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Cumulative Impacts Analysis

Minnesota Iron Range Industrial Development Projects

Assessment of Potential Visibility Impacts in Federal Class I Areas in Minnesota

Submitted in Support of the
NorthMet Mine and Ore Processing Facilities Project
Environmental Impact Statement

November 2006

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Overview

The environmental impact statements for PolyMet Mining Inc.'s NorthMet Project in Hoyt Lakes, Minnesota, and the Minnesota Steel project near Nashwauk, Minnesota, both require a series of similar cumulative impact assessments. Therefore, one report was prepared for both projects. This report evaluates whether the cumulative air emissions from these two projects and other currently proposed projects in northeast Minnesota are likely to cause or contribute to visibility impairment in the federal "Class I" areas, taking into account likely future national and state emission reductions.

The proposed projects would emit a small fraction of the visibility-impairing pollutants emitted in the state. Based on the cumulative impact assessment, the emission increases from the proposed projects will not harm visibility in Minnesota's Class I areas because, overall, national, state, and local emissions from existing facilities are likely to decline over the next decade. With these anticipated future emission reductions, visibility is likely to continue to improve.

Regional Haze

Persistent, widespread visibility impairment in areas like national parks is caused primarily by fine particles, typically aerosols. Coarse particles (predominantly soil dust) and gaseous nitrogen dioxide also can play a role in some areas. Fine aerosol particles consist almost entirely of just five pollutants: sulfates, nitrates, organics, elemental carbon and soil dust. In July 1999, the U.S. Environmental Protection Agency (EPA) published regulations intended to improve visibility in the nation's largest national parks and wilderness areas. This EPA rule, known as the Clean Air Visibility Rule, sets visibility goals for these "Class I" areas. The long-term goal is to reach natural background in all Class I areas by 2064. Minnesota has two Class I areas: the Boundary Waters Canoe Area (BWCA) and Voyageurs National Park (Voyageurs).

Measuring Visibility

Because visibility is difficult to measure directly, it usually is estimated from monitored ambient particulate concentrations. Measured concentrations of each of the major particulate components are multiplied by a specific factor to arrive at a total "light extinction coefficient." Higher light extinction coefficients indicate decreased visibility. EPA also uses a visibility metric called "deciviews." Deciviews are a logarithmic conversion of light extinction coefficients that reflect

more accurately how humans perceive visibility impairment. Visibility impairment often varies significantly from week to week and season to season.

Data Trends

As part of a nationwide monitoring network, particulate concentrations are measured at one site in the BWCA and at one site in Voyageurs. Based on these data, visibility in the BWCA has improved by about 16% between 1992 and 2004. Visibility also appears to have improved similarly in Voyageurs. This improvement is mostly due to a reduction in the concentrations of sulfate particulates, although nitrate particulate concentrations also have declined. Concentrations of organic particulates also contribute to reduced visibility in the summer in the BWCA and Voyageurs. The source of the summertime increase in organic particulate matter may be due, in part, to wildfires.

The Central Regional Air Planning Association (CENRAP) and others are trying to pinpoint the primary sources of visibility-impairing particulates in the BWCA and Voyageurs as part of their multi-state, regional modeling efforts. These efforts are an ongoing part of the implementation of the federal Clean Air Visibility Rule. Although final results are not yet available, local industrial sources in northeast Minnesota appear to have a limited impact on visibility in the BWCA and Voyageurs. For example, initial modeling and other studies indicate that 65% to 90% of the secondary sulfate and nitrate particulates in Minnesota Class I areas are formed from sulfur dioxide and nitrogen dioxide emitted by sources located outside the state—primarily in the eastern United States and Canada. This is significant because it indicates that northeast Minnesota sources have a small impact on visibility in nearby Class I areas. Just as important, however, this also indicates that statewide and nationwide emissions are important in evaluating cumulative impacts.

Future Emission and Visibility Trends

All of the proposed projects will be required to install pollution controls to minimize emissions of the pollutants that can decrease visibility. Estimated potential emissions from the proposed projects represent a small fraction, less than 1.5%, of existing statewide emissions of visibility-impairing sulfur dioxide or nitrogen oxides.

Increasingly strict state and federal air emission regulations are expected to continue to reduce sulfur dioxide and nitrogen oxide emissions from existing sources over the next decade, both nationally and statewide. These expected large emission reductions will, in turn, continue to reduce sulfate and nitrate particulate concentrations in northeast Minnesota. Also, over the next decade, currently proposed voluntary emission reductions at existing electricity generation plants in northeast Minnesota will more than offset the maximum emission increases expected from the proposed projects. Additional emission reductions from nearby existing sources are likely, due to various regulatory requirements.

Therefore, it also appears likely that visibility in the BWCA and Voyageurs will continue to improve even if all the currently proposed Iron Range projects are constructed as planned. Independent of this project, the state is working to develop a plan to reduce visibility impairing emissions to achieve interim "reasonable progress" visibility goals by 2018. Consistent with these goals, this report indicates that continued emission reductions from existing sources should allow both continued industrial development on the Iron Range and reasonable progress towards reaching natural background visibility conditions in the BWCA and Voyageurs.

Executive Summary

The Minnesota Department of Natural Resources is responsible for preparing an Environmental Impact Statement (EIS) for the following two Iron Range projects:

1. PolyMet Mining Inc.'s NorthMet Project in Hoyt Lakes, Minnesota; and
2. Minnesota Steel LLC's mining, direct-reduced iron and steel mill project near Nashwauk, Minnesota.

The scope of the EIS for both projects requires a series of cumulative impact assessments covering a range of environmental issues. These assessments are to address not only the impacts of these two projects but also that of other past and "reasonably foreseeable" proposed projects. In addition, the projects' potential cumulative air-quality impacts are to be evaluated within the context of increasingly strict state and federal regulations to be implemented over the next decade. In a separate report, the projects' potential cumulative impacts on concentrations of particulate matter less than 10 microns (PM_{10}) in the Boundary Waters Canoe Area Wilderness Area (BWCA) and Voyageurs National Park were evaluated. This report evaluates whether the projects' cumulative air emissions are likely to cause or contribute to visibility impairment in the federal "Class I" areas, taking into account likely future emission reductions from existing sources located in Minnesota and nationwide.

Causes of Haze

Persistent, widespread visibility problems in areas like national parks are primarily caused by fine particles less 2.5 microns in diameter ($PM_{2.5}$). Coarse particles (predominantly soil dust) and gaseous nitrogen dioxide (NO_2) can also contribute in some areas. Fine aerosol particles consist almost entirely of just five pollutants: sulfates, nitrates, organics, elemental carbon, and soil dust. Most of the visibility impairment in the BWCA and Voyageurs is due to sulfates, nitrates and organic compounds. These compounds are not typically emitted directly but are formed in the atmosphere through chemical reactions. Sulfur dioxide forms sulfate, and nitrogen oxides and ammonia form nitrates. Volatile organic compounds react to form secondary organic compounds which condense into fine particulate matter. Consequently, the air emissions from man made sources most often responsible for regional haze are sulfur dioxide, nitrogen oxides,

primary volatile organic particles, gaseous volatile organic compounds, elemental carbon, soil-material, and ammonia.

Regional haze is not necessarily caused by local emissions, nor does it depend on stagnant meteorological conditions. In the absence of precipitation, fine aerosol particles (and their gaseous precursors) can exist in the atmosphere for many days and can be carried great distances by winds. Therefore, regional haze is often primarily caused by conversion and transport of gaseous precursor emissions from distant sources. In addition, organic particles are produced as primary emissions from natural sources such as wildfire smoke, plant waxes, and pollen and as a result of conversion of volatile organic compound emissions such as terpenes and other hydrocarbons from trees and other natural sources.

Visibility Metric

For a variety of reasons, measuring and reporting visibility impairment can be complex. First, visibility is usually described in units called "light extinction coefficient" or "deciview." Deciviews are a logarithmic conversion of light extinction coefficient that more accurately reflects how humans perceive visibility impairment. Second, instead of being measured directly, visibility is usually indirectly estimated from monitored ambient particulate concentrations. The reconstructed light extinction coefficient is calculated by multiplying the six major particulate components by component-specific light extinction efficiencies. Finally, visibility impairment often varies significantly from week to week and season to season. Therefore, visibility data is routinely reported not as an annual average but as that measured on "20% worst," "median," and "20% best" days.

Regulatory Background

In July 1999, the U.S. Environmental Protection Agency (EPA) published regulations intended to improve visibility in the nation's largest national parks and wilderness ("Class I") areas. On June 15, 2005, EPA issued final amendments to its July 1999 rule. This rule and amendments are referred to as the Regional Haze Rule, or the Clean Air Visibility Rule. Minnesota has two Class I areas – the Boundary Water Canoe Area Wilderness and Voyageurs National Park. The 2005 EPA amendments require emission controls known as Best Available Retrofit Technology, or BART, for certain industrial facilities emitting air pollutants that reduce visibility. Also, by

December 2007, the Minnesota Pollution Control Agency (MPCA) must submit to EPA a State Implementation Plan (SIP) that identifies sources that contribute to visibility impairment in these areas and demonstrate reasonable progress toward reaching a specific 2018 visibility goal.

Report Scope

The proposed Iron Range projects' potential cumulative impacts on particulate concentrations (PM_{10}) in Minnesota's Class I areas were evaluated in a separate cumulative impact report. The PM_{10} report includes details regarding the currently proposed Iron Range projects and their potential emissions, historical and current concentrations of relevant particulate species in Minnesota Class I areas, local, state and national emission trends, and a summary of ongoing and future regulations that are likely to drive emission trends over the next decade. This visibility report, which focuses on visibility trends and impacts, summarizes but does not repeat this detailed information.

Summary Findings and Conclusions

1. **Class I Area Visibility Gradually Improving.** Between 1992 and 2004, visibility in the BWCA on the 20% worst days improved from 21.4 deciviews to 19.8 deciviews, based on a rolling five-year average. This 1.6 deciview reduction is equivalent to about a 16% improvement in visibility. Visibility also appears to have improved by more than 2.0 deciviews in Voyageurs, although continuous data at a single site are not available at Voyageurs as they are in the BWCA.

2. **Sulfate Particles Are Largest Contributor**. Sulfate particulates are the largest contributor to visibility impairment in the BWCA year round. Organic carbon particulates are the second largest contributor in warm weather months (April through September). Nitrates are the second largest contributor in cold weather months (October through March). Elemental carbon, soil, coarse particulate matter and gaseous species are minor contributors.

3. **Improvement Due to Reduced Sulfate and Nitrate Particulates.** The 1.6 deciview improvement in the BWCA on the 20% worst visibility days is mostly due to a reduction in sulfate particulate concentrations, although nitrate particulate concentrations also declined. Between 1992 and 2004, the calculated light extinction coefficient due to sulfate particulates declined by 24%, and the extinction coefficient due to nitrate particulates declined by 22%.

Changes in organic carbon concentrations did not significantly impact visibility in the BWCA, although organic carbon concentrations did decline in Voyageurs.

4. **Impairment Mostly due to Out of State Emissions.** Local industrial sources have a limited impact on visibility in BWCA and Voyageurs, based on $PM_{2.5}$ data and preliminary regional modeling and back-trajectory analyses. Modeling and other studies indicate that 65% to 90% of the secondary sulfate and nitrate particulates in Minnesota Class I areas are formed from SO_2 and NO_x emitted by many sources located outside the state—primarily in the eastern United States and Canada. The source of the increase in organic carbon fine particulates in the summer is not clear, but may be due in part to wildfires.

5. **Local Emissions have Limited Impact.** MPCA emission inventory data indicate that point source air emissions of both SO_2 and direct PM_{10} in northeast Minnesota have increased somewhat since 2001. Over the same time period, however, sulfate particulate concentrations and visibility have not changed significantly in the BWCA and Voyageurs. In part, this may be because 30% to 70% of the direct PM_{10} emitted by taconite facilities are relatively larger fugitive emissions that deposit within a mile of the facility. It is also likely that local SO_2 and NO_x emissions do not transform into secondary particulates fast enough to affect the nearby BWCA or Voyageurs.

6. **National Emission Reductions Likely to Drive Further Improvement.** Worst-case total potential emissions from the proposed Iron Range projects represent a comparatively small increase in statewide emissions: less than 1% of PM_{10}, 1.5% of SO_2, and 1.3% of NO_x emissions, currently, statewide. Over the next decade, voluntary and mandatory reductions in SO_2, NO_x and direct particulate emissions from existing sources in Minnesota and nationwide are likely to more than offset emissions from the proposed projects. More importantly, continued nationwide emission reductions over the next decade will likely allow for both industrial growth on the Iron Range and reasonable progress toward visibility goals in the nearby Class I areas.

1.0 Introduction

The Minnesota Department of Natural Resources is responsible for preparing an Environmental Impact Statement (EIS) for the following two Iron Range projects:

1. PolyMet Mining Inc.'s NorthMet Project in Hoyt Lakes, Minnesota; and
2. Minnesota Steel LLC's mining, direct-reduced iron and steel mill project near Nashwauk, Minnesota.

The scope of the EIS for both projects requires a series of cumulative impact assessments covering a range of environmental issues. These assessments are to address not only the impacts of these two projects but also that of other past and "reasonably foreseeable" proposed projects. In addition, the projects' potential cumulative air-quality impacts are to be evaluated within the context of increasingly strict state and federal regulations to be implemented over the next decade.[1] The scope of the air-quality related cumulative impact assessments required for the NorthMet Project and Minnesota Steel's project are essentially identical and were combined into one report.

As required by the EIS scope documents, a semi-quantitative emission trend analysis to assess whether the projects have the potential to contribute significantly to visibility impairment in the Federal Class I areas in Minnesota (Voyageurs National Park and the Boundary Waters Canoe Area Wilderness Area) was used.

1.1 Regional Haze and Visibility Impairment – Background

This section summarizes the issue of regional haze, the sources and types of visibility impairing particulate matter, visibility measurement methods and the applicable federal regional haze regulations.

1.1.1 What is Regional Haze?

As defined by EPA,[2] "regional haze" is visibility impairment caused by the cumulative air pollutant emissions from numerous sources over a wide geographic area. Visibility impairment

[1] MDNR 2005a,b,c
[2] EPA 2003

is primarily caused by very small particles, usually less than 10 microns in diameter (PM_{10}), including solid particles and liquid or aqueous aerosols.

PM_{10} can be divided into coarse and fine particulate fractions. The primary cause of regional haze in many parts of the country is light scattering resulting from fine particles (i.e., particulate matter less than 2.5 microns in diameter, referred to as $PM_{2.5}$) in the atmosphere.[3] Coarse particles between 2.5 and 10 microns in diameter can contribute to light extinction. However, larger coarse particles tend to settle out from the air more rapidly than fine particles and usually will be found relatively close to their emission sources.[4]

Visibility impairing particulates can also be categorized based on whether the particulate matter is emitted directly into the atmosphere or is indirectly formed when gaseous air pollutants react in the atmosphere[5]. These two major categories of particulate matter are called "primary particulate matter" and "secondary particulate matter."

- **Primary PM** consists of carbon (soot) — emitted from many sources including smokestacks, cars, trucks, heavy equipment, forest fires, and burning waste and crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations.
- **Secondary PM** forms due to chemical reactions in the atmosphere of gases. Some of these reactions require sunlight and/or water vapor in order to occur. Secondary PM includes: sulfates formed from sulfur dioxide emissions; nitrates formed from nitrogen oxide emissions; carbon formed from reactive organic gas emissions. Sulfur dioxide and nitrogen oxides are emitted from power plants, industrial facilities, cars and trucks. Organic gas emissions are emitted from these sources as well as from forest fires and biogenic sources such as trees.

The fine particulate fraction ($PM_{2.5}$), which usually consists of secondary particulates, can be transported long distances by wind and weather and can be found in the air thousands of miles from where they were formed and can contribute to visibility problems at remote locations, such

[3] EPA 2003
[4] EPA 2004b; MPCA 2005d
[5] EPA 2004b

as national parks[6]. The coarse fraction (particles with a diameter between 2.5 and 10 μm) is usually made up of primary particulates[7].

1.1.2 Fine Particulate Emission Sources

The air emissions most often responsible for regional haze are sulfur dioxide (SO_2, precursors of SO_4- particles), nitrogen oxides (NO_x, precursors of nitrate aerosols and NO_2), primary volatile organic particles, gaseous VOCs (precursor of secondary organic particles), elemental carbon, soil-material, and ammonia (NH_3) (a precursor of ammonium nitrate). Each of these components can be naturally occurring or the result of human activity. The natural levels of these species result in some level of visibility impairment in the absence of any human influences, and will vary with season, daily meteorology, and geography (EPA 2003b).

The major anthropogenic sources of atmospheric fine particles (less than 2.5 microns) and their major mission sources are described in detail in the PM_{10} cumulative impact report.[8] A summary of the major sources of the various species of fine particulate is provided below in Table 1.

[6] EPA 1997, EPA 2004b
[7] EPA 2003a; EPA 2004b
[8] Barr 2006

Table 1 Atmospheric Fine Particles ($PM_{2.5}$) and Their Major Emission Sources

Atmospheric Pollutant	Primary Sources		Secondary Sources	
	Natural	Man Made	Natural	Man Made
Sulfate (SO_4)	Sea spray	Fossil Fuel combustion	SO_2 from volcanoes, oceans, wetlands	SO_2 from fossil fuel combustion
Nitrate (NO_3)	N/A	Motor vehicle exhaust, fossil fuel combustion	NOx from soils, forest fires, lighting	NOx from fossil fuel combustion, vehicle exhaust, prescribed burning
Organic Carbon	Wildfires	Open burning, wood burning, prescribed burning, motor vehicles, incineration, tire wear	Oxidation of Hydrocarbons (terpenes and waxes) emitted by vegetation and wildfires	Oxidation of hydrocarbons by vehicles, open burning, wood burning, fuel storage, solvent use
Ammonia (NH3)	N/A	Motor vehicle exhaust		Animal agriculture, sewage, fertilizer

Reference: USEPA, 1997

1.1.3 How is Visibility Impairment Measured?

Visibility cannot be fully defined by a single parameter; therefore, monitoring only one indicator is not sufficient.[9] Visibility has historically been characterized either by visual range or by the light extinction coefficient. These two measures of visibility are inversely related; visual range decreases as the extinction coefficient increases. Visual range is presented in common units such as miles or kilometers and is commonly used in transportation safety, for example by providing information to determine the minimum distance required to land an aircraft.

All visibility monitoring programs photographically document the appearance of a scene under various levels of visibility. Visibility monitoring also includes instruments to record optical characteristics of the atmosphere and the composition of visibility reducing aerosols. Most often optical instruments measure either the scattering or extinction coefficient.

[9] NPS 1998

Extreme caution, however, must be applied when interpreting visual range data from historical sources where human observations were the source of the data (e.g., airport observations). The varying methods and procedures used by observers, the quality of the observer measurements, and the availability of adequate visibility targets all can have a dramatic effect on historical, observer-based data.

Light Extinction Coefficient

Because of the complications involved in direct measurements of visibility, most scientists use an indirect method to calculate extinction coefficient. Calculations of extinction coefficient are possible because there are direct relationships between concentrations of atmospheric constituents and their contribution to the extinction coefficient. Reconstructed extinction is expressed as the atmospheric concentration of species i ($\mu g/m^3$), summed for all light-interacting species (i.e., sulfate, nitrate, organic carbon, elemental carbon, other fine particles, coarse particles, other suspended particles, and NO_2). The above units, when multiplied by the appropriate coefficients, yield units for b_{ext} of $10^{-6}\ m^{-1}$ or $(10^6\ m)^{-1}$, or as typically labeled, inverse megameters (Mm^{-1}).

The total light extinction coefficient (b_{ext}) is the sum of the light scattering coefficient (b_{scat}) and the light absorption coefficient (b_{abs}). Apportioning the extinction coefficient to atmospheric constituents provides a method to estimate the change in visibility caused by a change in constituent concentrations. This methodology, known as extinction budget analysis, is important for assessing the visibility consequences of proposed pollutant emission sources or for determining the extent of pollution control required to meet a desired visibility condition.

As described in detail in Section 3.1 below, light scattering is the sum of the scattering caused by gases (b_{sg}) and the scattering caused by suspended particles (b_{sp}) in the atmosphere (aerosols). However, natural Rayleigh scatter (b_{Ray}) from air molecules (which causes the sky to appear blue) dominates the gas scattering component. Particle scatter (b_{sp}) can be caused by natural aerosol (e.g., wind-blown dust and fog) or by man-made aerosols (e.g., sulfates, nitrates, organics, and other fine and coarse particles).

Light absorption results from gases (b_{ag}) and particles (b_{ap}). Nitrogen dioxide (NO_2) is the only major light absorbing gas in the lower atmosphere; its strong wavelength-dependent scatter

causes yellow-brown discoloration if present in sufficient quantities. Soot (elemental carbon) is the dominant light absorbing particle in the atmosphere. Thus, the total light extinction is the sum of its components: suspended particles in the atmosphere (i.e., collectively known as aerosols) usually account for the dominant part of light extinction except under extremely clean conditions, when natural Rayleigh gas scattering predominates.

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program has monitored visibility throughout the United States using a reconstructed light extinction coefficient. Monitoring in Minnesota began in 1991. The detailed IMPROVE light extinction coefficient calculations and assumptions are provided in Section 3, below.

Haze Index (Deciview)

Neither visual range nor extinction coefficient measurements are linear with respect to the human perception of visual scene changes caused by uniform haze. For example, a given change in visual range or extinction coefficient can result in a scene change that is either unnoticeably small or very apparent depending on the baseline visibility conditions. Presentation of visibility measurement data or model results in terms of visual range or extinction coefficient can lead to misinterpretation by those who are not aware of the nonlinear relationship.

Therefore, using the relationship of a constant fractional change in extinction coefficient to perceived visual change, a new visibility index called deciview (dv) was developed. The deciview is a unit of measurement of haze, implemented in a haze index (HI), which is derived from calculated light extinction, and is designed such that uniform changes in HI correspond approximately to uniform incremental changes in perception, across the entire range of conditions, from pristine to highly impaired.[10]

The scale of the visibility index, expressed in deciview (dv), is linear with respect to perceived visual changes over its entire range, analogous to the decibel scale for sound. A one deciview change represents a change in scenic quality that would be noticed by most people regardless of the initial visibility conditions. A deciview of zero equals clear air, while deciviews greater than

[10] EPA 2003

zero depict proportionally increased visibility impairment.[11] For example, a value of 29 dv represents more visibility impairment than does a value of 11 dv.

The *HI* is defined by the following equation:

$$HI = 10 \ln\left(\frac{b_{TOTAL}}{10}\right)$$

where b_{TOTAL} is expressed in inverse megameters, or Mm^{-1}.[12] One dv change is approximately a 10% change in extinction coefficient, which is a small, but perceptible scenic change under many circumstances. The deciview scale is near zero (0) for a pristine atmosphere (dv = 0 for a Rayleigh condition at about 1.5 km elevation) and increases as visibility is degraded. Like the decibel scale for sound, equal changes in deciview are equally perceptible. Because the deciview metric expresses visual scene changes that are linear with respect to human perception, EPA supports the use of the deciview metric in characterizing visibility changes for regulatory purposes.

