Figure 8.31. Boundary Waters 36-km Minnesota$_{(MRPO)}$ Position on Glide Path with "Potentially Reasonable" Controls.

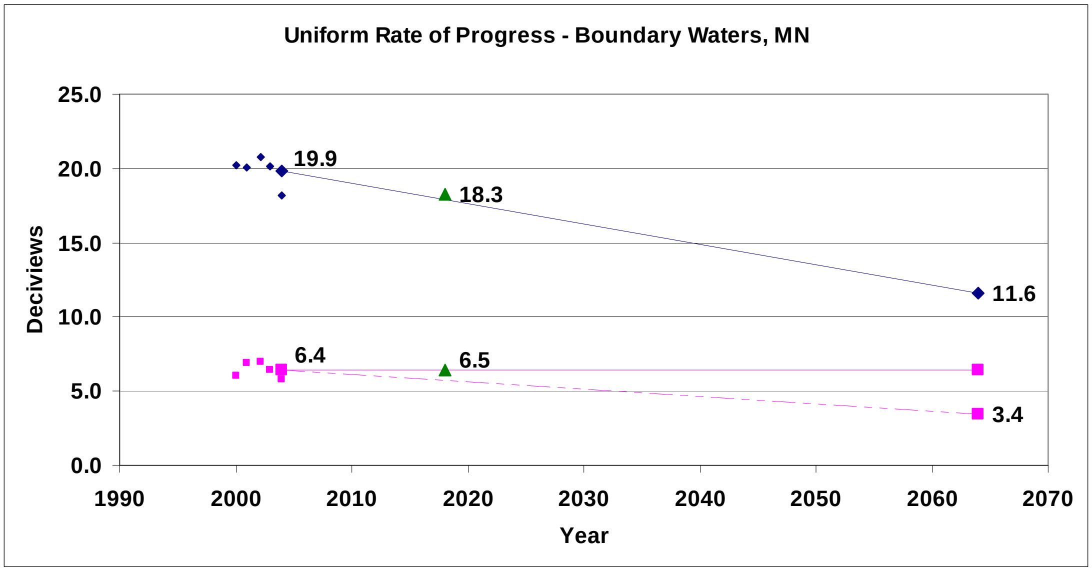
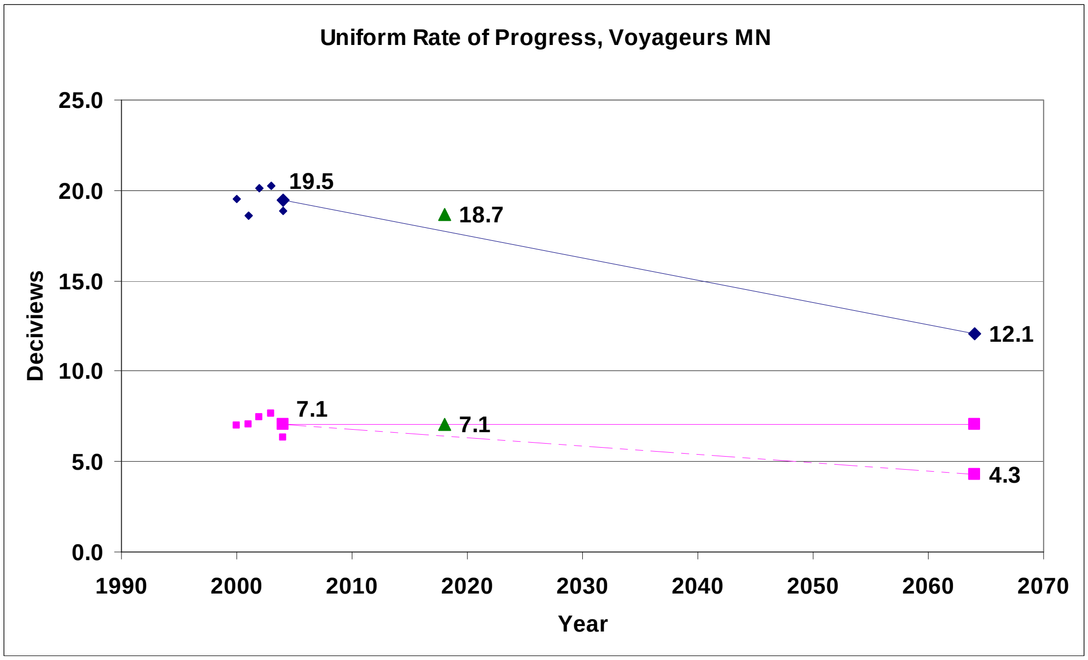


Figure 8.32. Voyageurs 36-km Minnesota$_{(MRPO)}$ Position on Glide Path with "Potentially Reasonable" Controls.