1.1.4 Federal Regional Haze Rule

Section 169A of the 1977 Clean Air Act Amendments (CAAA) established a national visibility goal to remedy existing impairment and prevent future impairment in 156 National Parks and wilderness areas across the country designated as mandatory Federal Class I areas. The EPA issued initial visibility regulations in 1980[13] that addressed visibility impairment in a mandatory Federal Class I area that is "reasonably attributable" to a single source or small group of sources.[14]

Then, to address widespread regional haze problems, the U.S. Environmental Protection Agency (U.S. EPA) published regulations to address visibility impairment in the nation's largest national parks and wilderness ("Class I") areas in July 1999. This rule is commonly known as the "Regional Haze Rule"[15] and is found in 40 CFR part 51, in §§ 51.300 through 51.309. In June 15, 2005, EPA issued final amendments to its July 1999 rule, now known as the "Clean Air Visibility Rule" or CAVR, including Appendix Y to 40 CFR part 51 "Guidelines for BART

[11] NPS 1998
[12] Pitchford and Malm, 1993
[13] 45 Federal Register 80084, Dec. 2, 1980
[14] EPA 2003
[15] 64 Fed. Reg. 35714 (July, 1999)

Determination Under the Regional Haze Rule." The MPCA has subsequently prepared a BART strategy for Minnesota sources and is in the process of moving forward with that strategy.[16]

Under these rules, by December 2007, Minnesota must submit to EPA a Regional Haze State Implementation Plan (SIP) that identifies sources that cause or contribute to visibility impairment in these areas. The Regional Haze SIP must also include a demonstration of reasonable progress toward reaching the 2018 visibility goal for each of the state's Class I areas.

In addition, the federal new source review (NSR) program generally requires air permit applicants to conduct a source impact analysis. For the NSR program, the impact analysis must demonstrate that the new or modified source will not cause or contribute to a violation of state or national air quality standards (NAAQS) or cause an adverse impact to visibility in any Federal class I area. Included in this impact analysis is the protection of Federal lands (national parks, wilderness areas, etc.) which have been designated as Class I areas for Prevention of Significant Deterioration (PSD) purposes. The EPA also administers several other programs designed to protect visibility including the secondary National Ambient Air Quality Standards (NAAQS) for PM_{10} and $PM_{2.5}$, and section 401 under the provisions for acid deposition control. EPA has also promulgated a series of related regulations likely to reduce "regional haze." See http://www.epa.gov/oar/visibility/actions.html.

Minnesota Class I Areas

Minnesota has two Class I areas – the Boundary Water Canoe Area Wilderness and Voyageurs National Park. The Class I areas in Minnesota are the current focus of this analysis due to their proximity to the proposed projects. Other Class I areas within 250 kilometers of the proposed Iron Range projects are Isle Royale National Park located to the northeast of the Iron Range off the northeast tip of Minnesota in Lake Superior and Rainbow Lake Wilderness located to the southeast of the proposed projects in northwest Wisconsin.

[16] MPCA 2005a

Rule Requirements

The federal Clean Air Visibility Rule includes the following key requirements:

- Certain emission sources "that may reasonably be anticipated to cause or contribute" to visibility impairment in downwind Class I areas are required to install Best Available Retrofit Technology (BART).

- Control strategy SIPs are due to EPA in 2007 – 2008, with individual states adopting progress goals for improving visibility from baseline conditions (represented by 2000 – 2004) to 2018 (represented by 2014 – 2018) for each Class I area in the state.
    - A state without any Class I areas will also need to adopt emission reduction strategies to address its contribution to visibility impairment problems in Class I areas located in other states.

- Specifically, a state is required to set progress goals for each Class I area in the state that:
    - Provide for an improvement in visibility for the most impaired (i.e., 20% worst) days over the period of the implementation plan; and
    - Ensure no degradation in visibility for the least impaired (i.e., 20% best) days over the same period.

- The reasonable progress goals must provide for a rate of improvement sufficient to attain natural (i.e., pristine) conditions by 2064, or justify any alternative to this rate based upon a number of factors to be considered by a state in developing the reasonable progress goals.
    - Reasonable progress goals are established by taking into account "reasonable progress factors", which include the costs of compliance, the time needed for compliance, the energy and non-air quality environmental impacts of compliance, and the remaining useful life of any existing source subject to such requirements.

- States will determine whether they are meeting their goals by comparing visibility conditions from one five-year rolling average to another (e.g., 2000-2004 to 2013-2017).

IMPROVE Monitoring Network and RPO's

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program has monitored visibility throughout the United States and has been operating in Minnesota since August 1991. After publication of the regional haze rule in 1999, the first step in the implementation process was the upgrade and expansion of the IMPROVE visibility monitoring network to 110 sites nationally. These sites were selected to represent all mandatory Federal

Class I areas.[17] Representative data from this network has been used to establish baseline conditions (for the 2000 – 2004 time period) for each Class I area and to track progress toward the goals to be established in each State's "State Implementation Plan" (SIP).

Five regional planning organizations (RPOs) have been formed to assist in implementing the regional haze rule. Minnesota belongs to the Central Regional Air Planning Association (CENRAP). These RPOs are newly defined entities that intend to respond to the transport of visibility-reducing pollutants within and across state and international boundaries. RPOs need to assess current haze conditions, establish baseline levels, specify and coordinate emissions reduction strategies, and evaluate the effectiveness of those strategies for the coming six decades. The goal is to achieve "natural" visibility conditions by 2065. Quantifying "natural" visibility levels beyond the defaults offered by EPA will be one of the major challenges faced by RPOs during its lifetime. Identifying the emissions sources causing excessive haze levels and determining where and when emissions reductions are needed to make reasonable progress is another major challenge.

States have joined the RPOs to develop state-specific budgets for pollutants leading to the formation of fine particles, with the requirement to develop state implementation plans (SIPs) by 2008 to reduce emissions within those budgets. Identifying the emission sources contributing to visibility impairment in a Class I area will be needed in order for states to develop their SIPs. Modeling results from CENRAP and the findings regarding the contributions of sources to visibility impairment in the Class I areas in Minnesota are presented and discussed later in this report.

1.2 Proposed Projects and Summary of Potential Emissions

Table 2 shows the estimated potential emissions of SO_2, NO_x, and PM_{10} from each of the proposed projects included in this analysis. Emission reductions due to the 2001 closure of the LTV Steel Mining Company (LTVSMC) taconite plant in Hoyt Lakes and other "reasonably foreseeable actions" are provided for comparison to the emissions estimated for the proposed projects. A detailed comparison of these projected emissions and future likely emission

[17] EPA 2003

reductions in the four-county area, the state, and nationwide is provided in a separate cumulative impact report assessing the projects' impact on PM_{10} increment in Class I areas.[18]

The PM_{10} emissions for the proposed projects include both stack and fugitive emissions. For regional haze and visibility impairment, emissions from high temperature stacks are considered to be of most importance due to their height of emission, potential buoyancy and ability to travel long distances. Fine particle emissions are typically associated with stack emissions. Fugitive emissions are typically coarse particulate and are most often ground-level emissions, having the potential for local air quality impacts near the facility, but likely not associated with impacts at distance from a facility.[19] For this report and the PM_{10} report,[20] however, past and project direct emissions of PM_{10} are used as a surrogate for direct emissions of $PM_{2.5}$ because readily available MPCA emissions inventory data only report PM_{10} emissions and $PM_{2.5}$ data are only available for 2004.

[18] Barr 2006
[19] EPA 2004b
[20] Barr 2006

Table 2. Maximum potential sulfur dioxide, nitrogen oxide, and particulate emissions from proposed projects in the four-county project area in comparison to selected likely statewide emission reductions. (Four-county project area = Itasca, St. Louis, Lake, Cook counties)

Project	Location In Minnesota	SO_2 (tpy)	NO_x (tpy)	PM_{10} [15] (tpy)	BACT/ MACT [16]
POTENTIAL INCREASES					
Cliffs Erie Railroad Pellet Transfer Facility [1]	Hoyt Lakes	0	0	140	No
Excelsior Energy, Mesaba Energy Project [2]	Subject to PUC Site Process	1300	2,822	478	Yes
Laurentian Wood Fired Energy Project [3]	Hibbing and Virginia	50	302	50	Yes
Mesabi Nugget DRI Plant [4]	Hoyt Lakes	417	954	514	Yes
Minnesota Steel Industries [5]	Nashwauk	539	1,599	1,525	Yes
Northshore Mining Company: Furnace 5 Reactivation [6]	Silver Bay	56	200	149	Yes
PolyMet Mining, NorthMet Project [7]	Hoyt Lakes	15	247	2,269	Yes
United Taconite – Emissions and Energy Reduction Project [8]	Forbes	0	0	14	Yes
UPM/Blandin Paper Mill Expansion: project Thunderhawk [9]	Grand Rapids	1	23	2	Yes
US-Steel Keewatin Taconite, Fuel Diversification and Pollution Control Upgrade [10]	Keewatin	35	35	-287	Yes
Total Potential Increases ("net")		2,413	6,182	4,855	
REDUCTIONS					
LTV Steel Mining Company: (Closure in 2001) [11]	Hoyt Lakes	1,150 [~4,500]	760 [~4,900]	3,720 [~11,079]	N/A
Minnesota Power – AREA Proposal [12] (voluntary action by 2009)	Aurora; Schroeder	3,552	3,745	--	Yes
Butler Taconite [14]	Nashwauk	n/a	n/a	1,372	N/A
Total Estimated Actual Reductions ("net")		4,702	4,505	5,092	
Net Emissions, Net Emissions = Total Potential Increases - Total Estimated Reductions		(-2,289)	1,677	(-237)	

Prepared September 2005; updated July 2006:

[1] Estimated limited emission increase from modification; PTE increase for permitting purposes is -3.8 tons per year due to contemporaneous decrease in PTE from shutdown of currently idled "LTV" equipment, from Technical Support Document for Air Emissions Permit No. 13700009-005, Table 1.

[2] Preliminary emission estimates (Phase I and Phase II) based on emission factors and heat inputs provide on Excelsior Energy Web site, www.excelsiorenergy.com, accessed on October 28, 2005.

[3] Potential to emit from Technical support documents for Virginia Public Utilities (MPCA permit #13700028-005) and Hibbing Public Utilities (MPCA permit #13700027-003)

[4] Mesabi Nugget's Proposed Direct Reduced Iron (DRI) Facility: No crushing/grinding at the site; receive concentrate from off-site. Air Permit Application, May 2005.

[5] SO_2 and NO_x estimates are expected updates to air permit application, which assume controlled emissions for the pellet plant and DRI plant.

[6] Northshore Mining's Furnace 5 Project: reactivating 2 crushing lines, 9 concentrating lines, one pellet furnace (Furnace 5); new sources emissions only; EAW Table 6 (May 20, 2005).

[7] PolyMet Mining's Proposed Facility: crushing/grinding of ore, reagent and materials handling, flotation, hydrometallurgical processing. Emissions from Scoping EAW Tables 23-2, 23-3, NO_x emissions: very conservative estimates of emissions because natural gas fired boilers operating at maximum capacity to generate heat and steam for all processes. Process changes have occurred since public notice of the EAW that affect particle emissions. Additional changes are likely to occur prior to finalizing the air permit. The current conservative estimate of PM_{10} emissions for the proposed NorthMet project is 2,269 tons/year (1,170 tons/year stack emissions, 52%; 1,099 tons/year fugitive emissions, 48%). Final emission calculations will be submitted in support of the air permit application.

[8 United Taconite – A minor permit amendment has been submitted to the MPCA. The projected increase in actual PM_{10} emissions, for PSD permitting purposes, is 14 tons/yr. The maximum permitted PM_{10} emissions are not yet available from the MPCA. The project is also expected to reduce NO_x emissions by ~ 2,000 tons/yr. However, since the permit amendment is only for PM_{10} emissions increase, the NO_x reduction is not included in this table. United Taconite LLC - Fairlane Plant, Forbes, Minnesota, MPCA, Permit Change/Modification Application Forms, Line 1 Emissions and Energy Reduction Project (EERP), September 2004.

[9] Difference in permitted allowable emissions from Blandin Project Thunderhawk Draft EIS, January, 2006.

[10] U.S. Steel Keewatin; Technical Support Document Permit Action #13700063-003, Dated 2/28/05

Table 2 footnotes (continued)

[11] LTVSMC: Actual past emissions as annual average emissions since 1996, from http://www.pca.state.mn.us/data/edaAir/index.cfm; downloaded on December 14, 2005. Permitted emissions (potential to emit) information from Technical Support Document for Air Emissions Permit No. 13700009-001, Table 1. Potential emissions are in parenthesis.

[12] MPCA, January 17, 2006, Review of Minnesota Power's Arrowhead Regional Emission Abatement (AREA) Project. Table 12. (MPCA 2006a). Just prior to the MDNR's Final Decision Document being made available to the public on October 25, 2005, Minnesota Power announced a major initiative to reduce pollutant emissions, including mercury, at several of its power plants in northern Minnesota. Due to the significance of the AREA project in regard to air emission reductions, this future project has been included in this analysis.

[13] Xcel Energy's Metropolitan Emission Reduction Project was approved by the Public Utilities Commission on June 13, 2006. SO_2 and NO_x emissions will be reduced by ~ 90%, and PM_{10} emissions will be reduced by more than 70%. Information from: MPCA 2002a; MPCA 2003.

[14] Butler Taconite facility closed in 1985. Estimates of SO_2 and NO_x emissions are not readily available, but historical PM_{10} data are available from earlier reports to the MPCA. Emission reduction of 1,370 tons/year PM_{10} is included (85% of 1,615 tons per year TSP assumed as PM10). From *Iron Range Air Quality Analysis*, MRI Draft Final Report to MPCA, MRI project No. 4523-L(2) June 5, 1979 (1976 inventory). Assumption of 85% TSP as PM_{10} based on Hannah Mining Co. (1980) submittal to MRI and MPCA dated August 8, 1980.

[15] PM_{10} emission estimates include point and fugitive emissions for all sources at a facility.

[16] MACT = Maximum Achievable Control Technology; BACT = Best Available Control Technology.

Abbreviations:

Tpy = tons per year;
BACT = Best Available Control Technology
MACT = Maximum Achievable Control Technology
SO_2 = sulfur dioxide
PM_{10} = particulate matter less than 10 micrometers in size
NO_x = nitrogen oxides
PUC = Public Utilities Commission
AREA = Arrowhead Region Emission Abatement
MERP = Metropolitan Emission Reduction Project
N/A = not applicable
DRI = Direct Reduced Iron

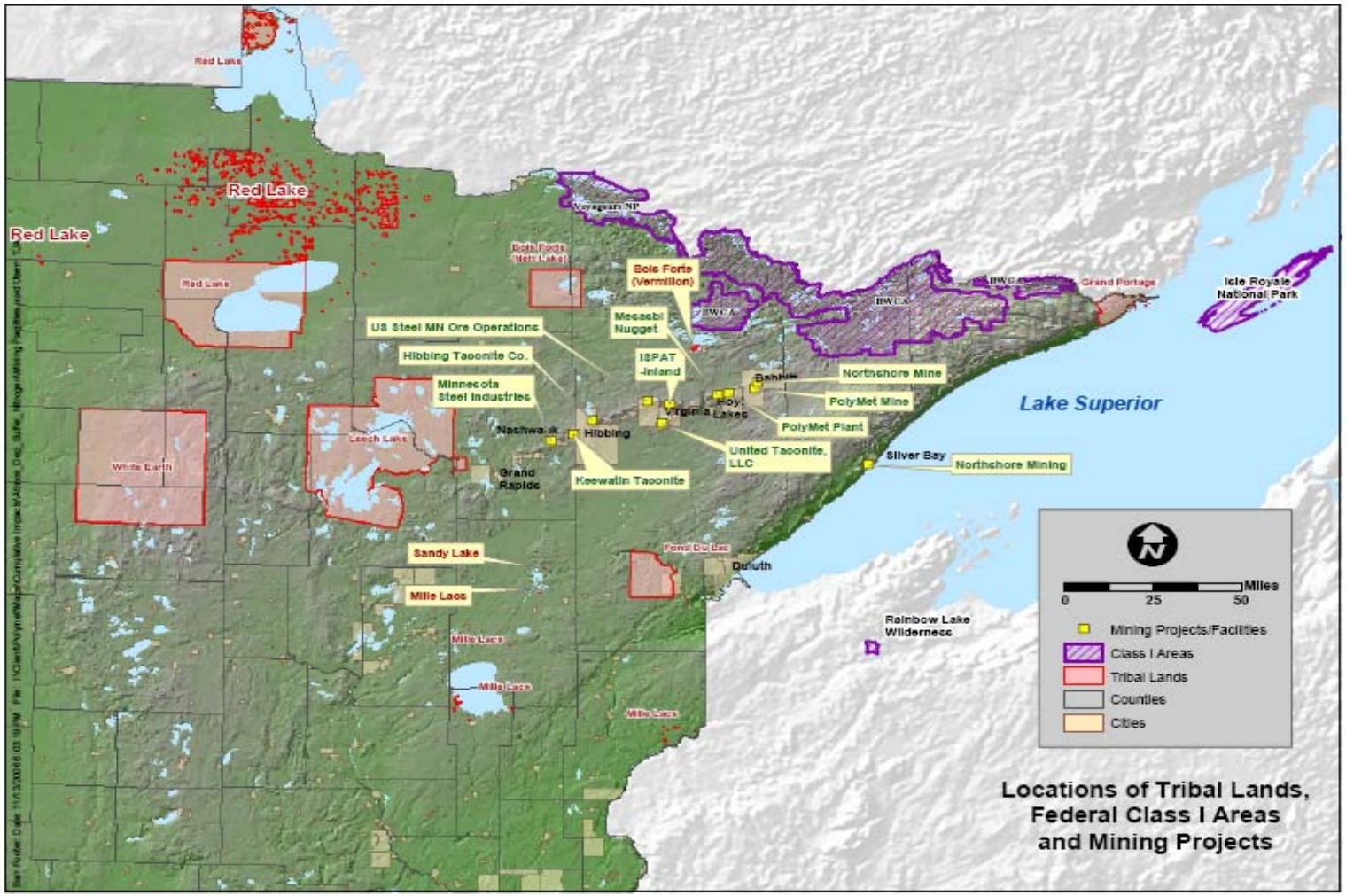
The MPCA emissions inventory data that is readily available to the public as of January 2006 and that has been used in this analysis is for total facility emissions and includes both fugitive emissions and stack emissions. For certain types of facilities, such as mining facilities, fugitive emissions can account for 50% or more of the particulate emissions. The inclusion of PM_{10} fugitive emissions in this analysis likely overestimates the potential cumulative impacts from the proposed projects in regard to the visibility impairment that is related to direct emissions of particulate (i.e., PM_{10}) since these emission typically fall out near where they are generated and would not reach the Class I areas.

Visibility protection in federal Class I areas is the responsibility of the Federal Land Managers (FLMs). Figure 1, on the following page, shows the general locations of the proposed projects in northeast Minnesota in relation to federal Class I areas within 250 kilometers of Minnesota's Iron Range, tribal lands, and existing taconite production facilities.

1.3 What Are "Cumulative Impacts"?

The Council on Environmental Quality's (CEQ) regulations, which implement the National Environmental Policy Act (NEPA), define "cumulative effects" as: "… The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-federal) or person undertakes such other actions. …" (40 CFR 1508.7). The Minnesota Environmental Quality Board environmental review rules use a similar definition for "cumulative impacts" instead of "cumulative effects" (see Minnesota Rules, part 4410.0200, Subp. 11).

Figure 1 **Locations of proposed mining projects in relation to Federal Class I Areas within 250 kilometers of the Iron Range, nearby Tribal Lands, and existing taconite mining operations in northeast Minnesota**



Some regulatory programs, in effect, require a form of quantitative cumulative impact assessment as part of a permit review. For example, air quality modeling of all significant nearby emission sources is required for "New Source Review" air permits. Likewise, water discharge permits often require the applicant to account for the impact of other discharges that affect the same water body as the proposed project. But for most cumulative impact issues, such as those to be addressed for the Minnesota Steel and PolyMet Mining EISs, there are only general guidelines. Therefore, the specific approach used to assess cumulative impacts must be developed case by case.[21]

1.4 Visibility Impairment "Cumulative Impact" Approach

The scope of the cumulative impact analysis for the Minnesota Steel EIS has some minor differences from the scope identified for the PolyMet Mining EIS with regard to the specific proposed projects to be included in the analysis and future regulatory actions to consider. However, the other details of the cumulative impact analysis are identical for each EIS[22]. Due to the essentially identical analyses to be conducted for each EIS, this analysis has been adjusted to accommodate the requirements of both projects and the results are presented in one report.

The assessment of potential cumulative impacts from the proposed projects is completed in essentially four parts:

1. Assess the Interagency Monitoring of Protected Visual Environments (IMPROVE) data for Voyageurs National Park and/or the Boundary Waters Canoe Area to provide the current status of PM_{10} air concentrations (depending on data availability), including a trends analysis (improvement, no change, or continued degradation given past, current and/or expected future emission reductions);

2. Assess available modeling results that identify emission sources and/or emission source regions as significant contributors to ambient air concentrations in the Class I areas located in Minnesota;

3. Evaluate statewide SO_2, NO_x, and PM_{10} emissions and trends using existing statewide emission inventory data (listing of sources and ton/year emissions). A detailed trend

[21] CEQ 1997
[22] MDNR 2005a,b,c

analysis providing a breakout of emissions by geographic area of the state is contained in a companion report on cumulative PM_{10}[23] and is not repeated here.

4. Evaluate the cumulative impacts from the proposed projects based on the potential increases in SO_2 and NO_x, and PM_{10} emissions in Minnesota from current and reasonably foreseeable projects and the projections for state and national emissions in regard to expected decreases in the future.

[23] Barr 2006

2.0 Analysis Boundaries

The 1997 CEQ Guidelines provide a minimum list of boundaries required to provide a coherent framework for a cumulative impact analysis. In this case, the following four analysis boundaries need to be defined:

1. The timeframe for the trends analysis, both past and future;
2. The list of specific past and future projects to be assessed in addition to the proposed project, including type, geographic limits, and project status;
3. The specific geographic area of concern ("zone of impact"), including resources, ecosystems, and populations of concern;
4. The extent and geographic limits of other sources that may affect resources in the zone of impact, for the specific issue under study;

1. Timeframe

The timeframe for this analysis is 1980 to 2020. This report summarizes historical emission rates and predicts expected future emission rates based on likely emission caps or other regulatory emission limits. More detailed summaries of past and future emission trends are provided in the companion PM_{10} cumulative impact report.[24] In this case, reliable visibility data from the IMPROVE network are only available from 1992 to 2004 (See Section 3.1). Future emission estimates are based on a comparison of existing emissions, and the likely impact of three categories of state and national regulations: existing ("on the books"), "on the way," or under consideration.

2. Proposed Projects and Reasonably Foreseeable Actions

Figure 1 shows the general locations of the "reasonably foreseeable" projects to be assessed for cumulative impacts, as well as the locations of existing taconite facilities and federally protected Class I areas. The projects selected as "reasonably foreseeable" are defined as those that are already underway, or for which a completed data portion of an environmental assessment worksheet has been submitted to the Minnesota Department of Natural Resources (MDNR) or the Minnesota Pollution Control Agency (MPCA). "Reasonably foreseeable actions" in regard to potential emission reductions include those regulatory actions that have been placed on public

[24] Barr 2006

notice by a government agency (e.g., draft rules or regulations) or there has been a submittal to a regulatory agency that provides details on a planned voluntary action being considered (e.g., Xcel Energy's Metropolitan Emission Reduction Project).

The following projects and actions are considered to be underway or "reasonably foreseeable":

- Proposed Projects:
    - Cliffs Erie Railroad Pellet Transfer Facility;
    - Excelsior Energy, Mesaba Energy Project, Coal Gasification Power Plant;
    - Laurentian Wood Fired Energy Project;
    - Mesabi Nugget Company, Direct Reduced Iron (DRI) Plant;
    - Minnesota Steel Industries, Mining/Taconite/DRI/Steel Plant;
    - Northshore Mining Company, Furnace 5 Reactivation Project;
    - PolyMet Mining, NorthMet Project;
    - United Taconite, Emissions and Energy Reduction Project;
    - UPM/Blandin Paper Mill Expansion, Project Thunderhawk, and
    - U.S. Steel-Keewatin Taconite, Fuel Diversification and Pollution Control Equipment Upgrade.

- Actions that reduce emissions:
    - Butler Taconite, facility closure* (1985);
    - LTVSMC Taconite Furnaces shutdown;
    - Minnesota Power Arrowhead Regional Emission Abatement (AREA) Project** (voluntary; proposed), and
    - Xcel Energy Metropolitan Emission Reduction Project (MERP) (voluntary; initiated).

*Butler Taconite was not identified in the list of actions in the original scope of work to be included in this cumulative impact analysis (MDNR 2005a,b,c). However, Minnesota Steel has proposed to locate its operations at the former location of the Butler Taconite operations and it is reasonable to account for the shutdown of the Butler operations in some manner in this cumulative analysis.

**Minnesota Power's AREA Project was not identified in the original scope of work in the list of foreseeable actions to be included in this cumulative analysis (MDNR 2005) because it had not yet been proposed. However, due to the significance of this voluntary action on emission reductions in northeast Minnesota, it is included in this analysis to provide additional perspective on the potential emissions from the proposed projects.

- Regulatory actions:
    - Implementation of the Taconite MACT;
    - Implementation of the Regional Haze Rule and Best Available Retrofit Technology (BART) Rule;

- Implementation of the Clean Air Interstate Rule (CAIR) Rule;
- The NOx SIP call (40 CFR parts 51, 72, 75, 96);
- EPA proposed rule for NOx in Class I areas (Fed. Register, Vol. 70, No. 35);
- State acid rain rule and statewide SO2 emissions cap, and
- Title IV of the 1990 Clean Air Act Amendments.

3. Zone of Impact

The "zone of impact" is defined as the area of concern to be evaluated for potential impacts due to the multiple proposed projects. This area depends, of course, on what cumulative impact is being studied. For visibility impairment in Class I areas in Minnesota, the selected zone of impact is defined as Voyageurs National Park and the Boundary Waters Canoe Area Wilderness (BWCA). Voyageurs is primarily located in St. Louis County, while the BWCA encompasses parts of St. Louis, Lake, and Cook Counties.

The Class I areas in Minnesota are the current focus of this analysis due to their proximity to the proposed projects. Other Class I areas within 250 kilometers of the proposed Iron Range projects are Isle Royale National Park located to the northeast of the Iron Range off the northeast tip of Minnesota in Lake Superior and Rainbow Lake Wilderness located to the southeast of the proposed projects in northwest Wisconsin (Figure 1). Prevention of Significant Deterioration (PSD) modeling results that have been reviewed by the FLMs for several of the proposed projects indicate that potential air quality impacts at Isle Royale and Rainbow Lake are below the respective "significant impact levels" (SILs). If each proposed project has modeled potential impacts below the respective SILs, there is a level of confidence that air quality is protected against potential cumulative impacts.[25] Based on the recent PSD visibility modeling results for Minnesota projects, Isle Royale and Rainbow Lake, these two relatively more distant Class I areas from the Iron Range projects are less likely to be affected than Voyageurs and the BWCA. Therefore, Isle Royale and Rainbow Lake were not included in this cumulative impacts analysis.

4. Geographic Extent

This boundary defines the area or sources that may affect resources in the zone of interest. In this case, the resource of concern is visibility in the Boundary Waters Canoe Area Wilderness and Voyageurs National Park. Air quality in remote Class I areas such as found in Minnesota,

[25] EPA 1996

including air concentrations of pollutants responsible for visibility degradation, are typically a region-wide/national emissions issue, and are not generally specific to an emission source region. However, in addition to national and statewide emissions, this analysis summarizes point-source emission trends in the area encompassed by Itasca, St. Louis, Lake, and Cook counties.

3.0 Assessment of Visibility Impairment in the Class I Areas in Minnesota

The assessment of visibility impairment in the Class I areas relies on four primary tasks:

- accessing data from the IMPROVE network,
- using the various calculation tools available on the IMPROVE website to derive estimates of 5-year averages for the specific pollutants,
- plotting the results of the various calculations, and
- interpreting those results.

The results can also be used to compare existing trends to the reasonable progress goal for the BWCA, which is approximately a 2 deciview improvement by 2018, and attaining natural background on the 20% worst days by 2064.[26] Natural background (i.e., pristine conditions) is estimated to be approximately 11 deciviews for the eastern U.S.[27]

3.1 IMPROVE Monitoring Data and Trends

Visibility monitoring by the Interagency Monitoring of Protected Visual Environments (IMPROVE) program has been ongoing in Minnesota since August 1991. IMPROVE monitoring was initiated for the Boundary Waters Canoe Area Wilderness at the Fernberg Lookout Tower (north and east of Ely along the Fernberg Road) and is shown in Figure 2. As of 2006, IMPROVE monitoring sites are also located in Minnesota at the following parks: Voyageurs National Park (northern Minnesota), in Blue Mounds State Park (southwest Minnesota), and in Great River Bluffs State Park (southeast Minnesota). However, the monitoring site in Voyageurs National Park has changed from the initial location near the Rainy Lake Visitor Center (western end) to near the Ash River Visitor Center (more central location in the park). The approximate locations of the two Voyageurs' monitoring sites are provided in Figure 3.

[26] MPCA 2005b
[27] EPA 2003

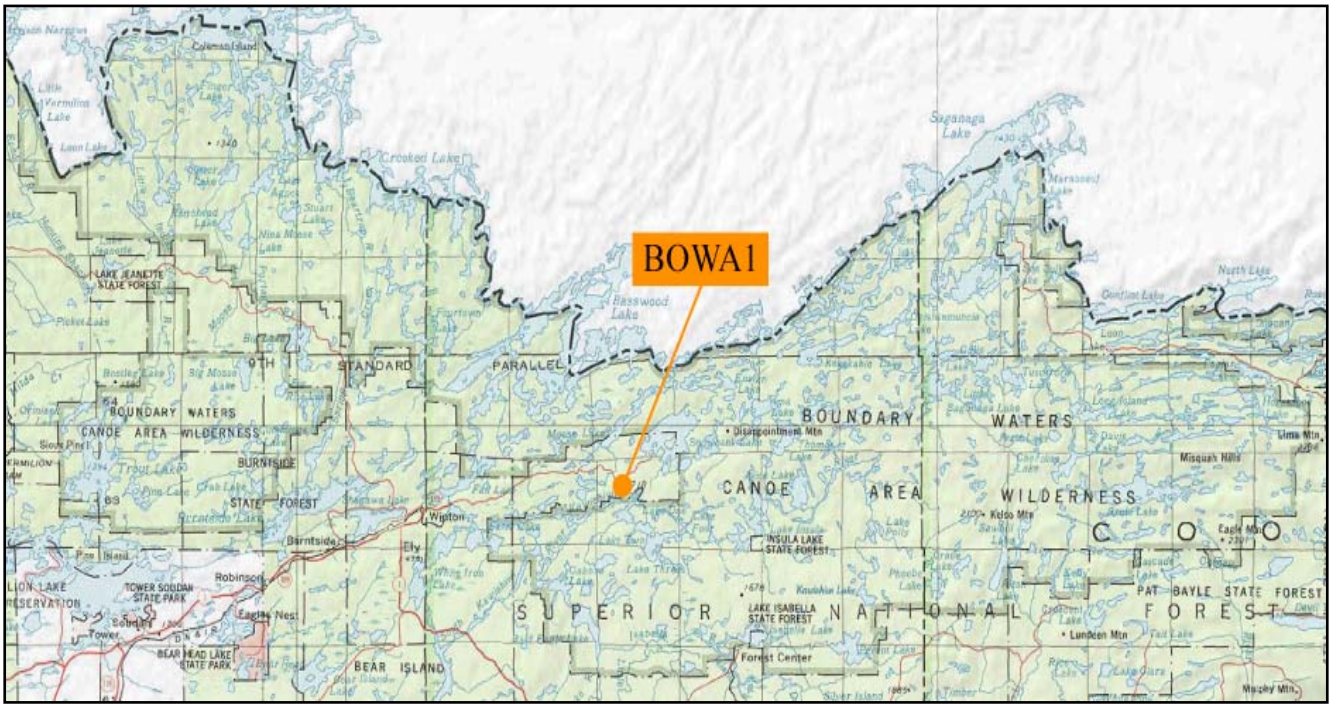


Figure 2 Approximate location of the BOWA1 IMPROVE monitoring site for the Boundary Waters Canoe Area Wilderness in northern Minnesota.

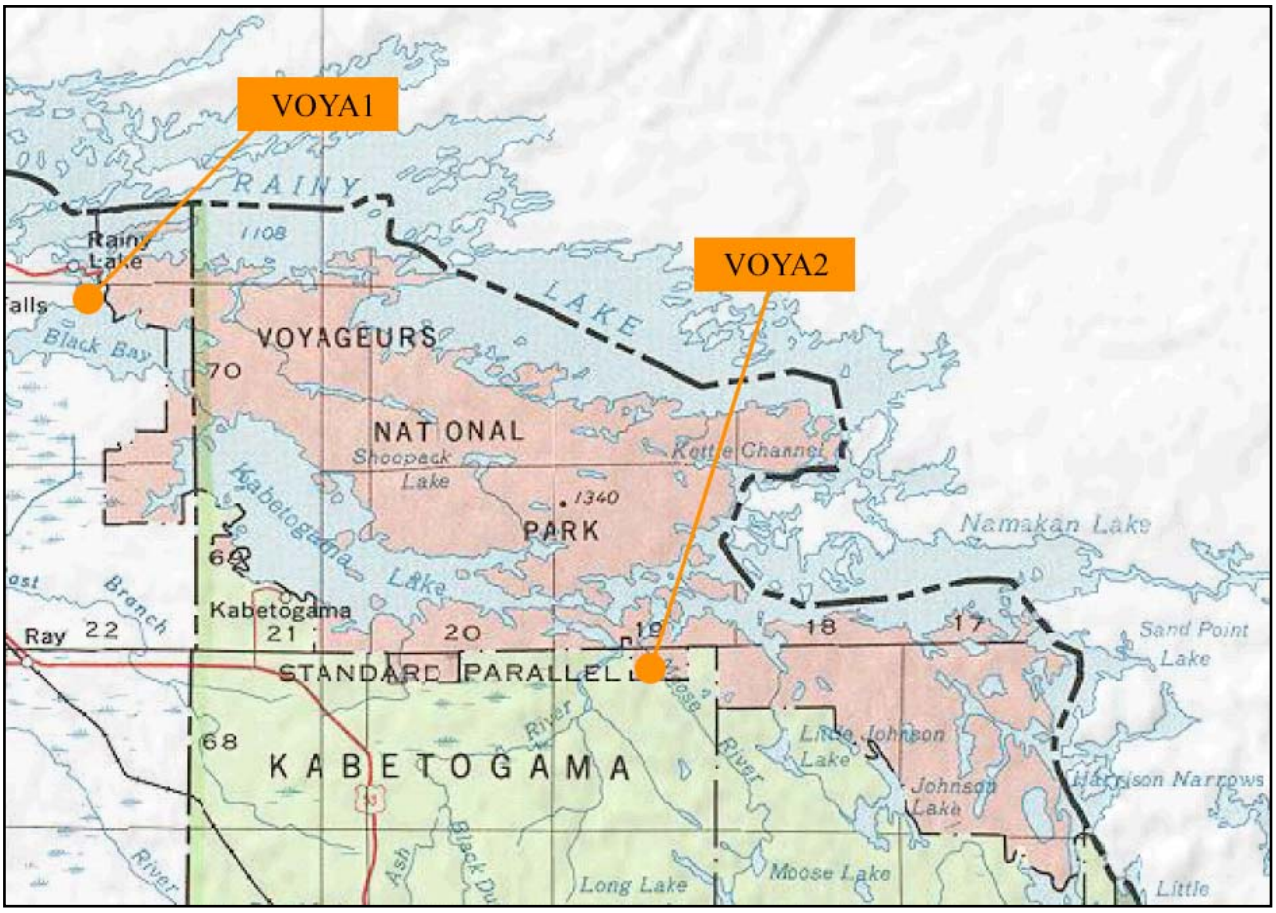


Figure 3 Approximate locations of the VOYA1 and VOYA2 IMPROVE monitoring sites within Voyageurs National Park in northern Minnesota.

Trend analyses are best conducted on data sets that cover a longer time period. Data sets typically encompassing less than 10 years are considered marginal for conducting trend analyses. As shown in Table 3, only the BWCA monitoring site provides a continuous historical record of visibility monitoring. Of the four IMPROVE monitoring sites in Minnesota, only the BWCA site has data that encompasses more than 10 years. This cumulative impacts analysis will therefore focus on the data from the BWCA site (i.e., the BOWA1 site).

Table 3 IMPROVE monitoring sites in Minnesota[1] and start and end dates for available quality assured data.

Monitoring Location	IMPROVE Monitoring Site Name	Starting Date	Ending Date (quality assured data)
Boundary Waters Canoe Area	BOWA1	AUG 1991	DEC 2004 [2]
Voyageurs National Park	VOYA1	MAR 1988	AUG 1993
	VOYA2	DEC 1999	DEC 2003
Blue Mounds	BLMO1	JUL 2002	DEC 2003
Great River Bluffs	GRRI1	JUL 2002	DEC 2003

[1] Summary data through 2003, updated February 2005 (http://vista.cira.colostate.edu/improve/Default.htm).

[2] Coarse PM and fine PM mass available through 2004; Quality assured data for fine fraction speciation only available through 2003 from BOWA1 as of January 2006.

3.1.1 Methods Used by IMPROVE to Calculate Light Extinction

The IMPROVE web site[28] provides ambient air concentrations for a number of pollutants; including particle chemical speciation, and relative humidity data for the BWCA site and the Voyageurs site.[29] The IMPROVE program also reconstructs the total light-extinction coefficient from aerosol measurements and from relative humidity data. IMPROVE recently updated and revised its light-extinction coefficient calculation methods because the older method tended to underestimate the highest extinction values and over-estimate the lowest extinction values.[30] A summary of the updated IMPROVE program's updated methodology and technical justification for the update is provided in Appendix A.

[28] http://vista.cira.colostate.edu/improve/Default.htm
[29] IMPROVE 2000
[30] IMPROVE 2006

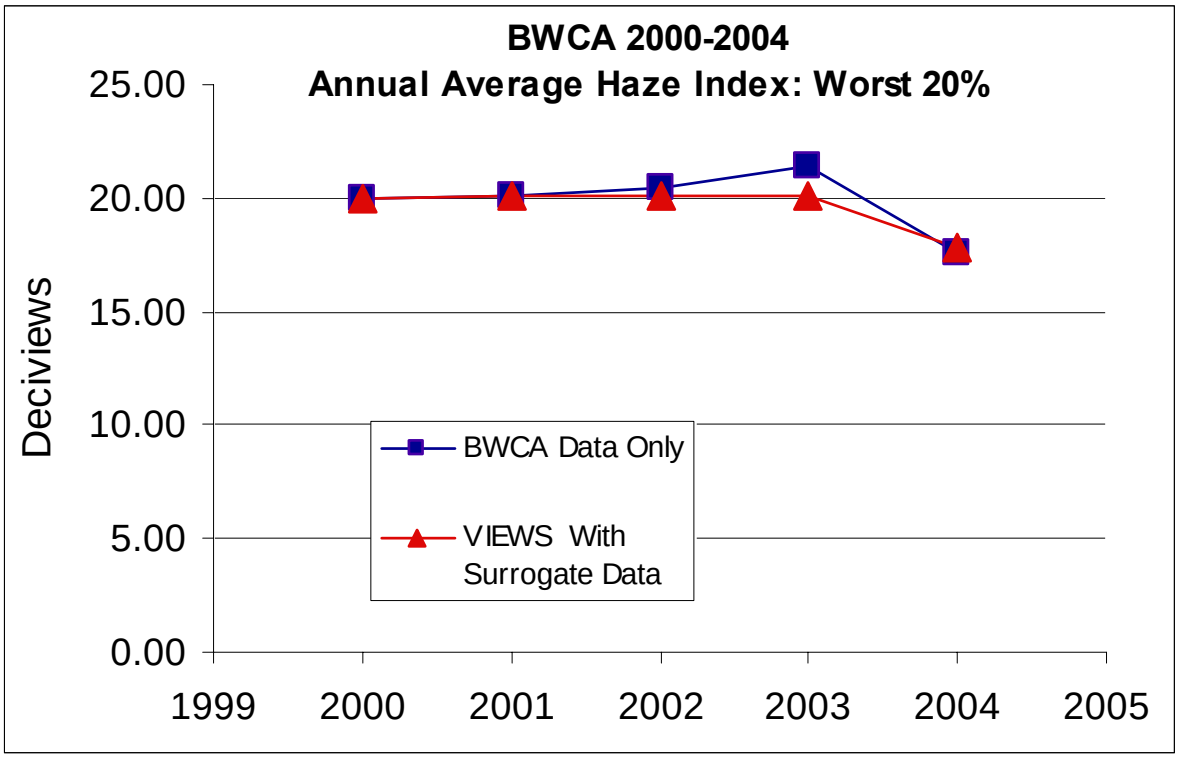
The data presented in this report are based on the updated and revised IMPROVE calculations that are available on the IMPROVE website. Daily, quarterly, and annual particulate concentration data and extinction coefficient and Haze Index calculations, using updated and revised methods, are available for all monitoring sites. However, as of September 2006, IMPROVE had not made available on its website the recalculated 5-year rolling averages using the revised calculation methods. Therefore, using the available annual data, 5-year rolling averages were calculated using the updated IMPROVE calculations and presented in this report.

In addition, for the years 2000 through 2004, BWCA data for fine soil, EC, OMC, and coarse mass data are missing on some days. Under strict EPA Clean Air Visibility Rule quality assurance and control protocols regarding annual data availability[31] the only years with calculable 5-year rolling averages are 1992, 1993, 1994, 1995, 1996, and 1999. A summary of the IMPROVE database completeness criteria and data availability for the BWCA is provided in Appendix B. As described in Appendix B, for the years 2000-2004, the BWCA data do not meet the strict regional haze annual criteria rule that complete data be available for at least 75 percent of all scheduled sampling days in a year. However, based on quarterly and daily data criteria alone, reliable rolling 5-year average data can be calculated for the BWCA monitoring site from 1992 to 2004, for all years except 1997 and 1998. Therefore, 5-year rolling annual average data for the BWCA for 2000 through 2004 were calculated for this report by excluding from the analysis those days for which any data was missing.

Alternatively, the Visibility Information Exchange Web Site (VIEWS) recently posted a surrogate data set for the BWCA for the years 2000 through 2004, based on linear regression analysis of data from Voyageurs.[32] Figure 4 compares the unadjusted annual average haze-index for the BWCA for 2000-2004 (as calculated for use in this report) to the VIEWS surrogate data set. This comparison shows that the two methods provide nearly identical annual average values (deciviews) for the 20% worst days for all years except 2003, when the uncorrected data is slightly higher. The resulting 5-year average for 2000-2004 using the VIEWS surrogate data (as posted November, 2006) is 19.59. The 5-year average for the worst 20% days using the uncorrected BWCA data, omitting days with missing data, is 19.89 deciviews. At both the

[31] EPA 2003a
[32] Visibility Information Exchange Web System (VIEWS) http://vista.cira.colostate.edu/views).

BWCA and Voyageurs, the annual average haze index for 2004 improved by over 1.5 deciviews compared to 2003 due to reductions in sulfate, nitrate and organic carbon.



VIEWS DATA: Site: BOWA1. **Series** - Parameter: dv. **Metadata** - Program: IRHR2, Poc: 1, Parameter: dv, Aggregation: Worst 20%, Method: Substituted dataset

Figure 4 Annual average Haze Index on 20% worst days in the BWCA for 2000-2004 (non-corrected data BOWA1; days with missing data omitted) compared to VIEWS surrogate estimate using Voyageurs data. VIEWS surrogate data downloaded 10-09-06. (http://vista.cira.colostate.edu/views). Baseline 5-year annual average for BOWA1 data for 2000-2004 is 19.89; 5-year baseline using surrogate data from VIEWS is 19.59.

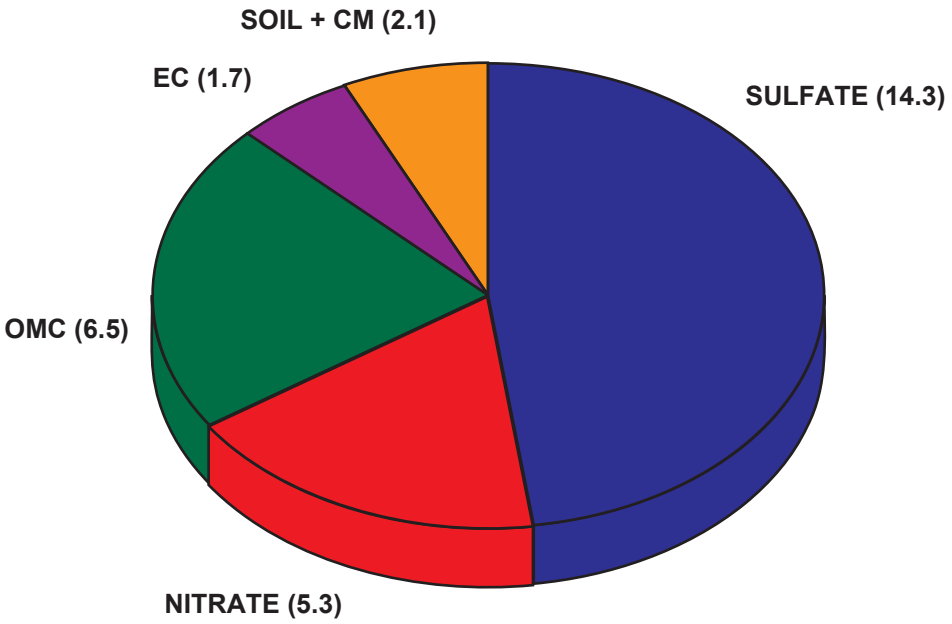
The unadjusted IMPROVE data were used to assess the following two items:

- The particle chemical species in ambient air predominantly responsible for visibility impairment, and
- The improvement in visibility with time (trend analysis).

3.1.2 Aerosols Predominantly Responsible for Visibility Impairment

The IMPROVE website provides the aerosol light-extinction coefficients reconstructed from the August 1992 through December 2004 aerosol data for the BWCA monitoring site. These light-

extinction coefficients were then accessed for use in this report. The average contribution of the 6 aerosol components to the average reconstructed aerosol light-extinction coefficient for the 1992 - 2004 time period is provided on Figure 5 (note: natural light extinction, $b_{RAYLEIGH}$, is not included). The average aerosol light-extinction coefficient for the 1992 – 2004 time period is 30.0 Mm^{-1}. Sulfate contributes the most to the aerosol light-extinction coefficient (50.6%); the next largest contributor is organics (21.7%) followed by nitrate (17.7%), soil and coarse particles (6.8%), and light-absorbing carbon (5.7%). Figure 5 shows these data in units of inverse megameters (Mm-1). These data are similar to those presented for the BOWA1 site on the Causes of Haze website (COHA 2005a).