8.3 Canadian Impacts and Control Strategies.

Many approaches have been proposed on how to quantify international impacts, specifically Canada's contribution to visibility in the Minnesota Class I areas. Many of those proposed include developing alternate glidepaths, assuming Canada emissions are zero. These assumptions are problematic because Canada emissions would still be included in the baseline observed values. Some have attempted to estimate how much Canada emissions might be in the baseline and try to remove it. Manipulating the observed values into something that is no longer the observed creates additional problems. Minnesota has avoided taking these approaches.

Including Canada emissions in the modeling has the advantage of setting the Minnesota RPG in relation to an observed baseline that includes Canada contributions to visibility. Keeping the emissions constant between the base year and the future year establishes a reasonable progress goal based on known, publicly available information from the United States. There is enough uncertainty in the Canada emissions that including their emissions changes from 2002 to 2018 could provide misleading results. There is enough compelling evidence from the PSAT results to show that Canada has a significant enough impact on visibility that collaboration with Canada on emissions and modeling could help better assess the RPG at Boundary Waters and Voyageurs. MRPO has begun such collaboration with Ontario; but it appears that Canadian impact at Boundary Waters and Voyageurs also comes from the more western provinces of Manitoba, Saskatchewan and Alberta, so additional collaboration would be useful from those provinces as well. As this would entail international relations, it is prudent for the EPA to lead this effort.

IV. Data Access

All data files used to support this TSD and the accompanying SIP are archived at the Minnesota offices and that provision has been made to maintain them. The MRPO and CENRAP maintain their own files for their work. The Minnesota$_{(MRPO)}$ files are generated and read on a Linux operating platform. Model output are processed with a series of Fortran programs invoked by C-shell scripts. To obtain files used in the analyses contact Margaret McCourtney at 651-757-2558 or margaret.mccourtney@pca.state.mn.us.

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VI. Glossary

- **20 Percent Best Days** – The 20% of days with the best visibility during each year in the baseline period.
- **20 Percent Worst Days** – The 20% of days with the worst visibility during each year in the baseline period.
- **Ainsworth Engineered (USA) LLC** – formerly Potlatch Corp.
- **Air Parcel** – a volume of air that tends to be transported about the earth as an intact entity and can be tracked.
- **Anthropogenic** – Caused by humans (i.e. pollutant emissions from industrial processes, automobiles and trucks).
- **Apportionment** – Proportional distribution or allocation.
- **ArcelorMittal Minorca Mine Inc**. – formerly Ispat Inland Inc.
- **Area Source** – an emisions source that are not identified by locational coordinate and stack parameters (i.e. agricultural operations, residential heating). Emissions are assigned to a grid cell.
- **Backtrajectory** – Tracking backward in time from where air parcels arriving at a particular destination of interest came.
- **BART** – Best Available Retrofit Technology – Regional Haze rule (70 FR 39104-39172) required controls on certain types of sources built between 1962 – 1977 and generally grandfathered under most Clean Air Act programs.
- **BaseC** – 2002 emissions inventory developed by CENRAP prior to Base G. BaseC is the version of the CENRAP inventory used in Minnesota modeling.
- **BaseF** – 2002 emissions inventory developed by CENRAP, final source contribution modeling with CAMx and model performance evaluation was conducted with this version of the CENRAP case; not BaseG.
- **BaseG** –2002 emissions inventory developed by CENRAP. BaseG is the final CENRAP emissions inventory for establishing reasonable progress goals for regional haze SIPs.
- **BaseK** – 2002 emissions inventory developed by MRPO which is the backbone for the $\text{Minnesota}_{\text{(MRPO)}}$ case. BaseK is the final 2002 MRPO emissions inventory for source contribution modeling, performance evaluation and for establishing reasonable progress goals.
- **BaseM** – 2005 emissions inventory developed by MRPO. BaseM is the final 2005 MRPO emissions inventory used for source contribution modeling, performance evaluation and for establishing reasonable progress goals.
- **Baseline Conditions** – Average visibility conditions (in deciviews) that exist for each Class I area over the 20 percent best and 20 percent worst days in the 5-year baseline period.
- **Baseline Period** – The years 2000 – 2004, as prescribed by the Regional Haze Rule.
- **Base Year** – The individual years comprising the Baseline Period. It also refers to the year modeled to establish the RPG.
- **BC** – Air concentrations coming into the domain from the East, West, North, South and above (i.e. intrusion of stratospheric ozone) of the domain.
- **B_{ext}** – Extinction Coefficient. Provides a direct, but non-linear, measure of the correlation between air concentrations of visibility impairing pollutants and visibility conditions.
- **Biogenic** – Caused by natural processes (i.e. emissions from respiration of trees).