Units: in parenthesis are inverse megameters (Mm^{-1})

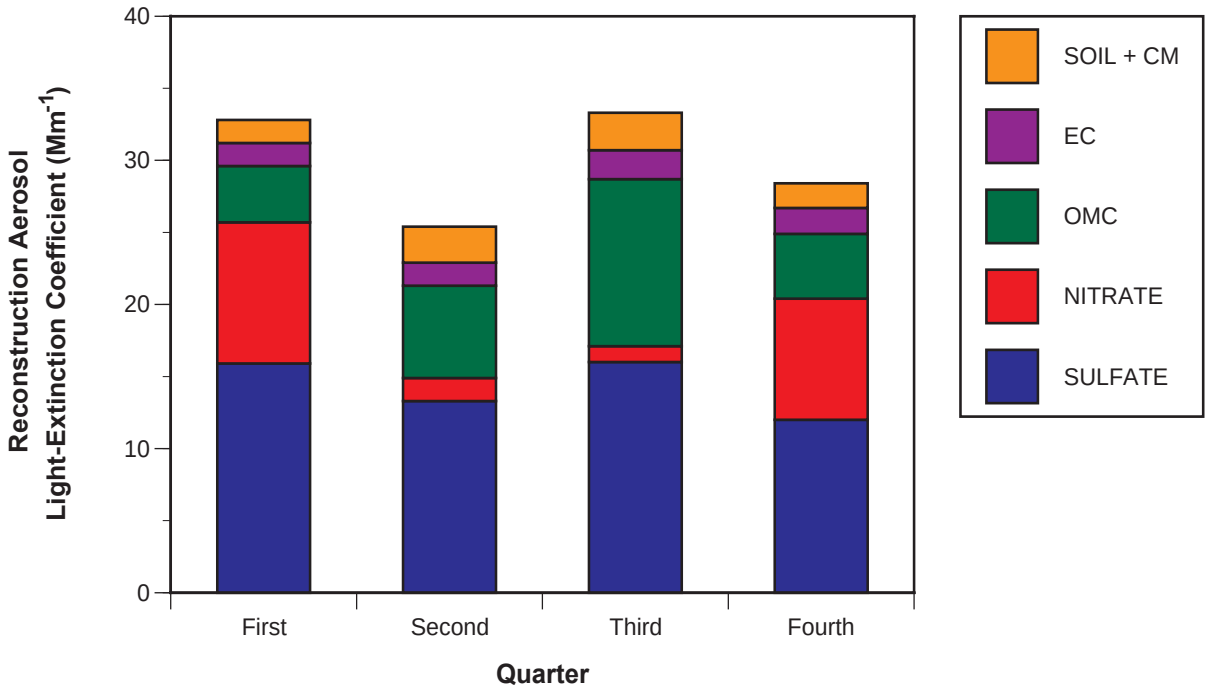
OMC = organic carbon mass; EC = elemental carbon; CM = coarse mass

From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values.

Figure 5 Average reconstructed aerosol light-extinction coefficient (Mm^{-1}) for all days at the BOWA1 IMPROVE monitoring site in northeast Minnesota, based on data for January 1992 through December 2004.

The reconstructed aerosol light-extinction coefficients, as shown on Figure 6, vary quarterly. They range from a high in the third quarter of 33.1 Mm^{-1} to a low of 25.5 Mm^{-1} in the second quarter. The composition of $b_{AEROSOL}$ as well as the magnitude of $b_{AEROSOL}$ also varies quarterly. During the warm months of the year (second and third quarters; April through September), the principle components of $b_{AEROSOL}$ are light-scattering by ammonium sulfate particles ($b_{SULFATE}$)

and organic particles (b_{OMC}). During the cold months (first and fourth quarters; October through March), the principle components are light-scattering by ammonium sulfate particles ($b_{SULFATE}$) and ammonium nitrate particles ($b_{NITRATE}$) (Figure 6).



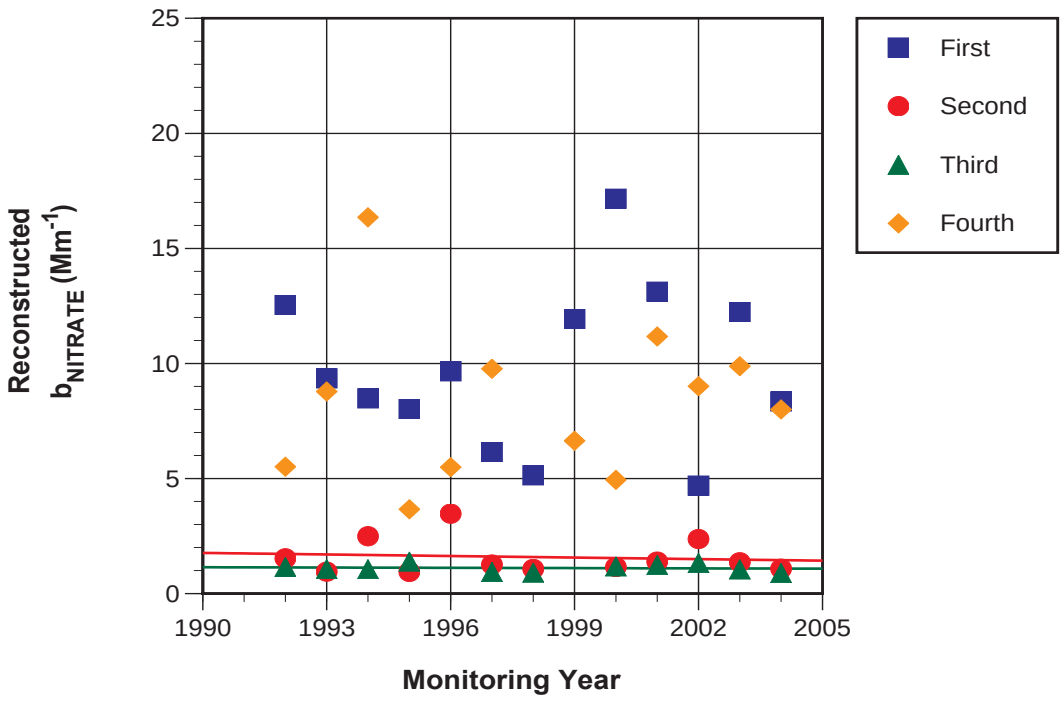
First Quarter (Jan. – March) Second Quarter (April – June) Third Quarter (July – Sept.) Fourth (Oct. – Dec.)
OMC = organic carbon mass; EC = elemental carbon; CM = coarse mass
From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values.
(http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 6 Quarterly-averaged reconstructed aerosol light-extinction coefficient ($b_{AEROSOL}$) (Mm^{-1}) for all days at the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

For the quarterly light-extinction coefficients, the relative importance of light scattering by ammonium nitrate and organic matter flip-flops for the warm and cold months (Figure 6). In warm months, the b_{OMC} value is larger than the $b_{NITRATE}$ value. During the cold months, $b_{NITRATE}$ value is larger than the b_{OMC} value (Figure 6). Organic matter emitted during prescribed burns or wild land fires may contribute to the higher b_{OMC} values during the warm months (COHA 2005a). Higher biogenic activity in the warm months also contributes to higher b_{OMC} (LADCO 2004).

The low air temperatures and high relative humidity during the cold months favor the partitioning of NO_X and nitric acid to particles,[33], thereby increasing the concentration of ammonium nitrate aerosols, which leads to an increased $b_{NITRATE}$ contribution to the reconstructed light-extinction coefficient. Also, temperature inversions can occur during the winter month which traps air pollutants and contributes to the 20%-worst visibility days that occur during the cold months[34]. The pattern of high (and variable) quarterly-averaged $b_{NITRATE}$ values during the cold months and low (and consistent) values during the warm months has persisted throughout the 1992 through 2004 time period (Figure 7). Despite the varying relative contributions of ammonium nitrate and organic matter in defining the reconstructed aerosol light-extinction coefficient, ammonium sulfate is the major component for all quarterly-averaged $b_{AEROSOL}$ values.

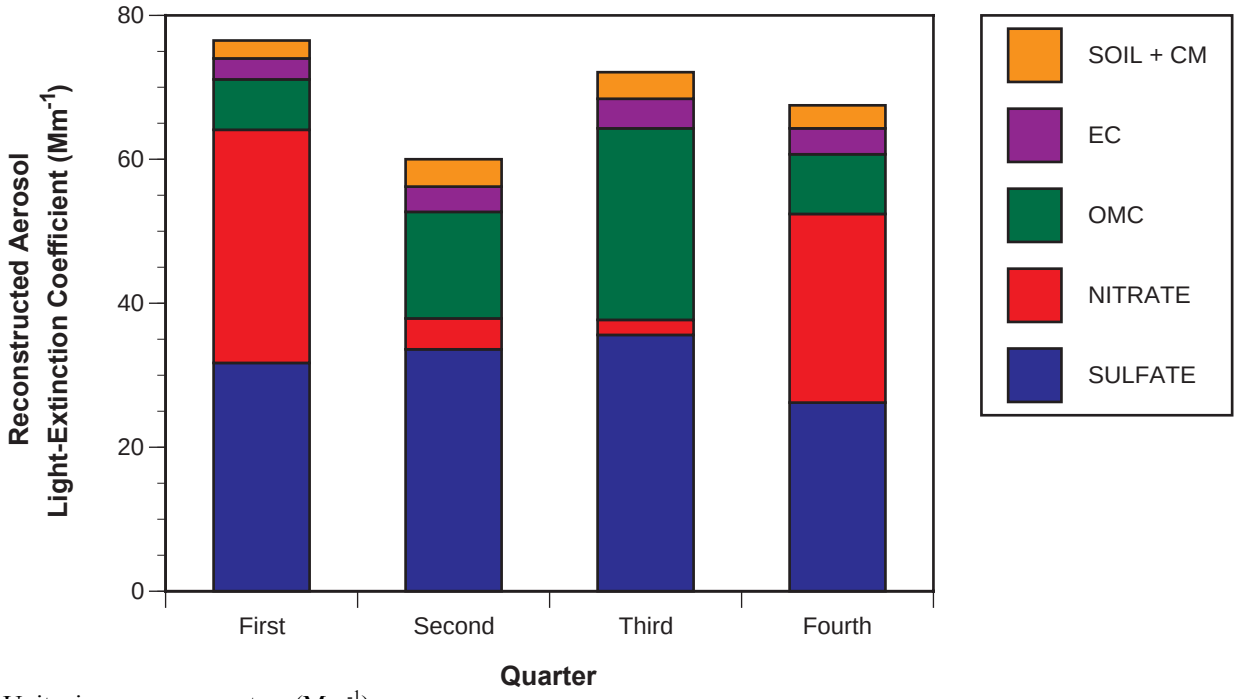
[33] COHA 2005a
[34] COHA 2005a



From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 7 Quarterly averages of the reconstructed light-extinction coefficient for nitrate ($b_{NITRATE}$) for all days at the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

The contributions of the major aerosol chemicals to the reconstructed total light-extinction coefficient for the 20%-worst visibility days are provided on a quarterly basis on Figure 8. Ammonium sulfate alone is the dominant aerosol for the 20%-worst days that occurred during the warm months, while ammonium sulfate and ammonium nitrate combined are the dominant contributors to the reconstructed aerosol light-extinction coefficient for the 20%-worst visibility days that occurred during the cold months (Figure 8).



Units: inverse megameters (Mm^{-1})

First Quarter (Jan. – March) Second Quarter (April – June) Third Quarter (July – Sept.) Fourth (Oct. – Dec.)

OMC = organic carbon mass; EC = elemental carbon; CM = coarse mass

Note: the vertical scale of this figure (up to 80 Mm^{-1}) is twice that of average light extinction data in Figure 6.

From IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 8 Quarterly-averaged reconstructed aerosol light-extinction coefficient ($b_{AEROSOL}$) (Mm^{-1}) for the 20% worst visibility days at the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

The dominance of ammonium sulfate during the warm months is due in part to the frequent southerly winds that pass "… through southern Minnesota, eastern Nebraska and Kansas, Iowa, Missouri and western Illinois …" to the BWCA, and result in high ammonium sulfate days.[35] In addition, "… Subsidence inversions associated with (the) buildup and stagnation of synoptic high pressure ridges are most likely to occur during the summer. They tend to cover a large area and are regional in nature, and may persist for periods of days, which helps to build up sulfate and results in worst haze days. …[36]

[35] COHA 2005a
[36] COHA 2005a

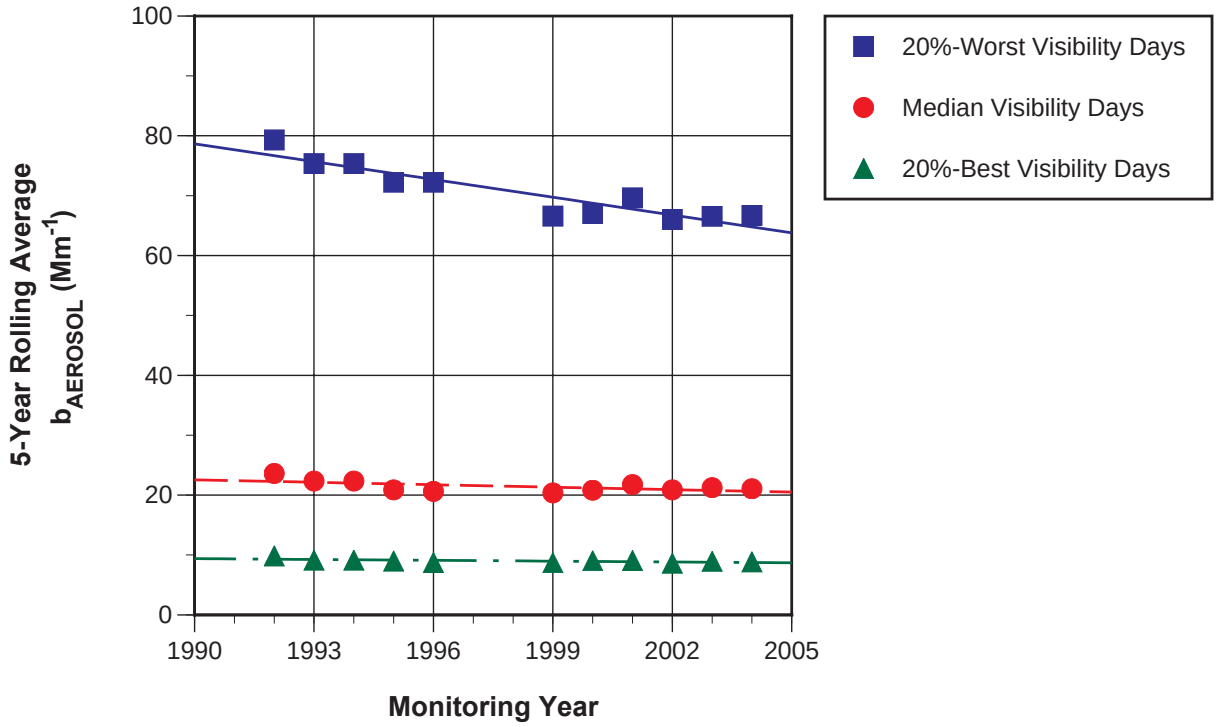
In summary, the primary contributors to the reconstructed aerosol light-extinction coefficients for the BWCA are ammonium sulfate particles, ammonium nitrate particles, and organic matter particles. Ammonium sulfate and organic matter are the dominant contributors during the warm months, while ammonium sulfate and ammonium nitrate are the major contributors during the cold months. The particles of elemental carbon, soil, and coarse matter have less significant roles in defining reconstructed aerosol light-extinction coefficients. These particular findings suggest that emissions of NO_X and SO_2 have the greatest potential for impact on visibility in Minnesota Class I areas. However, due to the time and conditions required for the formation of sulfate and nitrate aerosols, local sources of NO_X and SO_2 may not be the source of the nitrate and sulfate aerosols observed in Minnesota Class I areas.

3.1.3 Monitored Changes in Visibility with Time

A number of sites in the IMPROVE network have monitoring data for more than 10 years and the reconstructed aerosol light-extinction coefficients can be evaluated for trends. Data is available from the IMPROVE network to examine the trends in reconstructed aerosol light-extinction coefficients for the 20%-worst visibility days, the median visibility days, and 20%-best visibility days[37]. However, of the Minnesota sites, one had sufficient data for analysis and 5-year rolling averages. In the February 2005 update of the IMPROVE website, annual light-extinction values were provided for years 1992 to 2004 for the BOWA1 site. These annual light-extinction coefficients are the basis for the 5-year rolling averages presented below in Figure 9.

Figure 9 identifies that the 5-year rolling averages of the reconstructed aerosol light-extinction coefficient ($b_{AEROSOL}$) show a decline between 1992 and 2004 for the BOWA1 site. The biggest decline was observed for the 20%-worst visibility days, for which the average $b_{AEROSOL}$ value decreased by 12.6 Mm^{-1}. Smaller declines were observed for the median and 20%-best visibility days (2.5 and 1.0 Mm^{-1}, respectively). Thus, the IMPROVE monitoring data indicates that the visibility impairment caused by aerosols in the BWCA is diminishing with time indicating that visibility is improving (Figure 9).

[37] IMPROVE 2000



From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 9 Five-year rolling averages of the reconstructed aerosol light-extinction coefficient ($b_{AEROSOL}$) for the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

Voyageurs National Park also has signs of visibility improvement. Although there is insufficient data to analyze for trends, as was done for the BWCA (i.e. calculating rolling averages), the data from the two time periods represented by the VOYA1 and VOYA2 sites may be compared. Table 4 shows the average reconstructed light extinction coefficient ($b_{AEROSOL}$) at the two Voyageurs IMPROVE sites. This data suggests a 25% decrease in $b_{AEROSOL}$ from the 1989-1992 time period to the 2000-2004 time period. This decrease indicates that visibility impairment in Voyageurs is diminishing with time.

Table 4 Average reconstructed light extinction coefficients for the 2 IMPROVE sites in VNP.

Site	Timeframe	$b_{AEROSOL}$, Mm^{-1}
VOYA1	1989-1992	36.2
VOYA2	2000-2004	27.0

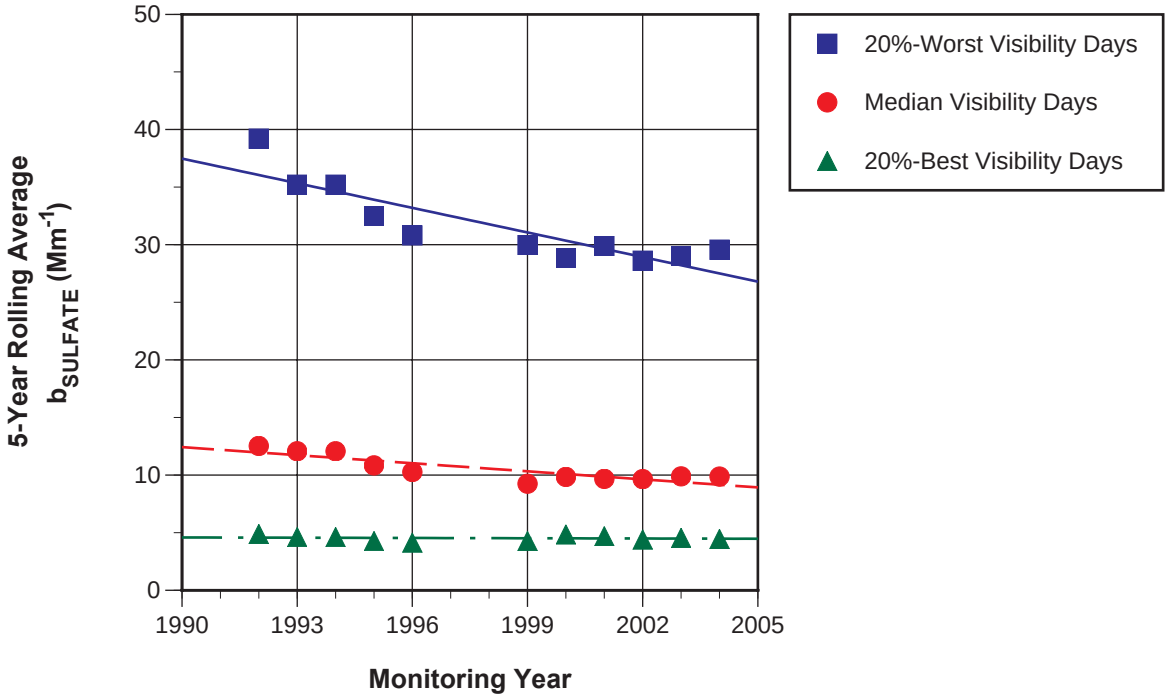
Source: IMPROVE 2005. IMPROVE Means for Best Middle and Worst 20% Visibility days (http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

Nationally, the trend for overall visibility impairment in Class I areas has been constant visibility in both the eastern US and western US from 1992-2001. The level of impairment however is much higher in the eastern US, where the visual range on the best visibility days is similar to that on the worst visibility days in the western US. The visibility range in the Class I areas in Minnesota, shows a decreasing trend and is in between that of the average for the eastern and western US[38].

The BWCA data may also be analyzed according to the major components that contribute to visibility impairment. The 5-year rolling averages for the ammonium sulfate component ($b_{SULFATE}$), the ammonium nitrate component ($b_{NITRATE}$), and the organic matter component (b_{OMC}) are provided on Figure 10, Figure 11, and Figure 12, respectively. In general, the 5-year rolling average $b_{SULFATE}$ values decreased by up to 24% from 1992 to 2004. The $b_{NITRATE}$ values decreased by up to 22 percent. The b_{OMC} values show smaller changes and include a mixture of small increases and decreases.

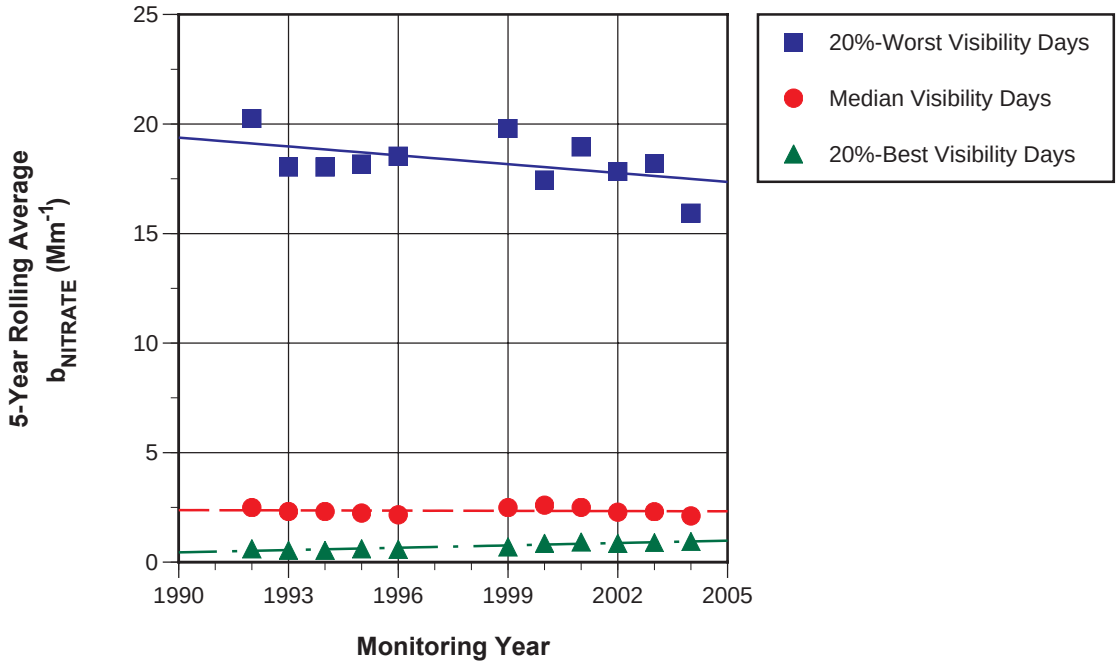
Of the 3 major contributors to $b_{AEROSOL}$ (ammonium sulfate, ammonium nitrate, and organic matter), the observed trend of declining $b_{AEROSOL}$ in Figure 9 is due primarily to a decline in the ammonium sulfate component. The "net" decreases/increases in the 5-year rolling averages for the three major constituents are compared to the "net" decreases for $b_{AEROSOL}$ in Figure 13. The net decreases in $b_{SULFATE}$ and $b_{NITRATE}$ from 1992 to 2004 tracks the net decrease in $b_{AEROSOL}$ during the same period. This net decrease in $b_{AEROSOL}$, $b_{SULFATE}$ and $b_{NITRATE}$ indicates an improvement in visibility. The other major contributors to $b_{AEROSOL}$ (b_{OMC}) have smaller net changes than $b_{SULFATE}$ and $b_{NITRATE}$, and its decrease is too small to account significantly for the observed change in $b_{AEROSOL}$ (Figure 13).

[38] EPA 2006



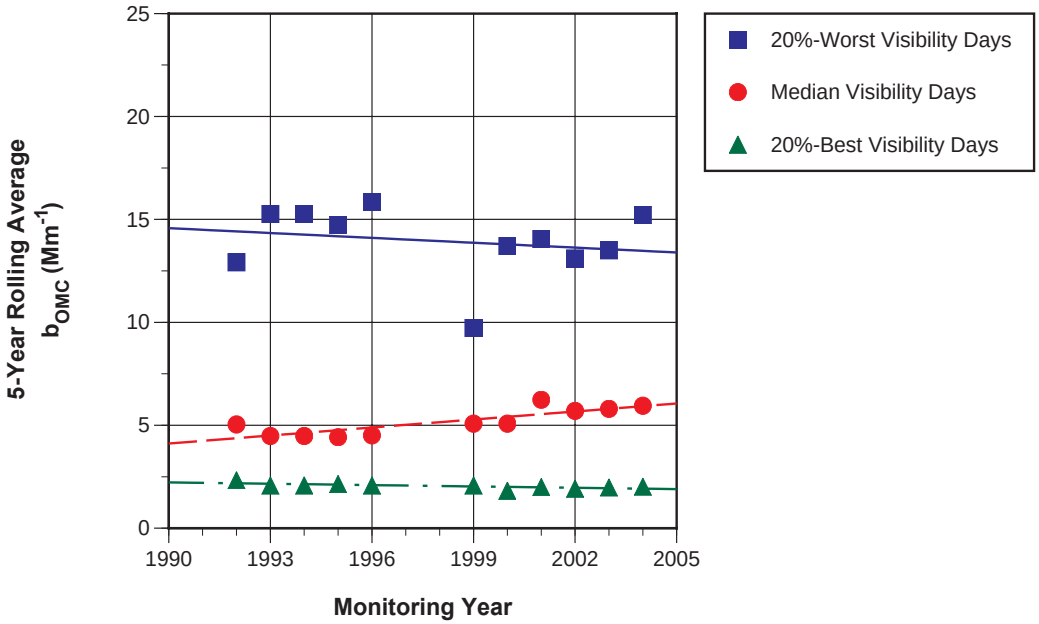
From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 10 Five-year rolling averages of the reconstructed sulfate light-extinction coefficient ($b_{SULFATE}$) for the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.



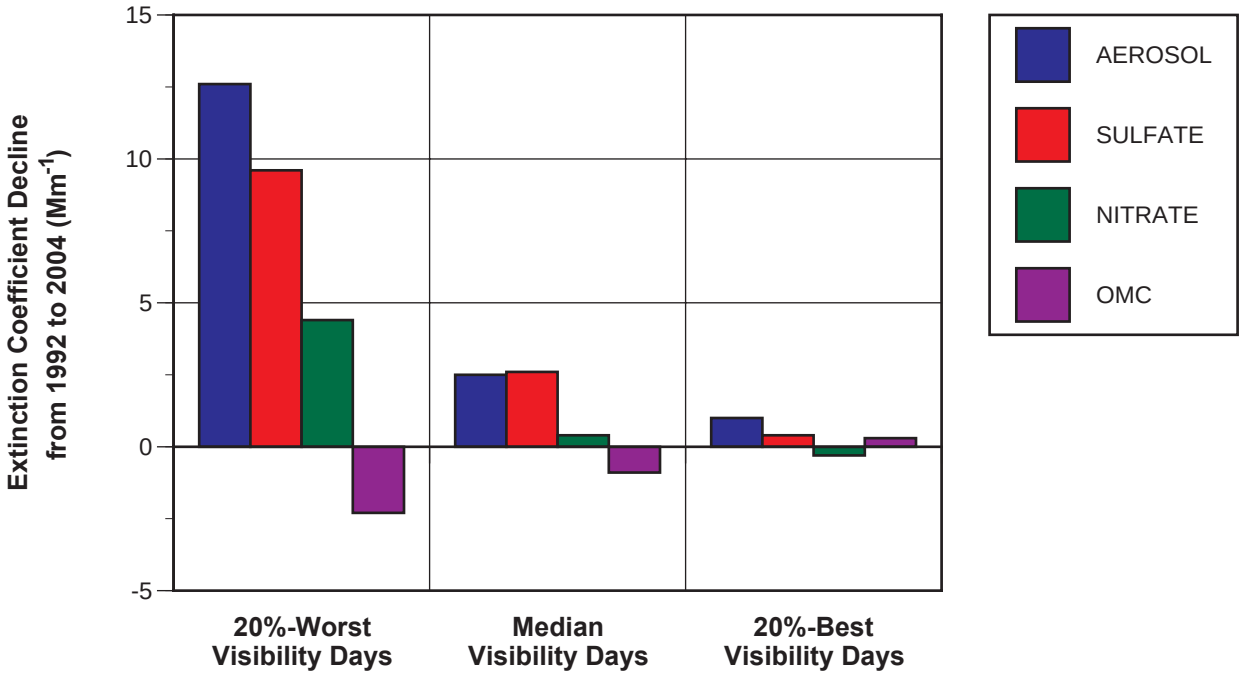
From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 11 Five-year rolling averages of $b_{NITRATE}$ for the BOWA1 IMPROVE monitoring based on data for the January 1992 through December 2004



From: (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 12 Five-year rolling averages of b_{OMC} for the BOWA1 IMPROVE monitoring site based on data for the January 1992 through December 2004.



Units: inverse megameters (Mm^{-1})

From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Note: Positive values represent a decline in the light-extinction coefficients (i.e., improvement in visibility, less visibility impairment) and plotted negative values represent an increase in light-extinction coefficients (i.e., more visibility impairment).

Figure 13 Comparison of the net change in the 5-year rolling averaged reconstructed light-extinction coefficients for aerosol ($b_{AEROSOL}$), sulfate ($b_{SULFATE}$), nitrate ($b_{NITRATE}$), and organic matter (b_{OMC}) (Mm^{-1}) for the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

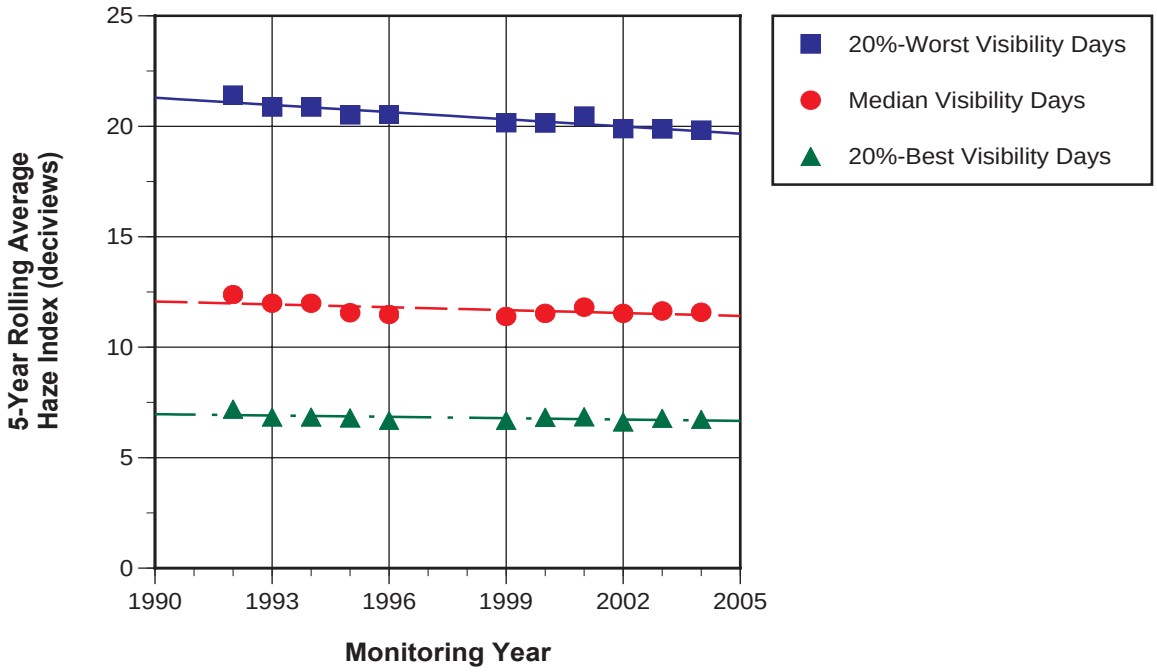
The decrease in the reconstructed aerosol and total light-extinction coefficients for the BWCA can be expressed in terms of a haze index (*HI*). The *HI* is defined by the following equation:

$$HI = 10 \ln\left(\frac{b_{TOTAL}}{10}\right) \tag{5.10}$$

in which *HI* is the haze index expressed in terms of deciviews (dv) and *ln* is the natural logarithm[39]. The *HI* was "specifically designed so that anywhere along its scale, haziness changes that are equally perceptible correspond to the same deciview difference.[40] A smaller *HI* value means less haze and improved visibility.

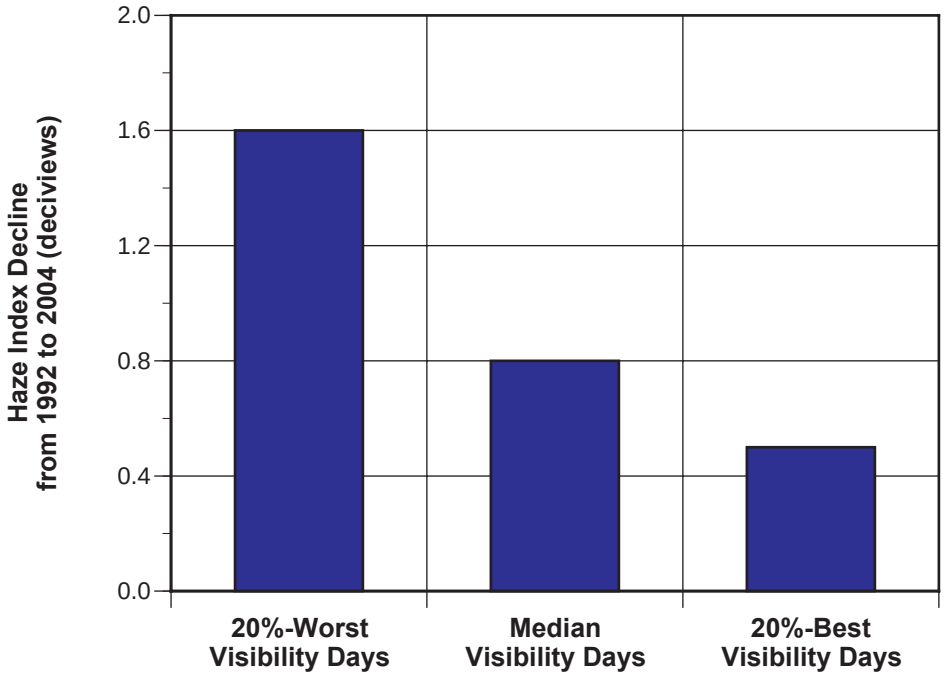
The 5-year rolling average *HI* values for the BWCA are provided on Figure 14 and show decreasing *HI* values with time, indicating improving visibility. As shown on Figure 15, the net decline in the haze index *HI* from 1992 to 2004 for the 20%-worst visibility days was 1.6 deciviews. The *HI* values for the median visibility days and the 20%-best visibility days had net declines of 0.8 and 0.5 deciviews, respectively.

[39] EPA 2003b
[40] EPA 1998



From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values. (http://vista.colostate.edu/improve/data/improve/summary_data.htm)

Figure 14 Historical trend in the Haze Index (HI) that is calculated from the five-year rolling averages of the reconstructed total light-extinction coefficient (b_{TOTAL}) for the BOWA1 IMPROVE monitoring site, January 1992 through December 2004.



Note: plotted positive values indicate a decline in the haze index value and represent an improvement in visibility.

From: IMPROVE. 2005. IMPROVE summary data. Daily values including patched values.

(http://vista.colostate.edu/improve/data/improve/summary_data.htm

Figure 15 Net change in the Haze Index *HI* (deciviews) that is calculated from the 5-year rolling average reconstructed total light-extinction coefficients (b_{TOTAL}) for the BOWA1 IMPROVE monitoring site located in northeast Minnesota, based on data for the January 1992 through December 2004 time period.

3.1.4 Summary of IMPROVE Data and Visibility Impairment

In summary, the 5-year rolling average reconstructed aerosol light-extinction coefficients ($b_{AEROSOL}$) collected by the IMPROVE program have declined since 1991 for the BWCA monitoring site. This decline in aerosol light-extinction coefficients indicates that visibility is improving. Net declines in the extinction coefficients are observed for the 20%-worst, median, and 20%-best visibility days. Net declines are also observed for the haze index *HI*. The decreasing *HI* values mean that the visibility on the 20%-worst, median and 20%-best visibility days are improving. A net reduction in the reconstructed light-extinction coefficient for ammonium sulfate ($b_{SULFATE}$) is largely responsible for the reduced haze index, indicating that the visibility resource improvement for the BWCA is due to a reduction in ambient ammonium sulfate concentrations.

The average reconstructed aerosol light extinction coefficient, $b_{AEROSOL}$, at the two Voyageurs National Park sites also indicate improvement in the visibility resource between the 1989-1992 time period and the 2000-2004 time period.

3.2 Emission Source Contributions to Haze in Minnesota

This section summarizes the status of modeling efforts to determine the relative contributions of emission sources (natural, background, and local, state, and national) that are estimated to contribute to visibility impairment in the Federal Class I areas located in Minnesota. As identified in Figure 5, the major components of $b_{AEROSOL}$ are fine aerosols including sulfate and nitrate fine aerosols. Subsequently, the following discussion focuses on emission sources of fine particulate ($PM_{2.5}$), including the precursor emissions of sulfate and nitrate aerosols, SO_2 and NO_X respectively.

3.2.1 Natural Background and Global Contributions

The long-range transport of fine particles, including soil dust from Asian sources, contributing to relatively high background air concentrations has been known for some time[41]. As described by Park *et al.* (2005), *background* refers to the concentrations that would be present in the absence of U.S. anthropogenic emissions, and includes contributions from both natural and transboundary pollution sources. Park *et al.* (2005) provide modeling results that indicate that *natural* concentrations for sulfate-nitrate-ammonia (SNA) aerosols are low (the highest contribution is marine sulfate from oxidation of dimethyl sulfide, DMS) and are distributed uniformly over the United States. However, *background* SNA concentrations are many-fold higher than *natural* concentrations and show strong spatial patterns (see Figure 16), reflecting transboundary pollution influences mostly from Canada and Mexico[42]. These background levels suggest the lowest achievable limit for these species regardless of local and regional U.S. contributions. As discussed by the Tennessee Valley Authority (TVA 2005):

> *"… Initial modeling work at Harvard University by Dr. Daniel Jacob provided estimates of both natural and man-made $PM_{2.5}$ levels entering the U.S. from Asia, Latin America and Africa. Asian dust and biomass burning in Central America and Mexico were found to contribute substantial $PM_{2.5}$ mass in the western U.S., while Saharan dust and biomass burning contributed to eastern $PM_{2.5}$. Dr. Jacob estimated that background levels of carbonaceous particles in the eastern U.S.*

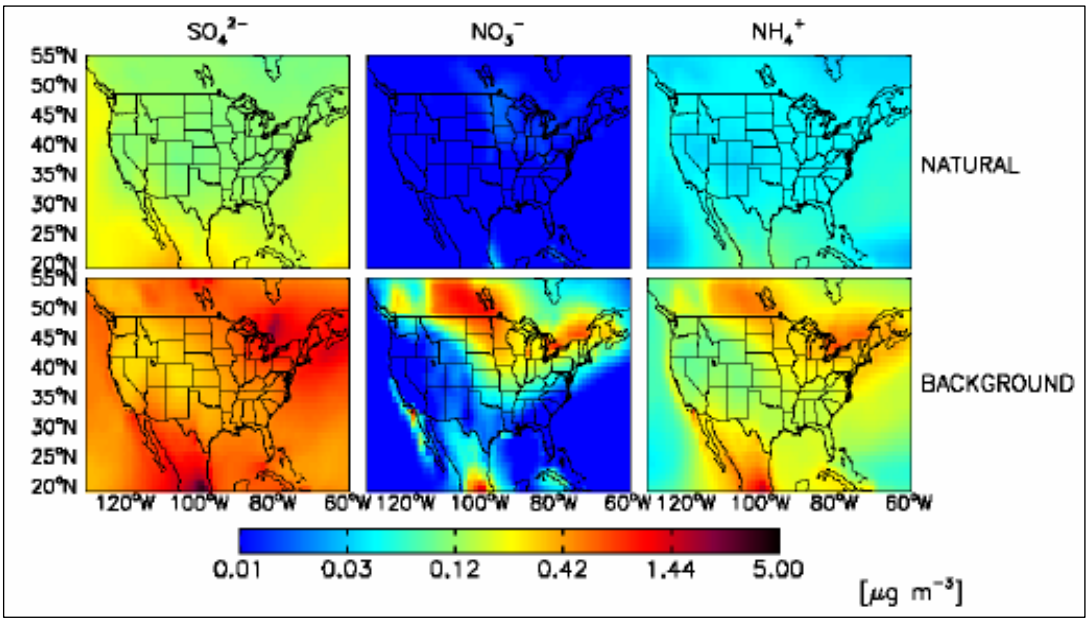
[41] Jaffe *et al.* 1999; Park *et al.* 2004
[42] Park *et al.* 2005

average about 1.2 µg/m3 on an annual basis. This is similar in magnitude to the default levels (~1.4 µg/m3) assumed by the EPA in setting natural background targets for visibility improvement. Background levels of ammonium sulfate and ammonium nitrate are substantially higher than previous estimates, however. The EPA estimates for the total of these two particle types is about 0.3 µg/m3 in the eastern U.S., whereas Dr. Jacob estimates an average of almost 0.8 µg/m3, or over a factor of two greater. Jacob's global modeling results suggest that, on average, eastern $PM_{2.5}$ levels include about 2.2 µg/m3 of carbonaceous, nitrate and sulfate mass from outside the U.S. ..." .[43]:

Based on the data from Park *et al.* (2005) in Figure 16, background concentrations of sulfate and nitrate combined are approximately 0.8 – 1.0 µg/m^3 in northern Minnesota. This background concentration represents approximately 16-23% of the average $PM_{2.5}$ air concentrations in Voyageurs and the BWCA (Table 4).

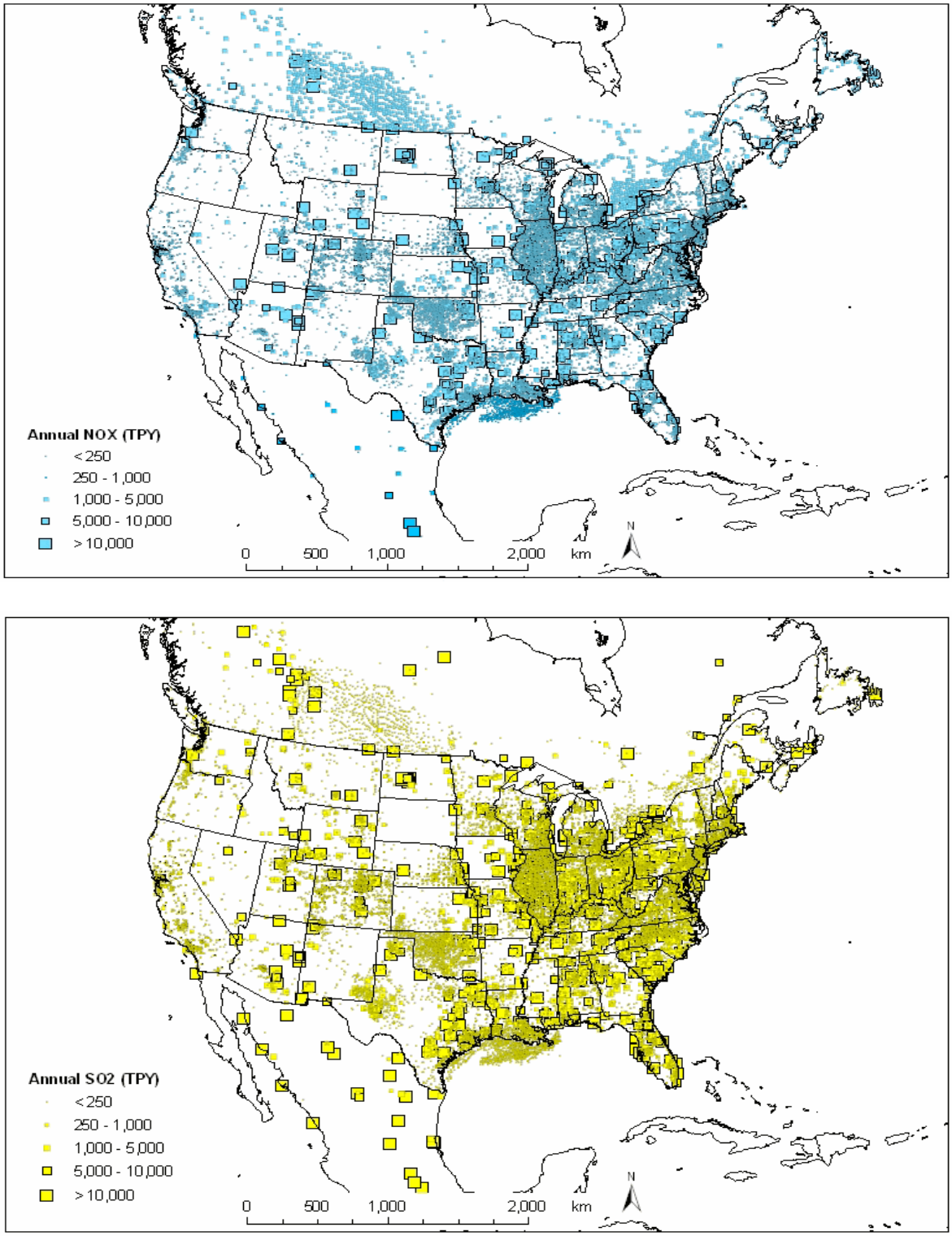
NO_x and SO_2 emission sources in Canada and Mexico are identified in Figure 17. The locations of the NO_x and SO_2 emissions in Canada and Mexico visually compare well with the background air concentration data provided by Park *et al.* (2005) in Figure 16. Park et al (2005) identify the contributions of sulfate and nitrate aerosols from Canada and Mexico to Class I areas on the respective northern and southern U.S. borders.

[43] TVA 2005



From: Park et al. 2005 (Figure 8).

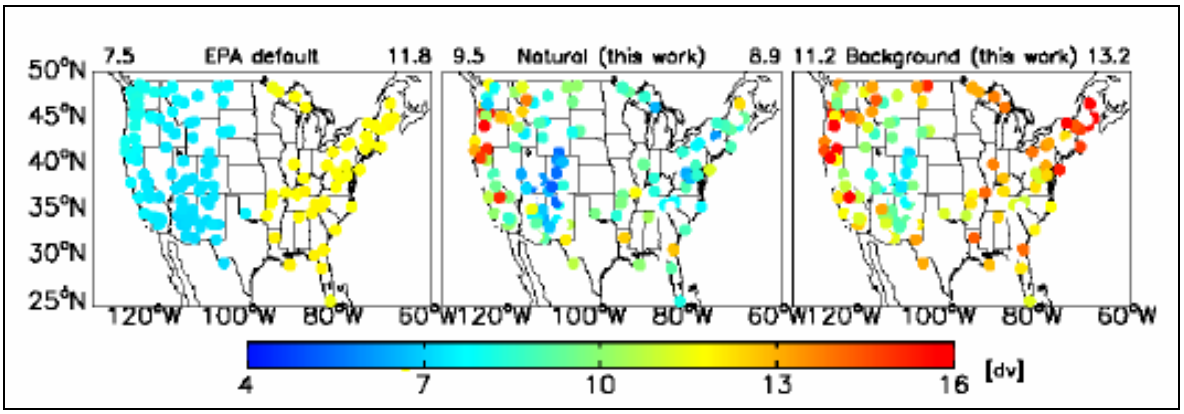
Figure 16 Natural and background concentrations of sulfate, nitrate, and ammonium aerosols in surface air. Values are modeled annual means with global and U.S. anthropogenic sources shut off, respectively.