- **Biomass** – Co-firing biomass with existing fuel.
- **Bkwh** – Billion kilowatt hours.
- **CAIR** – Clean Air Interstate Rule – A federal rule establishing a cap and trade program covering 28 Eastern States to reduce emissions of NO_X and SO_2 primarily from power plants. Initially finalized March 2005, vacated by the D.C. Circuit Court of Appeals July 2008, and remanded to EPA December 2008. EPA proposed to stay CAIR in Minnesota January 2009.
- **CAMx** – Comprehensive Air quality Model with extensions - an Eularian air quality grid model that simulates atmoshperic and surface processes affecting the transport, chemical transformation and deposition of air pollutants and their precursors; a contemporary of CMAQ. Used by MRPO and Minnesota to establish reasonable progress goals, and for source apportionment by these and other organizations (i.e. CENRAP).
- **CASTnet –** Clean Air Status and Trends Network. A regional long-term monitoring program established in 1987 and administered and operated by EPA's Clean Air Markets Division and collects deposition data from air pollution. The National Park Service sponsors 27 monitor sites located in Class I areas.
- **CENRAP** – Central Regional Air Planning Association – Regional planning organization covering the central portion of the U.S, including states and tribal areas of Nebraska, Kansas, Oklahoma, Texas, Minnesota, Iowa, Missouri, Arkansas, and Louisiana.
- **CENRAP Case –** 2002 BaseG inventory developed by CENRAP for use in establishing the 2018 reasonable progress goals for regional haze SIPs. See BaseG.
- **CIRA** – Cooperative Institute for Research in the Atmosphere – Research institute contracted by the National Park Service to work on visibility information, including IMPROVE and VIEWS.
- **Class I Area** – Areas of special national or regional value, whether natural, scenic, recreational or historic, for which the Clean Air Act provides special protection. Mandatory Class I areas are managed either by the Forest Service, the National Park Service or Fish and Wildlife Service.
- **CMAQ** – Community Multiscale Air Quality model - an Eularian air quality grid model that simulates atmoshperic and surface processes affecting the transport, chemical transformation and deposition of air pollutants and their precursors; a contemporary of CAMx. An EPA supported moded used to support CAIR, and used regional planning organizations (i.e. CENRAP) to establish reasonable progress goals.
- **Coarse Particulate Mass –** Particulate mass with a diameter between 2.5 and 10 microns, between $PM_{2.5} – PM_{10}$.
- **CONCEPT –** CONsolidated Community Emissions Processing Tool. A model that calculates air pollutant emission inventories generating hourly speciated emissions on a gridded basis for input to an air quality model. A evolution of the EMS-2003 model, but with open source software and multiple levels of quality control.
- **Deciview** – A standard visual index defined in terms of the extinction coefficient that is linear with perceived changes in visibility. One to two deciviews is the smallest change in visibility that is perceptive to the human eye.
- **Extinction** – Attenuation of light due to scattering and absorption as it encounters a particle.
- **Extinction Coefficient** – See B_{ext}.
- **Dv** – see Deciview.