From: http://coha.dri.edu/web/state_analysis/Minnesota/BoundaryWatersCanoeAreaWA_emissions.html

Figure 17 North American emissions of nitrogen oxides, NO_X (top), and sulfur dioxide, SO_2 (bottom).

Transboundary pollution influences also result in a higher background visibility endpoint being calculated by Park *et al.* (2005). Park *et al.* (2005) estimate that regional means for the background visibility endpoint are 11.2 and 13.2 dv in the western and the eastern United States, respectively, which are higher than the EPA defaults of 9 and 11 dv, respectively (Figure 18). The findings from Park *et al.* (2005) may have particular relevance for Voyageurs and BWCA given their close proximity to the Canadian border and the estimated background air concentrations for sulfate, nitrate, and ammonia (as identified by Park *et al.* 2005) (Figure 16).



From: Park *et al.* 2005 (Figure 11).

Note: "this work" indicates the work of Park *et al.* 2005

[1] EPA default values for the means of the 20% worst days (left) are computed as the 92nd percentiles of the probability distributions for natural visibility degradation, using default values for the means and standard deviations of natural visibility degradation in the west and east as recommended by the RHR document [EPA, 2003]. Simulated natural (middle) and background (right) values are averages of the upper 20% of the probability distributions of daily visibility degradation from the model sensitivity simulations with anthropogenic emissions shut off globally and in the United States, respectively. Regional averages (west vs. east) over the ensemble of sites divided at 95° W are shown on top of each panel. (Park *et al.* 2005).

Figure 18 Mean natural and background visibility degradation for the 20% worst visibility days as 2064 endpoints for the application of the U.S. EPA Regional Haze Rule[1].

3.2.2 Regional and Local (Minnesota) Contributions Based on Particle Speciation

The MPCA has identified that most of the fine particulate matter measured in the Twin Cities is from regional sources[44]. Figure 19 identifies an average regional contribution of approximately 77% to urban fine particulate air concentrations across the Midwest Region, ranging from a low of approximately 61% for St. Louis (~11 of 18 µg/m^3 is from regional contribution) to a high of approximately 81% for the Twin Cities Metro area (~10.5 of 13 µg/m^3 is from regional

[44] MPCA 2005c. In this MPCA report, "regional" is defined as sources more than approximately 100 kilometers downwind of the urban area.

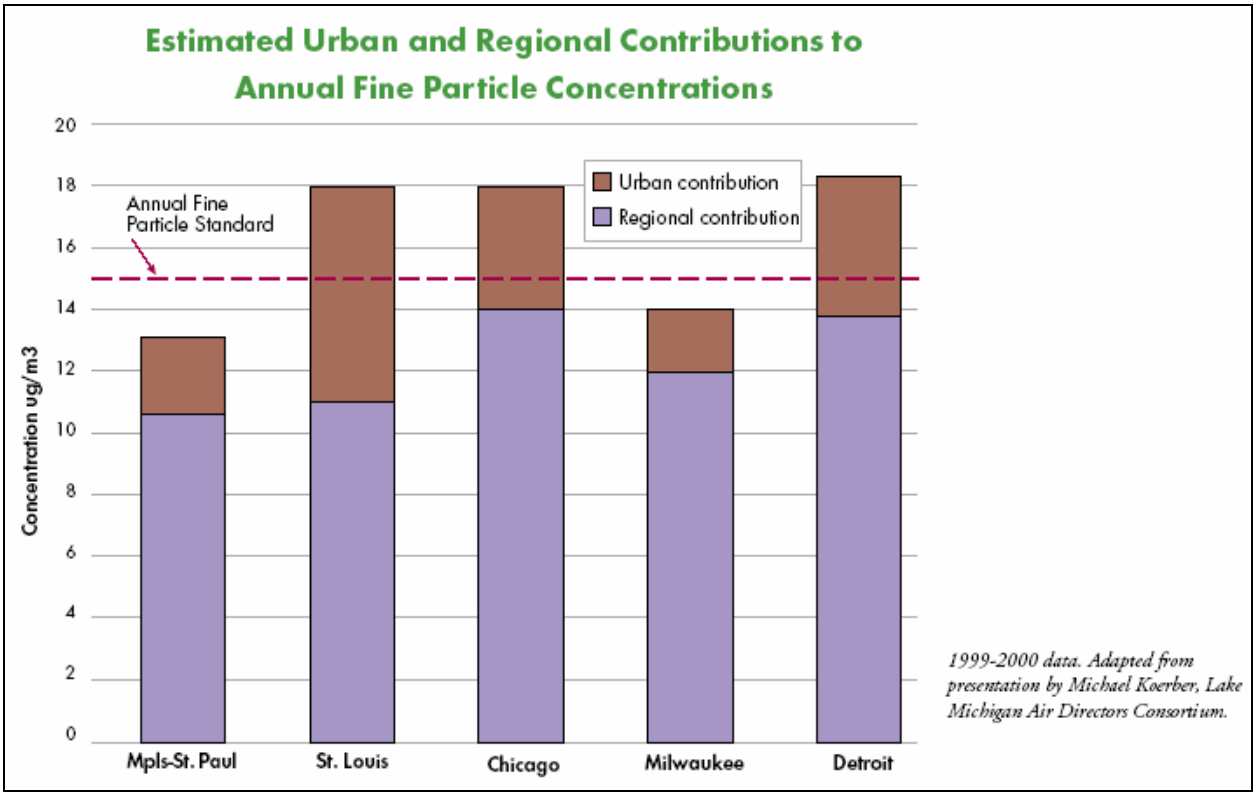
contribution). These findings are consistent with EPA's [45]findings that regional pollution accounts for more than 50% of the fine particulate in the eastern U.S. EPA data support the conclusion that sulfate and nitrate air concentrations tend to be primarily from regional sources (Figure 20).

Based on Figure 19, approximately 20-25% of the fine particulate in the Twin Cities Metro area is due to local sources, leaving 75-80% due to regional and background sources. In rural locations, traffic and point-source emissions are usually lower than in urban areas like the Twin Cities. Therefore, if up to 80% of fine particulate in the Twin Cities is due to downwind regional sources, it is logical then to assume that at least 80% of the fine particulate in rural areas of the state, such as the BWCA, also originates from regional and background sources, most of which are located outside the state.

In addition, local source contributions to fine particles can also be estimated through the use of marker species. This method has some uncertainty associated with it but it does provide additional information on potential contributions from local sources, such as mining, to Voyageurs and the BWCA. Data from the IMPROVE monitoring site in Voyageurs (VOYA2) has been speciated for the various constituents that make up the fine particle mass. As identified in Figure 21, the iron processing category (interpreted to represent currently active iron mining activities) accounts for less than 1% of the fine particulate mass. This indicates that direct particulate emissions from existing taconite facilities contribute only a small amount to the fine particulate concentrations (and therefore to visibility problems) in Voyageurs. Also, most of the secondary sulfate formation in the United States and Minnesota has been attributed to power plants.[46] The EPA[47] and the MPCA[48] have also identified that power plants and highway vehicle emissions are large contributors to secondary nitrate aerosol formation. The specific contribution of mining operations to sulfate and nitrate secondary aerosol has not been identified as of this time. However, given that the primary sources of nitrates are power plants and mobile sources and that state sources contribute at most 20% to 30% to fine particulate concentrations in

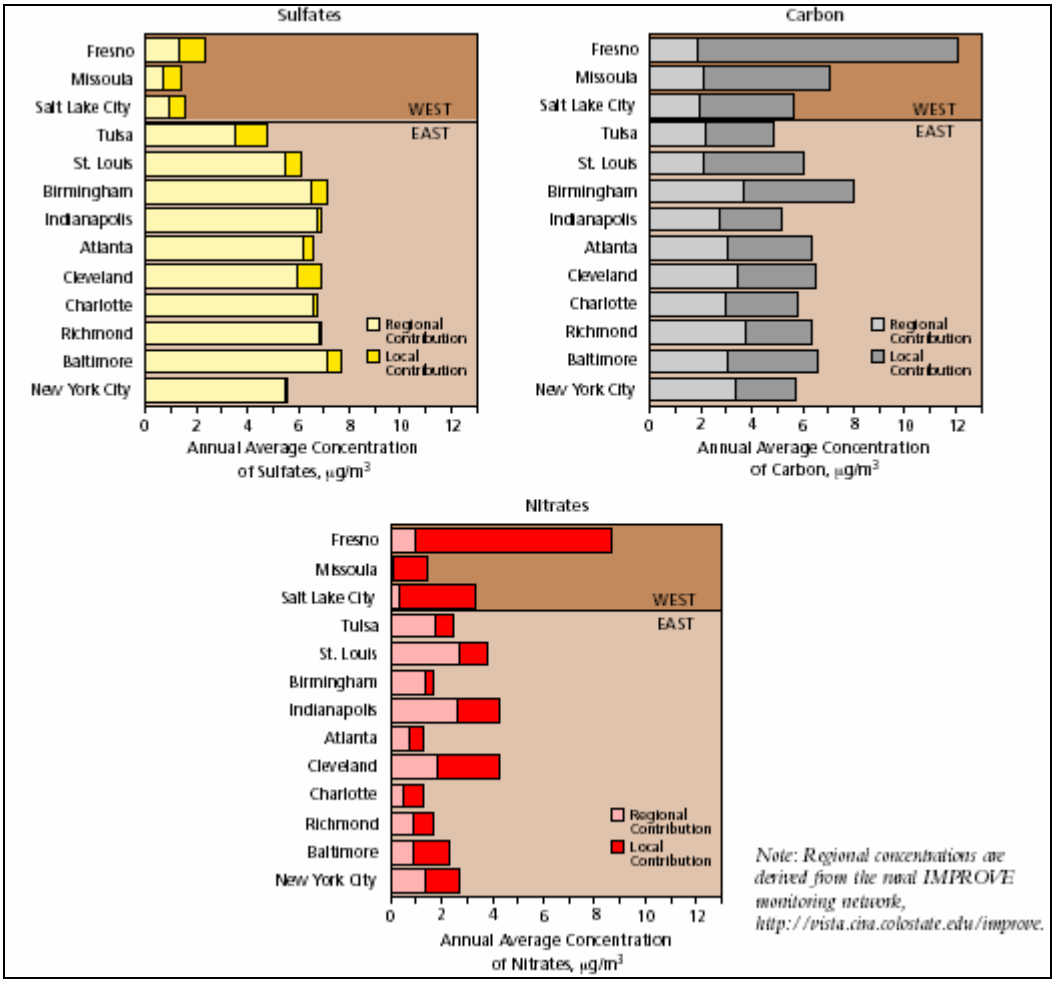
[45] EPA 2004b
[46] EPA 2004b; MPCA 2005c
[47] EPA 2004b
[48] MPCA 2005c

Voyageurs and the BWCA, it seems unlikely that mining operations would be a large contributor to secondary aerosol in Voyageurs and the BWCA.



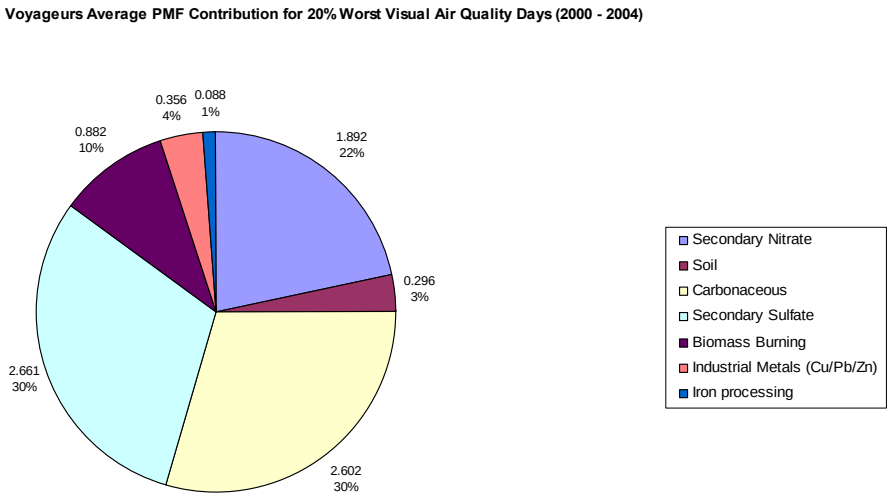
From: Minnesota Pollution Control Agency. 2005. Air Quality in Minnesota, Progress and Priorities. 2005 Report to the Legislature. P. 21. February 2005.

Figure 19 Estimated urban and regional contributions to annual fine particle concentrations in selected cities in the Midwest Region.



From: EPA, 2004b. The Particle Pollution Report. Current understanding of air quality and emissions through 2003. EPA 454-R-04-002. December 2004. Figure 7.

Figure 20 Local and regional contribution to fine particulate ($PM_{2.5}$) chemical components.



From: Causes of Haze Phase III presentation – Voyageurs National Park.

http://www.cenrap.org/reports_presentation.asp#

Note: Iron processing = 0.053 µg/m3; ~ 1% of PMF mass of 4.536 µg/m3.

Figure 21 Average fine particulate matter (PMF) contributions to Voyageurs National Park for the 20 percent worst visual air quality days (2000 – 2004 data).

3.2.3 Regional Contributions Based on Modeling Studies

The importance of regional and national contributions of sulfate and nitrate aerosol to Minnesota has been identified in air dispersion modeling studies conducted for acid deposition[49]. These modeling studies estimated that out-of-state sources contribute 85-90% of the acid deposition (as wet sulfate and wet nitrate) being deposited in Minnesota, while Minnesota sources contribute about 10-15% to acid deposition in Minnesota.

Regional modeling studies related to fine particle impacts and source contributions are being conducted by Regional Planning Organizations (RPOs). These RPOs have been created to evaluate, determine methods to improve, and track improvements in regional haze at sensitive locations within their jurisdictions. The RPOs that have conducted analyses that involve the Class I areas in Minnesota and/or assessments of contributions of Minnesota sources to modeled impacts in other states include the Western Regional Air Partnership (WRAP), Central States Regional Air Partnership (CENRAP), and the Lake Michigan Air Directors Consortium (LADCO) as part of the Midwest Regional RPO.

Emission estimates are critical for any modeling study. The CENRAP states have compiled point-source emissions for their modeling effort. Summary emissions information is presented as follows:

- Emissions from point sources in Minnesota are relatively small compared to the emissions from most of the states belonging to CENRAP (Figure 22).
- Figure 23 and Figure 24, below, show the location of regional sources of NO_x and SO_2, respectively, used in previous modeling efforts.[50]

[49] MPCA 1985; NAPAP 1991; Shannon 1999
[50] COHA 2004a,b

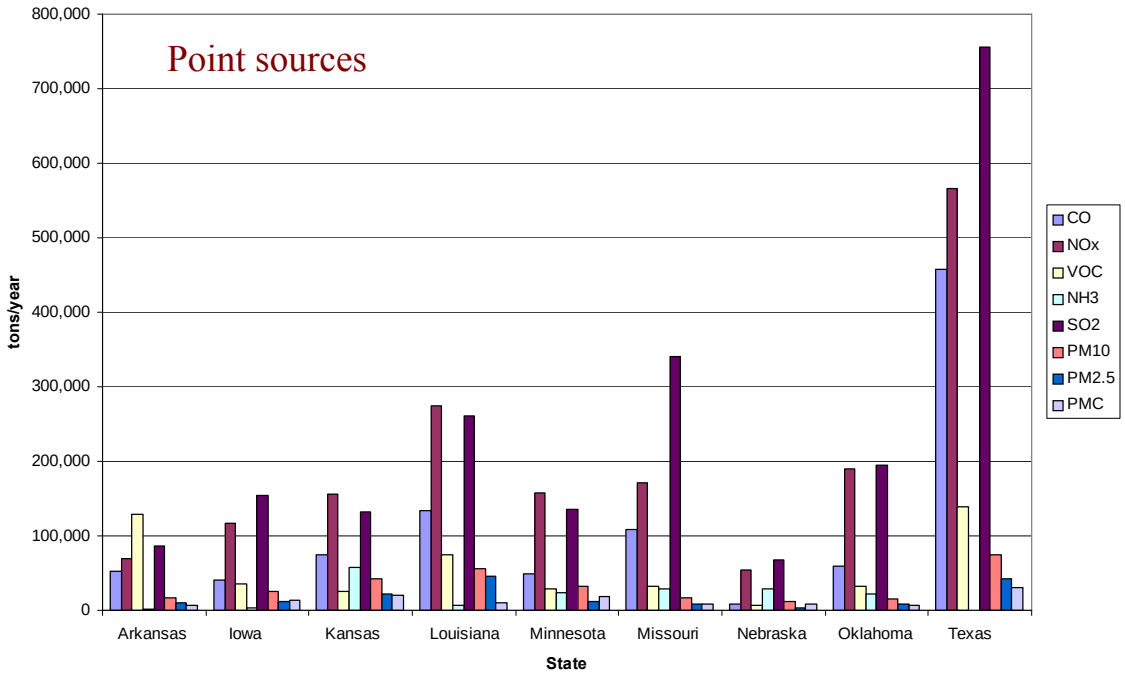
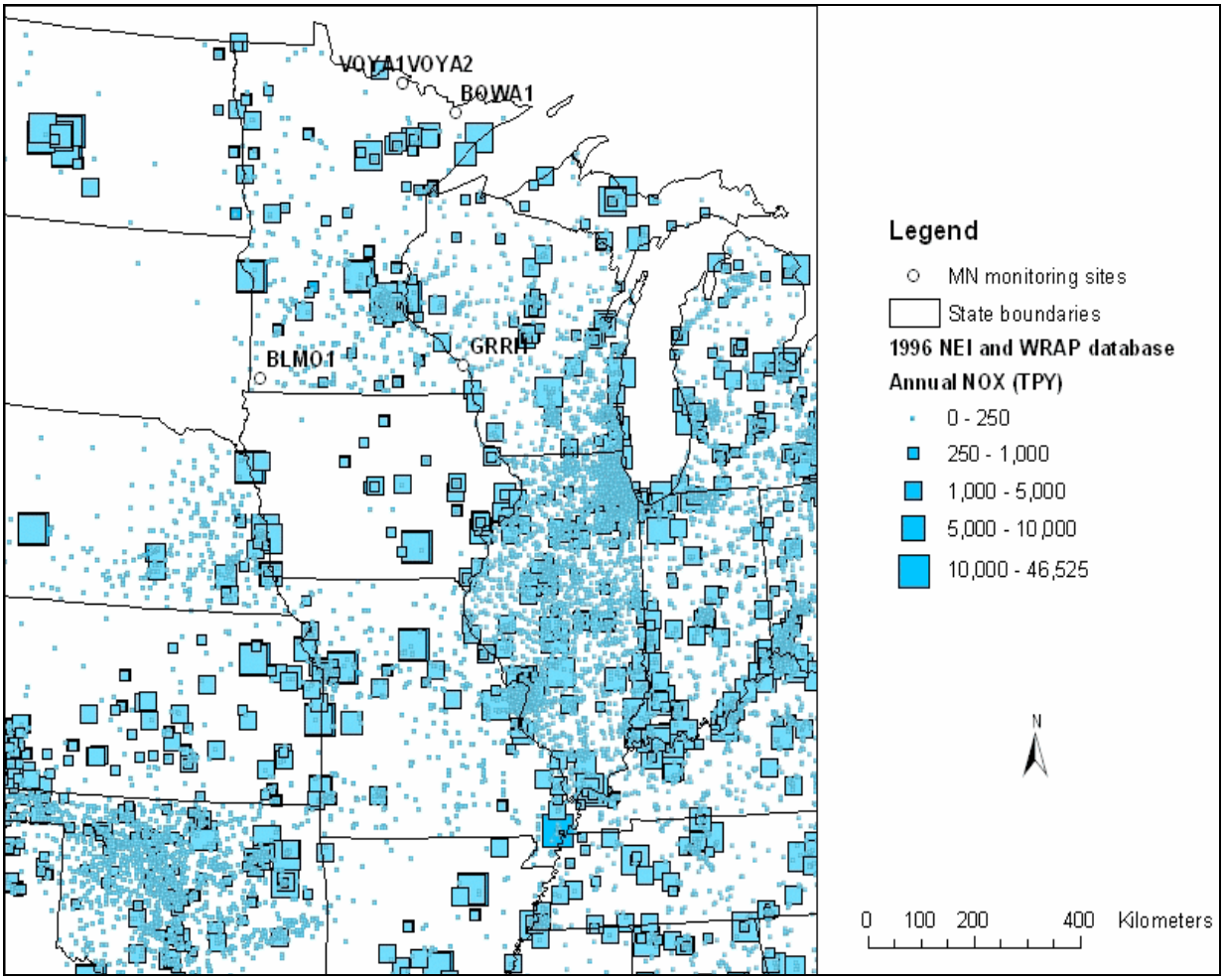


Figure downloaded from: http//www.causesofhaze.com; January 2006.

Figure 22 Magnitude of point source emissions for those states participating in the Central States Regional Air Partnership (CENRAP).



IMPROVE Monitoring sites in Minnesota: VOYA1, VOYA2 (Voyageurs National Park; northern MN)

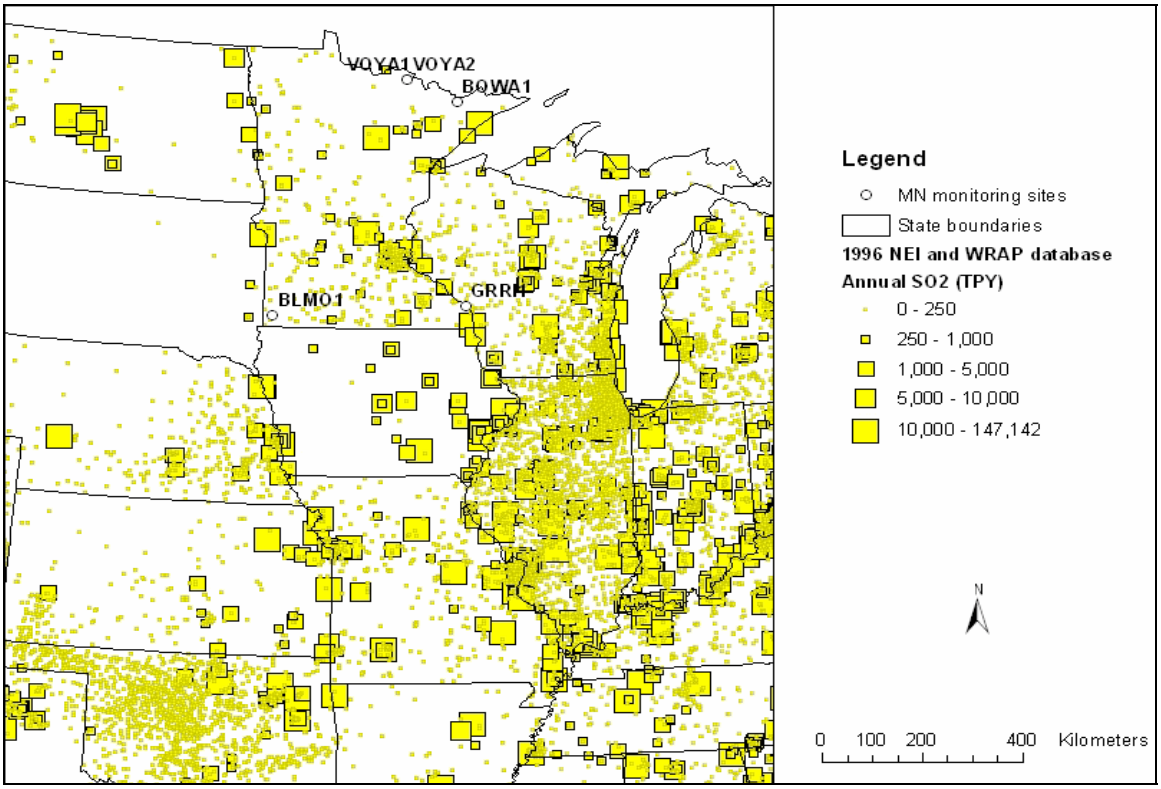
BOWA1 (Boundary Waters Canoe Area Wilderness; northern MN)

BLMO1 (Blue Mounds State Park; southwest MN)

GRRA (Great River Bluffs State Park; southeast MN)

Source: Causes of Haze Assessment website, Preliminary Conceptual Model – Causes of Haze in the Boundary Waters Canoe Area Wilderness (BOWA1). From: http://coha.dri.edu/images/clipart/mn_regional_emiss_nox.gif Note: Canadian sources are not identified in this figure.