- **EDAS** – Eta Data Assimilation System – the data assimilation system associated with the Eta mesoscale weather forecast model.
- **EGU** – Electric Generating Unit. Any device that combusts solid, liquid, or gaseous fuel for the purpose of producing electricity for sale or for use onsite.
- **EC** – Elemental Carbon
- **EMS** – Emissions Modeling System – A model that calculates air pollutant emission inventories generating hourly speciated emissions on a gridded basis for input to an air quality model. The most current version of EMS available is EMS-2003.
- **EPA** – United States Environmental Protection Agency.
- **EVTAC** – Currently United Taconite LLC (UTAC).
- **FGD** – Fabric Filter/Flue Gas Desulfurization. A scrubber device to control SO_2 that uses an alkaline reagent to absorb and react to produce a solid compound. Typically applied to stationary coal- and oil-fired combustion units (i.e. utility and inductrial boilers)
- **FIPS** – Federal Information Processing Standards, a standard set of numeric codes issued by the National Insittute of Standars and Technology to ensure uniform identification of geographic entities throughout all federal government agencies.
- **FSI** – Furnace Sorbent Injection. A control technology that reduces SO_2 emissions by injecting a dry sorbent into the upper part of the furnace, where the sorbent reacts to form salts that are then removed by a fabric filter or electrostatic precipitator. This technology can reduce SO_2 by varying amounts depending on the application. In applications in Minnesota within the SIP, this technology can reduce SO_2 by 40%.
- **Glidepath** – another term for the Uniform Rate of Progress. See URP.
- **GREASD PiG** – An option in CAMx designed to treat the early chemical evolution of large NO_X point source plumes before oxidant production becomes important to facilitate source apportionment of particulate matter.
- **HYSPLIT4** - HYbrid Single-Particle Lagrangian Integrated Trajectory – Model for computing simple air parcel trajectories.
- **IC –** Initial conditions are the inputs at the start-up of the model run and should not appear in the results if the model run accounts for appropriate spin-up time.
- **Integrated Planning Model –** a model developed by ICF that EPA uses to evaluate future impact of pollution control policies on EGUs in combination with projected energy needs.
- **IPM3.0** – See Integrated Planning Model (version 3.0)
- **IMPROVE** – Interagency Monitoring of Protected Visual Environments – Cooperative program to monitor visibility in the Class I areas.
- **Ispat Inland Inc** – Currently ArcelorMittal Minorca Mine Inc.
- **LADCO** – Lake Michigan Air Directors Consortium – Air quality planning organization for Illinois, Indiana, Michigan, Ohio, and Wisconsin; conducts air quality technical assessments for and assists its member States on air quality issues.
- **Lb/MMBtu** – Pounds per million British thermal units, the measurement of heat created by burning any material
- **LNB** – Low NO_X Burner. A control technology that reduces NO_X by controlling fuel and air mixing in the burner, reducing peak flame temperature. Over-fire air (OFA) and SNCR can be added to LNB to increase NO_X removal efficiency. Depending on the application in Minnesota within the SIP, LNB/OFA can reduce NO_X by 40-50%.

- **MAR** – Marine (i.e. ore boats on Lake Superior), aircraft and recreational (i.e. snowmobiles) vehicles. See Nonroad.
- **Minnesota$_{\text{(MRPO)}}$ Case** – Minnesota modified MRPO 2002 Case (BaseK) inventory for use in source contribution modeling, performance evaluation and for the 2018 reasonable progress goals at Boundary Waters and Voyageurs for Minnesota's regional haze SIP.
- **$\mathbf{MM^{-1}}$** – Inverse megameters. The units for extinction coefficient.
- **MM5** – Mesoscale Meteorological Model – A numerical model for weather prediction from one kilometer to continental scales, developed by Pennsylvania State University/National Center for Atmospheric Research.
- **MRPO** – Midwest Regional Planning Organization – Regional planning organization for regional haze, covering the Midwest states (Illinois, Indiana, Michigan, Ohio, and Wisconsin). See LADCO.
- **MRPO 2002 Case** – The 2002 inventory developed by MRPO for use in establishing the 2018 reasonable progress goals for regional haze SIPs. See BaseK. Serves as the backbone of the Minnesota$_{\text{(MRPO)}}$ Case.
- **MRPO 2005 Case** – The 2005 inventory developed by MRPO for use in establishing the 2018 reasonable progress goals for regional haze SIPs. See BaseM.
- **Mton** – Megaton
- **$\mathbf{\mu g/m^3}$** – micrograms (or microns) per cubic meter
- **Natural Conditions** – Estimation of visibility in the absence of man-made influence.
- **NEI** – National Emission Inventory – Compilation of annual emissions by pollutant, source category by County for each State; EPA requires States to submit to EPA on a 3-year cycle.
- **$\mathbf{NH_3}$** – Ammonia
- **$\mathbf{NH_4}$** – Ammonium ion
- **$\mathbf{NO_3}$** – Nitrate ion
- **$\mathbf{NO}_X$** – Nitrogen oxides
- **Nonattainment** – Areas of the country designated by EPA where pollutant levels exceed national ambient air standards.
- **NonEGU** – an industrial point source that is not an EGU. See EGU.
- **Nonroad** – mobile equipment not traveling on roadways (i.e. recreational vehicles, construction and agricultural equipment). Marine vessels, airplanes and locomotives are also considered nonroad sources, however, emission estimation techniques vary from those of other nonroad equipment. Emissions are assigned to grid cells
- **$\mathbf{NO_X}$** – Nitrogen Oxides. The sum of nitric oxide and nitrogen dioxide.
- **OC** – Organic Carbon
- **Onroad** – mobile sources, automobiles and trucks that travel on paved roadways. Emissions are assigned to a grid cell
- **PiG** – Plume in Grid, a module within CAMx to treat the early dispersion and chemistry of point source plumes.
- **Plume-in-Grid** – See PiG
- **$\mathbf{PM_{2.5}}$** – Fine particulate mass with a diameter less than or equal to 2.5 microns.
- **$\mathbf{PM_{10}}$** – Particulate mass with a diameter less than or equal to 10 microns.
- **Point Sources** – industrial sources that are identified by locational coordinate and stack parameters (i.e. facilities with state permits). Emissions are assigned to a grid cell based on

the locational coordinate of the stacks, except in cases where PiG is applied (emissions directly released from the stack).

- **Potlatch Corp** – currently Ainsworth Engineered (USA) LLC.
- **PSAT** – Particulate Matter Source Apportionment Technology, a tool within CAMx that tracks the original source of particulate species by geographic region and source category.
- **PSD** – Prevention of Significant Deterioration; a program established by the Clean Air Act that limits the amount of additional air pollution that is allowed in Class I and Class II areas.
- **Rayleigh Scattering** – The scattering of light by particles smaller than the wavelength of light that is scattered.
- **Reasonable Progress Goal** – State established interim goals, expressed in deciviews, representing incremental visibility improvement over time toward the ultimate goal of natural conditions.
- **Regional Haze** – A cloud of aerosols extending up to hundreds of miles across a region impairing visibility.
- **Relative Response Factor** – the ratio of the future year $PM_{2.5}$ air concentrations to the base year concentrations predicted near a monitor location and averaged over the 20 percent best or 20 percent worst days.
- **RH** – Relative Humidity
- **ROFA** – Rotating Opposed Fire Air System. A boosted injection of over-fire air in the boiler or furnace to reduce NO_X. Flue gas mixes with added air in the presence of heat, improving particle burnout in the upper furnace therefore reducing NO_X. Typically applied to coal fired power plants. ROFA can reduce NO_X about 50%.
- **RPG** – See Reasonable Progress Goal
- **RPO** – Regional Planning Organization
- **RRF** – See Relative Response Factor
- **SCC** - Source Classification Code – Code used by EPA to classify different types of anthropogenic emission activities.
- **SCR** – Selective Catalyic Reduction. Flue gases are direceted through a reaction unit containing a catalyst while ammonia is injected into the inlet gas stream. The ammonia reacts with NO_X in the presence of oxygen to form nitrogen and water. This technology can achieve from 70-90% control of NO_X depending on the application.
- **SIC** – Standard Industrial Classification codes are standardized codes that indicate a company's type of business.
- **SIP** – State Implementation Plan
- **SMOKE** – Sparse Matrix Object Kernel Emission – EPA supported model to process and prepare emission data for air quality model input.
- **SNCR** – Selective Non-Catalytic Reduction. An add-on technology to control NO_X. When applied to boilers, ammonia is injected into the furnace above the combustion zone, where it reacts with NO_X to reduce it to N_2 and water. In applications in Minnesota within the SIP, this technology can reduce NO_X by 40%.
- **SO_2** – sulfur dioxide.
- **SO_4** – sulfate ion.
- **STN** – Speciation Trends Network. EPA monitoring network that began in 1999 and provides speciated, urban fine particle data.
- **TPY** – Tons per year

- **TSD** – Technical Support Document
- **URP** – Uniform Rate of Progress – The linear rate of visibility improvement from the 2000-2004 baseline period to natural conditions in 2064 at each Class I area.
- **UTAC** – United Taconite LLC, formerly EVTAC.
- **UTM** – Universal Transverse Mercator
- **VIEWS** – Visibility Information Exchange Web System – Web repository of visibility information. http://vista.cira.colostate.edu/views/
- **VISTAS –** Visibility Improvement States and Tribal Association of the Southeast. The RPO consisting of the States and Tribal areas within Alabama, Tennesee, Virginia, West Virginia, Georgia, Kentucky, Florida, Mississippi, North Carolina and South Carolina.
- **VOCs** – Volatile Organic Compounds.
- **WRAP** – Western Regional Air Partnership. The RPO consisting of the States and Tribal areas within Arizona, California, Colorado, Idaho, Montana, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington and Wyoming.