Figure 23 Regional emissions of nitrogen oxides (NO_x) in relation to the IMPROVE monitoring sites located in Minnesota.



IMPROVE Monitoring sites in Minnesota: VOYA1, VOYA2 (Voyageurs National Park; northern MN)

BOWA1 (Boundary Waters Canoe Area Wilderness; northern MN)

BLMO1 (Blue Mounds State Park; southwest MN)

GRRA (Great River Bluffs State Park; southeast MN)

Source: Causes of Haze Assessment website, Preliminary Conceptual Model – Causes of Haze in the Boundary Waters Canoe Area Wilderness (BOWA1). From: http://coha.dri.edu/images/clipart/mn_regional_emiss_so2.gif

Note: Canadian sources are not identified in this figure.

Figure 24 Regional emissions of sulfur dioxide (SO_2) in relation to the IMPROVE monitoring sites located in Minnesota.

The importance of local emissions versus the long-range transport of emissions from large sources distant from a specific receptor is an important issue for Minnesota and other states with Class I areas and their ability to comply with reasonable progress goals of the Regional Haze Rule. As identified in Figure 23 and Figure 24, there are several relatively large sources of NO_x and SO_2 within the four-county project area. However, in order to contribute sulfate and nitrate aerosol to the fine PM air concentrations, gas-to-particle conversion involving atmospheric reactions and/or water uptake must take place within the transport time to the respective Class I area. Due to the time needed for this conversion of NO_x and SO_2 to nitrate and sulfate aerosol, respectively, and depending on meteorological conditions, it is likely that the regional sources contribute as much or more fine PM to the total measured PM_{10} in Voyageurs and the BWCA as do Minnesota sources. Based on available data from urban areas, this regional contribution may be as high as 70-80% (Figure 19) of the measured fine particle in Voyageurs and the BWCA.

Modeling results conducted by several RPOs that included Voyageurs and the BWCA in their preliminary assessments of potential source contributions are summarized below, along with a discussion of uncertainty in the model results.

3.2.3.1 CENRAP/WRAP Modeling

Modeling for visibility impairment has been conducted for the BWCA and Voyageurs using a preliminary conceptual model.[51] The preliminary conceptual modeling is based on a series of descriptive data analyses. As discussed on the COHA website[52] the purpose of the descriptive data analysis is to assist researchers in the general and detailed description of the meteorological setting of each site leading to the conceptual models of reduced visibility at all Class I areas in the WRAP and CENRAP regions. The analysis will also help researchers to understand the source-receptor relationships through spatial data analysis and data visualization.

The major findings from the preliminary conceptual models, with regard to fine particle mass and source contributions that are considered to be applicable to this cumulative impacts report, are as follows for the BWCA and Voyageurs:

[51] COHA 2004a,b
[52] http://coha.dri.edu/ index.html

Boundary Waters Canoe Area:[53]

- Analysis of 20% worst visibility days by season:
    - Summer (July August): Particulate sulfate, > 50% of fine particulate; associated with southerly winds.
    - Winter (December, January): Particulate nitrate, ~ 45% of fine particulate. Factors contributing to nitrate's importance in the winter time:
        - local and regional source contributions
        - cold temperatures that favor the partitioning of nitric acid to the particle phase
        - Frequently occurring temperature inversions.

Voyageurs National Park[54]***:***

- Analysis of 20% worst visibility days by season:
    - Summer:
        - Particulate sulfate, 40-50% of fine particulate; transported from south/southeast of the site.
        - OC/EC makes up 30-40% of fine particulate in June/July; prescribed burns or wild fires identified as major contributors of OC/EC.
    - Winter (December, January):
        - Particulate nitrate, ~ 50% of fine particulate. Factors affecting nitrate's importance in the winter are the same as identified for the BWCA.
        - Particulate sulfate, 20-30% of fine particulate; transported from south/southeast of the site.

The COHA analysis[55] identifies that airflows in winter are primarily from the north/northwest (out of Canada) at Voyageurs. COHA assumed this finding also holds for the BWCA given the close proximity of the BOWA1 monitoring site to the VOYA2 site (BOWA1 within ~ 40 km of the VOYA2 site). General emission source culpabilities in the preliminary conceptual analysis

[53] COHA 2004a
[54] COHA 2004b
[55] COHA 2004b

for both Voyageurs and the BWCA are based on source locations as depicted in Figure 23 (local Minnesota and regional NO_x sources) and back-trajectory analysis.[56]

Since the preliminary conceptual analysis was conducted for Voyageurs and the BWCA, Park *et al.* (2005) have provided more information on the contribution of nitrate and sulfate aerosol from emission sources in Canada to the Class I areas on the Canadian – U.S. border. In the case of Voyageurs and the BWCA, Park *et al.* (2005) have identified that the contribution of sulfate and nitrate aerosol from Canadian sources is larger than had been previously estimated. The transboundary pollution issue and winter nitrate concentrations are two issues that have been identified to be addressed in the detailed modeling to be conducted by the RPOs. In the COHA analysis,[57] the winter nitrate concentrations are identified as being of "local" origin. However, there are numerous factors that raise the uncertainty as to the importance of local nitrate versus regional nitrate (regional in this case meaning from outside of Minnesota and likely from outside of the U.S.). These factors include: the predominance of airflows from the north/northwest in the winter for both Voyageurs and the BWCA, the presence of NO_x sources in the prairie provinces of Canada (Figure 17), a regional fine particle contribution of approximately 70-80%, and the identified nitrate and sulfate aerosol contributions from Canadian sources (Park *et al.* 2005) to Voyageurs and the BWCA.

There is also uncertainty as to the relationship between the modeled SO_2 and NO_x contributions from Iron Range emission sources and measured nitrate and sulfate air concentrations in Voyageurs and the BWCA. The conversion of NO emitted from a specific emission source to nitrate (NO_3), and likewise SO_2 converting to sulfate (SO_4), requires time and the presence of oxidizing chemicals in the atmosphere. Therefore, it is uncertain whether NO_x and SO_2 emissions from Iron Range sources would have sufficient time to convert to the aerosol species given the relatively short distances and travel times involved from these sources to Voyageurs and/or the BWCA. The atmospheric chemistry component of the regional air quality models that are currently under development is a critical component that is currently being revised and

[56] COHA 2004a,b
[57] COHA (2004a,b)

refined to better represent the transport of air pollutants and the transformation over time of SO_2 and NO_x to sulfate and nitrate aerosol, respectively.[58]

3.2.3.2 The Lake Michigan Air Directors Consortium (LADCO)

LADCO[59] conducted a "contribution assessment" as prescribed by the Regional Haze Regulations to identify potential emission source contributions of fine particles to 10 Class I areas in the eastern U.S., including Voyageurs and the BWCA. The findings from this initial assessment are summarized below.

- The use of 48-hour back-trajectories was first used as an initial indicator of potential contributions to the selected Class I areas.[60] The 48-hour fine particle species-based back trajectories were examined to identify those (upwind) states which may be potentially impacting each Class I area on a species-by-species basis. The plots generally show that higher sulfate concentrations are associated with regions of high sulfur emissions (e.g., Ohio River Valley), higher nitrate concentrations with the region of high ammonia emissions in the upper Plains, and higher organic concentrations with nearby urban areas.
- A second analysis used 72-hour back trajectories and identified notable contributions to Voyageurs and the BWCA, respectively, of greater than 2% from: Iowa (6%, 5%), Wisconsin (6%, 8%), Ontario (14%, 16%), Manitoba (10%, 7%), and Minnesota (35%, 35%).[61]
    - Minnesota sources were estimated to contribute 5% to the Seney Wilderness in Michigan. Source contributions to Isle Royale National Park were not provided in the LADCO report.
    - The use of 48-hour back-trajectories identified Missouri and South Dakota as potential contributors to Voyageurs and the BWCA, but the 72-hour back-trajectories did not confirm those results.
    - Sulfates and nitrates are the predominant source of the fine particle fraction and the long-range transport of these pollutants.
    - In general, the 72-hour plots show that higher sulfate concentrations are associated with the Ohio River Valley (region of high SO_2 emissions), higher nitrate concentrations with the upper Plains (region of high ammonia emissions),

[58] Pun *et al.* 2004
[59] LADCO 2003
[60] LADCO 2003
[61] LADCO 2003

and higher carbon concentrations with the Southeast (region of high biogenic and fire emissions).

Back-trajectory analyses are a common tool used by the RPOs in their preliminary assessments of source contributions to specific Class I areas. As described by Fast and Berkowitz (1997), back trajectories have long been a standard tool in air-quality studies for characterizing source-receptor relationships in air pollution field campaigns, examining meteorological mechanisms associated with pollutant observations, and establishing time scales for various chemical reactions. Forward and back trajectories are also very useful in describing the atmospheric dynamics of various weather systems.

However, the errors in identifying potential source areas contributing to specific receptors can be relatively large.[62] In most cases, back-trajectory analysis tends to be more inclusive of potential source areas and likely includes source areas that have zero contributions, based on the analysis by Fast and Berkowitz (1997). In this regard, the estimates of Minnesota source contributions to Voyageurs and the BWCA of 35% have uncertainty associated with them and they are possibly conservatively high estimates (i.e., likely over-estimates) based on the discussions by Fast and Berkowitz (1997).

3.2.3.3 Detailed Modeling

Detailed and complex models are currently being tested, refined and revised for the assessment of emission source contributions to specific Class I areas. These detailed models have special modules programmed to account for the atmospheric chemistry and conversion of primary emissions of SO_2 and NO_x to sulfate and nitrate aerosol, as well as accounting for the chemistry associated with other pollutants such as ammonium (NH_4^+).

Model performance is judged in part by how well the modeled air concentrations for sulfate and nitrate match with monitored concentrations in the specific Class I areas for specific time periods. To date, the modeling efforts done for CENRAP to predict sulfate and nitrate aerosol concentrations and sulfate and nitrate deposition have had mixed results.[63] Past issues with model performance included the over-prediction of winter nitrate and under-prediction of

[62] Fast and Berkowitz, 1997
[63] Pun *et al.* 2004; Morris *et al.* 2005

summer sulfate[64]. Model improvements have included better accounting for ammonia in winter and transboundary pollution from Canada and Mexico.[65]

The atmospheric chemistry associated with the formation of regional haze is complex. The RPOs are currently working to refine models, model inputs, and model protocols that better predict haze formation. As additional research is conduced and data collected, the understanding and ability to model haze and attribute it to specific source areas will continue to improve. This detailed modeling, along with modeling to be completed for final BART requirements, will be used by Minnesota and other states to prepare their State Implementation Plan (SIP). Preliminary results indicate that additional emission reductions may be necessary in order to meet the interim 2018 goal set by the regional haze rule.[66] If final modeling still indicates a need, the SIP will include facility-specific emission reductions needed for meeting the reasonable progress goals under the Regional Haze Rule.

[64] Pun *et al.* 2004
[65] Pun *et al.* 2004; Morris *et al.* 2005
[66] See, e.g, "Technical Questions Document" at http://www.ladco.org/Regional_Air_Quality.html

4.0 Summary of State and National Emission Trends

This cumulative impact report is based on the potential emissions from ten currently proposed mining, processing, or energy projects on or near Minnesota's Iron Range. The primary air pollutants from these facilities that may affect visibility in the Class I areas are SO_2, NOx and PM_{10}. The PM_{10} cumulative report for these projects includes a summary of local, state, and national emission trends.[67]

Local Emission Trends

The PM_{10} cumulative report submitted for these projects includes a detailed summary of MPCA emission inventory trends for the four-county data (Itasca, St. Louis, Cook, Lake Counties). As described in more detail in the PM_{10} report, the projects' combined potential emissions represent an increase of about 6% SO_x, 11% NO_x, and 29% PM_{10} over existing point-source inventory emissions in the four-county area. (For PM_{10}, however, point-source emissions represent only about 4% of total PM_{10} emissions statewide; therefore, the predicted emission increase would actually be a much smaller percentage of total PM_{10} emissions in the local area.) More importantly, in the four-county area, Minnesota Power's Arrowhead Regional Emission Abatement (AREA) proposal is expected to reduce SO_2 and NO_x emissions by 3,552 tons/year and 3,745 tons/year, respectively. The proposed emission reduction project at Minnesota Power's Clay Boswell facility and other efforts would further reduce emissions from existing local sources over the next decade.

Emissions from northeastern Minnesota sources, in any case, appear to have only a limited impact on visibility in the nearby Class I areas. Figure 25, below, compares historical emissions of SO_2 in the four-county project area since 1992 with IMPROVE sulfate-only reconstructed light extinction coefficient ($b_{SULFATE}$) for the BWCA over the same time period. As shown in Figure 25, visibility impairment due to sulfate particulates, which is the primary contributor to impairment in the BWCA, has not increased since the mid-1990's despite apparent increases in four-county industrial emissions of SO_2 (local NO_x emissions have not changed significantly).

[67] Barr 1996

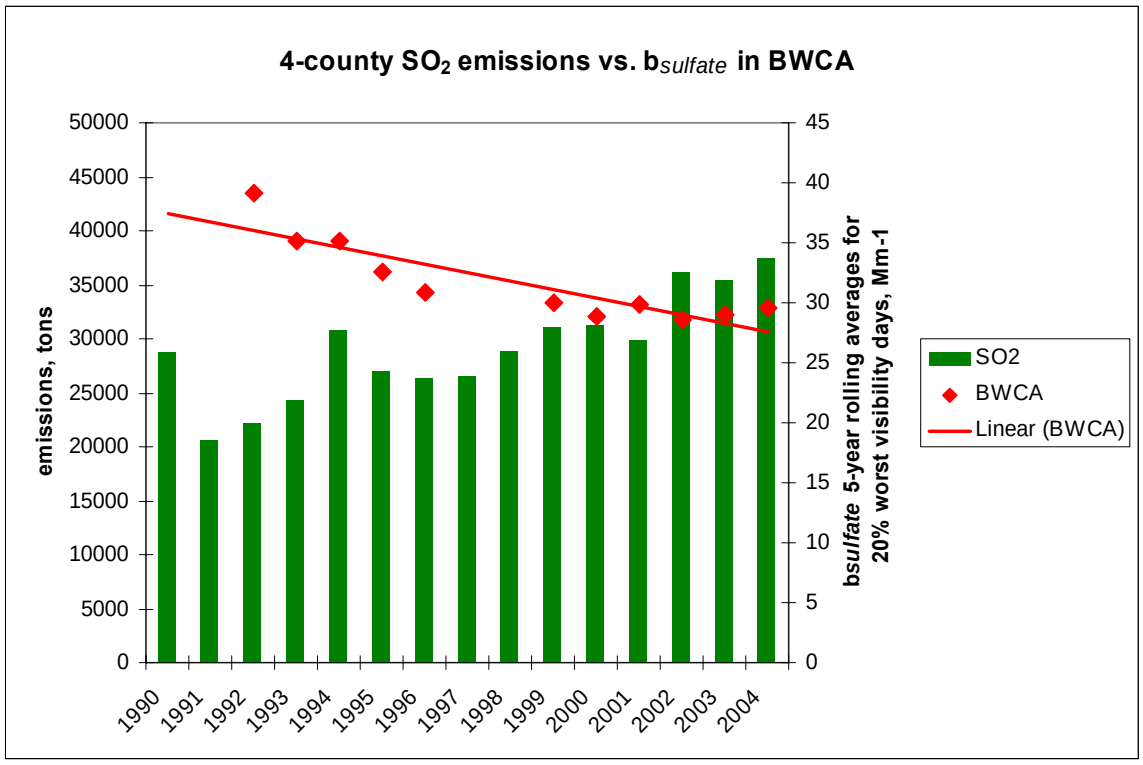


Figure 25 Historical emissions of SO_2 (1990 – 2004) in four-county area from MPCA inventory data compared to historical IMPROVE 5-year rolling average $b_{sulfate}$ extinction coefficient (20% worst days) in the BWCA.

State Emission Trends

Below is a summary of potential state emission trends assuming all ten projects are constructed as proposed and emissions from existing sources decline as expected over the next decade.

SO_2 Emissions

As shown in Table 2, above, cumulative potential SO_2 emissions from the reasonably foreseeable projects are approximately 2,413 tons per year (tons/year). (Actual cumulative emissions from these sources would be less). In 1980, statewide actual SO_2 emissions were about 250,000 tons/year[68]. Minnesota point source emissions have remained about 130,000 tons/year from about 1990 to 2002[69]. Currently, total (all sources) estimated SO_2 emissions in Minnesota are approximately 162,000 tons/year,[70] of which about 82% are from point sources (about 132,000

[68] MPCA 1990
[69] MPCA 1997; MPCA 2004
[70] MPCA 2006a

tons/year). Therefore, the cumulative potential emissions from the proposed projects represent about a 1.5% potential increase in statewide SO_2 emissions.

The estimated potential increase in local and statewide emissions do not take into account the Minnesota Power AERA project, Xcel Energy's MERP, or the Clean Air Interstate Rule (CAIR), which are expected to reduce electric generation SO_2 emissions in Minnesota by at least 40,000 tons/year by 2010. In 2004, statewide total SO_2 emissions were about 162,000 tons/year[71], of which about 100,000 tons/yr are from electric generating units. Under CAIR, electric utility SO_2 emissions are to be capped at 50,000 tons in 2010, and 38,000 tons/yr by 2015. Assuming Xcel Energy's MERP project, Minnesota Power's AREA initiative, CAIR, and existing Title IV acid rain regulations are implemented as planned, electric generating unit reductions will drive total state SO_2 emissions down from about 162,000 tons/yr currently to perhaps less than 100,000 tons/yr in 2015. Other federal "on the way" regulations such as BART may require additional SO_2 emissions reductions by 2015. Therefore, even if all the proposed projects move forward as planned, statewide SO_2 emissions are expected to decline over the next decade.

NO_x Emissions

Table 2 shows that cumulative potential NO_x emissions from the reasonably foreseeable projects are approximately 6,182 tons/year. Although point-source NO_x emissions have declined recently, total statewide NO_x emissions have been increasing gradually since the mid-1980's and are currently about 483,600 tons/year[72]. Of this, about 31% is from point sources (150,000 tons/yr) and the remainder is from vehicles. The potential 6,182 tons/year increase in NO_x emissions due to the projects is about 1.3% of total statewide emissions. This potential increase is within the year-to-year variability in actual statewide point-source emissions.

These estimated potential increases do not take into account the Minnesota Power AERA project, Xcel Energy's MERP, or the mandatory emission reductions (such as CAIR) whereby Minnesota utilities are expected to reduce their NO_x emissions by at least 50,000 tons/year by 2009, and future federal mobile source emission reduction requirements. Total statewide NO_x emissions in 2004 were about 483,600 tons/year, of which 31% is from point sources[73]. Electric generation

[71] MPCA 2006b
[72] MPCA 2006a
[73] MPCA 2006b

units in Minnesota currently emit about 90,000 tons/yr of NO_x (MPCA 2006b). Under CAIR, NO_x emissions from these units are to be capped at 50,000 tons/yr by 2009, and 26,000 tons/yr by 2015. Minnesota utilities may meet the 2010 caps through voluntary reductions (related to MERP and Minnesota Power's AREA initiative) and through allowance trading. However, they will likely need to reduce their own NO_x emissions to meet the 2015 CAIR cap. And, as with SO_2, BART and other future federal regulations are likely to require further reductions in statewide NO_x emissions, including northern Minnesota.

PM_{10} Emissions

Fine particulate ($PM_{2.5}$), SO_2, and NO_x are long-range transport pollutants most responsible for visibility impairment. For this report, however, direct emissions of PM_{10} are used as a surrogate for direct emissions of $PM_{2.5}$ because MPCA emission inventory data for $PM_{2.5}$ were only readily available for year 2004.

As shown in Table 2, above, cumulative potential PM_{10} emissions from the proposed projects are approximately 4,830 tons/year. Overall, statewide point source PM_{10} emissions have declined from about 41,000 tons/year in 2000 to about 31,350 tons/year in 2004.[74] While point source emissions have declined, they only represent about 4% of statewide PM_{10} emissions. PM_{10} emissions from other sources have increased since 2000, with approximately 783,466 tons/year emitted in 2004.[75] On a statewide basis, therefore, potential emissions from the proposed projects represent a 0.6% increase from 2004 levels.

These estimated potential increases do not take into account the potential emission reductions associated with the MERP project or mandates from regulatory actions such as CAIR, the taconite MACT, or the Regional Haze/BART rule. The specific reductions for direct PM_{10} emissions from Minnesota sources over the next decade are not quantified at this time. However, nationwide, EPA expects that implementation of BART at older existing power plants will result in significant reductions in PM emissions.[76] EPA estimates that national direct $PM_{2.5}$ emissions will be cut by 200,000 tons in 2015, compared to 2001 levels. Therefore, even if the

[74] MPCA 2006b
[75] MPCA 2006b
[76] EPA 2004b

currently proposed projects move forward, statewide PM_{10} emissions are not expected to increase significantly above 2004 levels and will be within recent (since 1996) historic levels.

Comparison of Future Project Emissions and Voluntary Statewide Reductions

Table 5 compares project emissions to net statewide emissions of PM_{10}, SO_2 and NO_x using a year 2000 baseline. If all of these projects are constructed and operated as planned, cumulative potential direct PM_{10} emissions from the proposed projects (4,847 tons per year) represent about a 15% increase in point-source emissions statewide. Of this, only a portion consists of fine particulates ($PM_{2.5}$), which is the form most likely to remain in the atmosphere long enough to affect visibility in the BWCA and Voyageurs. Cumulative SO_2 emissions due to the proposed projects are estimated to be 2,413 tons per year by 2015. This represents a potential increase of about 1.5% in statewide SO_2 emissions. Cumulative potential total NO_x emissions from the projects are estimated to be 6,182 tons per year by 2015. This represents an increase of about 1.3% increase over current statewide NOx emissions.

Table 5 Particulate matter, sulfur dioxide and nitrogen oxide emission comparison of proposed projects, past reductions since 2000, and expected future reductions due to Minnesota voluntary actions.

Description	Direct PM_{10} Emissions (tons/year)	SO_2 Emissions (tons/year)	NO_x Emissions (tons/year)
Total Statewide Point Source Emissions in 2000	41,000	134,642	165,184
Emission Reductions from Point Sources 2000-2004*	(9,650)	(2,475)	(15,259)
Potential Emission Increases from Proposed Projects**	4,847	2,413	6,182
Reasonably Foreseeable Future Reductions (2003-2015)***	(670)	(36,010)	(26,615)
Sum	35,527	98,570	129,492
Net Change in Emissions	(5,473)	(36,072)	(35,692)

**Emission reductions are estimated from emissions data in MPCA's annual pollution reports to the Minnesota Legislature in 2003 and 2006 for the year 2000 and the year 2004, respectively. Point source emissions are used in this analysis for comparison to potential emissions from the proposed projects.

** In addition to the Minnesota Steel project and PolyMet Mining's NorthMet project, this analysis includes eight other proposed projects, including the Mesabi Nugget DRI project. Table 2 in Section 1.1 of this report lists the proposed projects included in this analysis and their estimated potential SO_2 and NO_x emissions.

***Future emission reductions include: 3,550 tons/year SO_2 and 3,745 tons/year NO_x from the Minnesota Power AERA project; 670 tons/year a PM_{10}, 32,460 tons/year SO_2 and 22,870 tons/year NO_x from the Xcel Energy MERP. The relationship between the voluntary emission reductions and the potential reductions under the Clean Air Interstate Rule are undefined at this time. To avoid potential double-counting of reductions, the estimated reductions due to the Clean Air Interstate Rule are not included in this table at this time but potentially represent additional reductions in the future.

These data indicate that to the extent local and state sources contribute to visibility problems in the BWCA and Voyageurs, emissions from new sources will be offset by recent and future emission reductions within Minnesota and nationwide. For example, the shutdown of Butler Taconite (1985) and LTVSMC (2001) reduced nearby direct PM_{10}, SO_2, and NO_x emissions. And Minnesota Power's proposed Arrowhead Region Emission Abatement Project alone is expected to reduce local SO_2 emissions by 3,550 tons per year by 2009 – a decrease that is more than the total potential emissions from all currently proposed Iron Range projects. In addition, PM_{10}, SO_2 and NO_x emissions from electric generating plants, taconite facilities, and other state and local sources are likely to decline further over the next decade because of a variety of voluntary efforts and regulatory programs, including the Metropolitan Emission Reduction Project (MERP), the proposed Clay Boswell Unit 3 emission reduction project, the Clean Air Interstate Rule (CAIR), Clean Air Visibility Rule (CAVR) and other regulations.

National Emission Trends

Nationally, SO_2 emissions are currently about 16 million tons/year, which is about 32% below emissions reported in 1990. Total electric generating unit emissions are about 10.5 million tons/year. By 2010, existing acid rain regulations will cap national SO_2 emission allowances from electric generation units at 8.7 million tons annually, or about 2 million tons/year below existing levels. EPA's recent CAIR rule requires additional reductions of SO_2 and NO_x in twenty-three eastern and southern states. EPA[77] expects the CAIR rule to cut nationwide utility SO_2 emissions to 6.1 million tons/year by 2010, to 5.0 million tons/year by 2015, to 4.3 million tons/year by 2020, and to 3.5 million tons/year at full implementation.

NO_x emissions in the U.S. have also declined over the last fifteen years, but not as much as SO_2. In 2003, total annual NO_x emissions were about 18% below 1990 levels, with most of these reductions occurring in the late 1990's. NO_x emissions from electric generators have been reduced from 5.5 million tons/year in 1990 to about 4.4 million tons/year currently. NO_x emissions from electric generation units in the affected CAIR states will be further reduced by 50% by 2010, and by 60% by 2015. In addition, EPA required mobile source regulations are

[77] EPA 2005b

expected to further reduce NO_x emissions in Minnesota and nationwide between 2007 and 2010.[78]

Direct emissions of PM_{10} in the U.S. have declined by approximately 25% since 1988[79]. Due to implementation of CAIR and BART, direct emissions of PM_{10} are expected to further decline by 2015. EPA projects that direct $PM_{2.5}$ emissions will be reduced approximately 200,000 tons/year by 2015. In addition, national mobile source regulations affecting heavy-duty diesel engines, highway vehicles and other mobile sources are expected to further reduce direct PM (including $PM_{2.5}$) NO_x, and SO_2 emissions nationwide.[80]

[78] MPCA 2005c
[79] EPA 2004b
[80] EPA 2004b

5.0 Findings and Conclusions

Visibility Trends

1. Visibility in the BWCA gradually improved by 1.6 deciviews (about 16%) from 1992 to 2004 on the 20% worst visibility days, based on a 5-year rolling average. Visibility in the BWCA improved by 0.8 deciviews on median visibility days and by 0.5 deciviews on 20% best visibility days. The primary reason for the improvement in the BWCA on the 20% worst days is a 24% decline in the sulfate particulate contribution, although the nitrate particulate contribution also declined.

2. In Voyageurs the average reconstructed aerosol light-extinction coefficient, which is also a measure of visibility impairment, decreased approximately 25% from the 1989-1992 time period to the 2000-2004 time period.

Source Contribution

3. A recent analysis of speciation of fine particulate by the Central States Regional Air Partnership[81] indicates that iron processing accounts for only about 1% of the $PM_{2.5}$ in Voyageurs National Park

4. LADCO (2003) used a conservative back trajectory analysis to estimate that Minnesota emission sources contribute about 35% of fine particles to Voyageurs and the BWCA. These analyses have identified the predominance of sulfate and nitrates and the long-range transport of these pollutants. These analyses tend to identify some nearby source areas as significant contributors when the actual contribution may be small and sometimes zero[82].

5. Acid deposition modeling, which also includes the long-range transport of SO_2 and NO_x emissions and their transformation to sulfate and nitrate aerosol, respectively, indicates that out-of-state sources contribute 85-90% to acid deposition in Minnesota, while Minnesota emission sources only contribute 10-15%[83].

6. $PM_{2.5}$ monitoring data indicates that in urban areas the regional contribution of fine particles averages approximately 77% across the Upper Midwest cities of St. Paul and Minneapolis,

[81] CENRAP 2005
[82] Fast and Berkowitz 1997
[83] MPCA 1985; NAPAP 1991; Shannon 1999

St. Louis, Chicago, Milwaukee, and Detroit (MPCA 2005c). This means it is likely that at least 80% of fine particulates in rural areas of Minnesota, such as the BWCA, originate from sources located at least 100 kilometers away. Many of these sources would be located outside the state.

7. CENRAP will further define in-state and out-of-state source contributions to fine particle concentrations in Class I areas in Minnesota that will then be used along with other information to determine any additional emission reductions that are needed to meet the requirements of the Clean Air Visibility Rule (formerly known as the Regional Haze Rule).

Emission Trends

8. The potential PM_{10}, SO_2 and NO_x cumulative emissions increase from the proposed projects are relatively small in comparison to statewide emissions. To the extent local emissions affect visibility in the BWCA and Voyageurs, the potential increases in SO_2 and NO_x and PM_{10} point source emissions from the proposed projects are within historical emission levels for the four county project area and the state as a whole.

Emission Category	PM_{10} (tons/yr)	SO_2 (tons/yr)	NO_x (tons/yr)
Proposed Projects (Potential Emissions):	4,847	2,413	6,182
Statewide Emissions (all sources, 2004):	783,466	162,000	483,600
Current Four-County Area Emissions (point-source only)	16,980	37,400	54,200
Maximum Statewide Increase From Projects:	0.6%	1.5%	1.6%

9. In addition, the potential emission increases from the proposed projects will be offset by reductions from other Minnesota sources due to voluntary actions and current and foreseeable federal regulations such as EPA's acid rain program, CAIR, and Regional Haze/BART. In northeast Minnesota, Minnesota Power's Arrowhead Regional Emission Abatement (AREA) proposal reduces SO_2 and NO_x emissions by 3,552 tons/year and 3,745 tons/year, respectively. The proposed emission reduction project at Minnesota Power's Clay Boswell facility will reduce local emissions further. Finally, Xcel Energy's Metropolitan Emission Reduction Project (MERP) will reduce its emissions of SO_2, NO_x and PM_{10} emissions by approximately 32,460 tons/year, 22,870 tons/year, and 670 tons/year, respectively.

10. The visibility improvements in Voyageurs and BWCA compare well with national point source reductions of SO_2, NO_X and PM_{10} emissions identified by the EPA[84]. However, nationwide, such declines in visibility impairment are not apparent[85]. Nonetheless, it is likely that the national emission reductions in SO_2, NO_x, and $PM_{10/2.5}$ from the foreseeable regulatory actions will continue the trend of declining $PM_{10/2.5}$ air concentrations in Voyageurs and the BWCA[86].

Conclusion

The net effect from the proposed projects, the voluntary actions of Minnesota Power and Xcel Energy and the foreseeable regulatory actions will be to reduce emissions of SO_2, NO_x, and PM_{10} in Minnesota. Subsequently, these foreseeable Minnesota emission reductions should continue to improve the visibility in Voyageurs and the BWCA, although it is uncertain as to the degree of visibility improvement that will be obtained from the Minnesota emission reductions alone. Additional improvement in the air quality of Voyageurs and the BWCA is expected due to national reductions of SO_2, NO_x, and $PM_{10/2.5}$ emissions. Therefore, the gradual visibility improvement in Voyageurs and the BWCA since approximately 1990 is expected to continue into the future.

[84] EPA 2004b
[85] EPA 2006
[86] EPA 2005b,c

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Abbreviations / Acronyms / Selected Definitions

[Visibility related abbreviations and definitions adapted from EPA 2003; Guidance for Tracking Progress Under the Regional Haze Rule; EPA-454/B-03-004.]

BART	Best Available Retrofit Technology
BWCA	Boundary Waters Canoe Area (Wilderness); located in northeast Minnesota
CAA / CAAA	Clean Air Act / Clean Air Act Amendments
CAIR / CAMR	Clean Air Interstate Rule / Clean Air Mercury Rule
CENRAP	Central States Regional Air Partnership: one of five regional planning organizations for Implementing the Regional Haze Rule. Member states include Minnesota, Iowa, Nebraska, Missouri, Arkansas, Kansas, Oklahoma, Texas, Louisiana
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CIRA	Cooperative Institute for Research in the Atmosphere, Colorado State University
COHA	Causes of Haze website; sponsored by the WRAP and CENRAP (http://coha.dri.edu/)
CM	Coarse particle mass (same as PMC)
DRI	Direct Reduced Iron
DMS	dimethyl sulfide (from Park et al. 2005)
Dv or dv	Deciview, unit of the haze index
EC	Elemental carbon
EIS	Environmental Impact Statement
EPA, USEPA	United States Environmental Protection Agency
IMPROVE	Interagency Monitoring of Protected Visual Environments
km	kilometer
LAC	Light absorbing carbon
LADCO	Lake Michigan Air Directors Consortium (member states include IL, IN, MI, OH, WI)
LTVSMC	LTV Steel Mining Company
MACT	Maximum Achievable Control Technology
MERP	Xcel Energy's Metropolitan Emission Reduction Project
MDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
Mm^{-1}	Inverse megameter (10^{-6} m^{-1})
NO_X	Oxides of nitrogen

LAC	Light absorbing carbon
OC	Organic carbon
OMC	Organic carbon mass
PIXE	Proton induced x-ray emission spectroscopy
PM	Particulate matter
PMC	Particulate matter, coarse (aerodynamic size fraction between 10 and 2.5 microns) (same as CM)
PMF	Particulate matter, fine (typically referred to as $PM_{2.5}$)
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than 2.5 microns
PM_{10}	particulate matter with an aerodynamic diameter less than 10 microns
PSD	Prevention of Significant Deterioration
PTE	Potential-to-emit as defined at 40 CFR 52.21(b)(4)
RH	Relative humidity
RPO	Regional Planning Organization
SIP	State Implementation Plan
SO_2	Sulfur dioxide
SO_x	Sulfur oxides – including all of the oxides of sulfur
ton	Short ton = 2,000 pounds
ton, long	Long ton = 2240 pounds
ton, metric	Metric ton = 2204.6 pounds
$\mu g/m^3$	micrograms per cubic meter
µm	micrometer or micron; one-millionth of a meter.
U.S.	United States
VNP	Voyageurs National Park; located in northeast Minnesota
WRAP	Western Region Air Partnership. One of five regional planning organizations formed to implement the Regional Haze Rule. Member states include: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming
Yr or yr	year

Selected Definitions

Aerosols – suspensions of tiny liquid and/or solids particles in air.

Class I Area – Under the Clean Air Act, a Class I area is one in which air quality is protected more stringently than under the national ambient air quality standards; Federal Class I areas include national parks, wilderness areas, monuments, and other areas of special national and cultural significance. Mandatory Federal Class I

areas include certain national parks (over 6,000 acres), wilderness areas (over 5,000 acres), national memorial parks (over 5,000 acres), and international parks that were in existence as of August 1977.

Federal Class I Areas in Minnesota – Boundary Waters Canoe Area Wilderness and Voyageurs National Park.

Coarse mass – mass of particulate matter with an aerodynamic diameter greater than 2.5 microns but less than 10 microns.

Deciview (dv) – the unit of measurement of haze, as in the haze index (HI) defined below.

Fine soil – particulate matter composed of pollutants from the Earth's soil, with an aerodynamic diameter less than 2.5 microns. The soil mass is calculated from chemical mass measurements of fine aluminum, fine silicon, fine calcium, fine iron, and fine titanium as well as their associated oxides.

Haze Index – a measure of visibility derived from calculated light extinction measurements that is designed so that uniform changes in the haze index correspond to uniform incremental changes in visual perceptions, across the entire range of conditions from pristine to highly impaired. The haze index [in units of deciviews (dv)] is calculated directly form the total light extinction [b_{ext} expressed in inverse megameters (Mm^{-1})] as follows:

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

Light absorbing carbon – carbon particles in the atmosphere that absorb light; also reported as elemental carbon.

Least-impaired days – data representing a subset of the annual measurements that correspond to the clearest, or least hazy, days of the year.

Light extinction – a measure of how much light is absorbed or scattered as it passes through a medium, such as the atmosphere. The aerosol light extinction refers to the absorption and scattering by aerosols, and the total light extinction refers to the sum of the aerosol light extinction, the absorption of gases (such as NO2), and the atmospheric light extinction (Rayleigh scattering).

Most impaired days – data representing a subset of the annual measurements that correspond to the dirtiest, or haziest, days of the year.

Nitrate – solid or liquid particulate matter containing ammonium nitrate [NH_4NO_3] or other nitrate salts. Atmospheric nitrate aerosols are often formed from the atmospheric oxidation of oxides of nitrogen (NO_X).

Organic carbon – aerosols composed of organic compounds, which may result from emissions from incomplete combustion processes, solvent evaporation followed by atmospheric condensation, or the oxidation of some vegetative emissions.

Particulate matter – material that is carried by liquid or solid aerosol particles with aerodynamic diameters less than 10 microns. The term is used for both the in situ atmospheric suspension and the sample collected by filtration or other means.

Particulate matter, coarse (PMC) – particulate matter with an aerodynamic diameter less than 10 microns but greater than 2.5 microns.

Particulate matter, fine (PMF) – particulate matter with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$).

Rayleigh scattering ($b_{RAYLEIGH}$) – light scattering of the natural gases in the atmosphere. At an elevation of 1.8 kilometers, the light extinction from Rayleigh scattering is approximately 10 inverse megameters (Mm^{-1}). This is the standard value used in visibility calculations regardless of site elevation in keeping with the practice of rounding each constant in the aerosol extinction coefficient to one significant digit and to simplify comparisons of values among sites at a variety of elevations.

Relative humidity – partial pressure of water vapor at the atmospheric temperature divided by the vapor pressure of water at that temperature, expressed as a percentage.

Sulfate – solid or liquid particulate matter composed of sulfuric acid [H_2SO_4], ammonium bisulfate [NH_4HSO_4], or ammonium sulfate [$(NH4)_2SO_4$]. Atmospheric sulfate aerosols are often formed form the atmospheric oxidation of sulfur dioxide.

Taconite – low-grade iron ore processed by crushing and concentrating to yield a pellet for use in iron smelters. Taconite has low mercury concentrations but large volumes of the material are heated during processing, which releases significant quantities of mercury into the atmosphere.

Total carbon – sum of the light absorbing carbon and organic carbon.

Visibility impairment – any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions. This change in atmospheric transparency results from added particulate matter or trace gases.

Appendix A

Methods Used by IMPROVE to Calculate Light Extinction

The method used by the IMPROVE program reconstructs the total light-extinction coefficient from aerosol measurements and from relative humidity data. IMPROVE recently updated and revised its calculation methods because the older method tended to underestimate the highest extinction values and over-estimate the lowest extinction values (IMPROVE 2006).

The revised IMPROVE program's methodology considers

- the scattering of light by particles,
- the scattering of light by atmospheric gases (Rayleigh scattering),
- the adsorption of light by elemental carbon particles (soot), and
- the adsorption of visible light by nitrogen dioxide (NO_2).

The reconstructed total light-extinction coefficient (b_{TOTAL}) has twelve components. Components may be a composite of multiple measured species, or may be derived from measured species by appropriate conversion factors (IMPROVE 2006). Standard practice in visibility calculations is to round each constant in the aerosol extinction calculation to one significant digit, regardless of site elevation (EPA 2003a).

The total light-extinction coefficient has three fundamental components: aerosol, Rayleigh, and NO_2 adsorption.

$$b_{TOTAL} = b_{AEROSOL} + b_{RAYLEIGH} + b_{NO2} \qquad \text{(A.1)}$$

in which

b_{TOTAL} is the reconstructed total light-extinction coefficient expressed as inverse megameters (1/Mm or Mm^{-1}),
$b_{AEROSOL}$ is the reconstructed light-extinction coefficient for the scattering and adsorption of light by aerosols (Mm^{-1}),
$b_{RAYLEIGH}$ is the site-specific light-extinction coefficient for the Rayleigh scattering of light by atmospheric gases and is a function of elevation and annual average temperature (Mm^{-1}), and
b_{NO2} is the reconstructed light-extinction coefficient for the adsorption of visible light by gas-phase NO_2 (Mm^{-1}).

The IMPROVE program has defined a $b_{RAYLEIGH}$ value of 11 Mm^{-1} for BOWA1 (IMPROVE 2006).

As of the March 2006 update of the IMPROVE database, the determination of b_{TOTAL} for BOWA1 does not include b_{NO2}.[87] Thus, the impact of b_{NO2} is not considered in assessing the long-term haze index trends for the Boundary Waters Canoe Area.

The reconstructed aerosol light-extinction coefficient $b_{AEROSOL}$ describes the scattering and adsorption of light by particles and has several components.

$$b_{AEROSOL} = b_{SULFATE} + b_{NITRATE} + b_{OMC} + b_{EC} + b_{SOIL} + b_{CM} + b_{SEASALT} \qquad (A.2)$$

in which

$b_{SULFATE}$ is the light-extinction coefficient for the scattering of light by ammonium sulfate particles (Mm^{-1}),
$b_{NITRATE}$ is the light-extinction coefficient for the scattering of light by ammonium nitrate particles (Mm^{-1}),
b_{OMC} is the light-extinction coefficient for the scattering of light by particles of organic matter (Mm^{-1}),
b_{EC} is the light-extinction coefficient for the adsorption of light by particles of elemental carbon (Mm^{-1}),
b_{SOIL} is the light-extinction coefficient for the scattering of light by soil particles (Mm^{-1}),
b_{CM} is the light-extinction coefficient for the scattering of light by particles of coarse matter (Mm^{-1}), and
$b_{SEASALT}$ is the light-extinction coefficient for the scattering of light by sea salt particles (Mm^{-1}).

The individual particulate extinction coefficients are reconstructed from the measured particle chemical species. The extinction coefficient for the scattering of light by ammonium sulfate particles is defined by the following equation:

$$b_{SULFATE} = 2.2 f_S(RH)[Small\ SULFATE] + 4.8 f_L(RH)[Large\ SULFATE] \qquad (A.3)$$

in which

2.2 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$),
$f_S(RH)$ is the relative humidity scatter enhancement factor for the small particle size fraction (dimensionless),
[*Small SULFATE*] is the concentration of the small ammonium sulfate particles ($\mu g/m^3$),
4.8 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$),

[87] (http://vista.cira.colostate.edu/view/web/improve/summarydata.aspx)

$f_L(RH)$ is the relative humidity scatter enhancement factor for the large particle size fraction (dimensionless), and
[*Large SULFATE*] is the concentration of the large ammonium sulfate particles ($\mu g/m^3$).

The distribution of ammonium sulfate particles into the small and large particle size fractions varies with the total ammonium sulfate concentration [*Total SULFATE*]. When the total ammonium sulfate concentration is less than 20 $\mu g/m^3$, the small and large particle size fractions are defined by the following two equations

$$[Large\ SULFATE] = \frac{[Total\ SULFATE]^2}{20} \tag{A.4}$$

$$[Small\ SULFATE] = [Total\ SULFATE] - [Large\ SULFATE] \tag{A.5}$$

in which 20 has the units $\mu g/m^3$. When [*Total SULFATE*] is greater than or equal to 20 $\mu g/m^3$, all of the ammonium sulfate particles considered of the large particle size fraction:

$$[Large\ SULFATE] = [Total\ SULFATE] \tag{A.6}$$

$$[Small\ SULFATE] = 0 \tag{A.7}$$

The same total concentration test and equations [(A.4) through (A.7)] are used to determine the distribution of ammonium nitrate and organic matter particles into small and large particle size fractions. Figure A.1 illustrates the distribution between the small and large fractions as a function of total particle concentration.

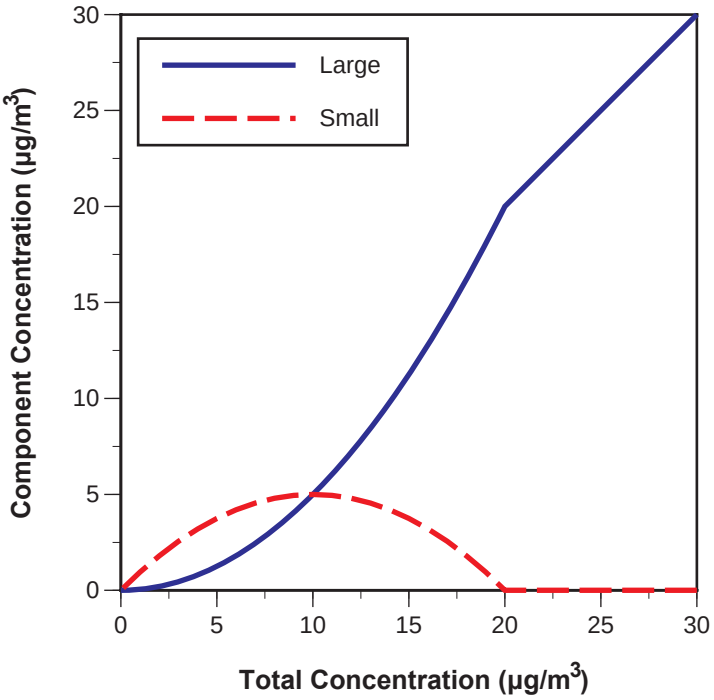


Figure A.1 **Small and large particle size fraction concentrations as a function of total particle concentration. The updated IMPROVE methodology uses the plotted component distributions for ammonium sulfate particles, ammonium nitrate particles, and organic matter particles.**

The extinction coefficient for the scattering of light by ammonium nitrate particles is defined by the following equation:

$$b_{NITRATE} = 2.4 f_S(RH)[Small\ NITRATE] + 5.1 f_L(RH)[Large\ NITRATE] \qquad \text{(A.8)}$$

in which

2.4 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$),
[*Small NITRATE*] is the concentration of the small ammonium nitrate particles ($\mu g/m^3$),
5.1 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$), and
[*Large NITRATE*] is the concentration of the large ammonium nitrate particles ($\mu g/m^3$).

The distribution of ammonium nitrate particles into the small and large particle size fractions has the same relationship as ammonium sulfate with the total particle concentration (Figure A.1).

The extinction coefficient for particles of organic matter is obtained from

$$b_{OMC} = 2.8 f_S(RH)[Small\ OMC] + 6.1 f_L(RH)[Large\ OMC] \quad (A.9)$$

in which

2.8 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$),
[*Small OMC*] is the concentration of the small organic matter particles ($\mu g/m^3$),
6.1 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$), and
[*Large OMC*] is the concentration of the large organic matter particles ($\mu g/m^3$).

The distribution of OMC particles into the small and large particle size fractions has the same relationship as ammonium sulfate with the total particle concentration (Figure A.1). The total concentration of organic matter particles is assumed equal to 1.8 times the measured organic carbon concentration.

$$[Total\ OMC] = 1.8[OC] \quad (A.10)$$

The factor of 1.8 adjusts the organic carbon concentration [*OC*] for the other elements associated with molecules of organic matter.

The extinction coefficient for the adsorption of light by elemental carbon particles (soot) is defined by the IMPROVE method as:

$$b_{EC} = 10[EC] \quad (A.11)$$

in which

10 is an empirical constant ($m^3\ \mu g^{-1}\ Mm^{-1}$), and
[*EC*] is the calculated concentration of elemental carbon ($\mu g/m^3$).

The extinction coefficient for the scattering of light by soil particles is:

$$b_{SOIL} = 1[SOIL] \quad \text{(A.12)}$$

in which

1 is an empirical constant (m^3 μg^{-1} Mm^{-1}), and
[*SOIL*] is the calculated concentration of soil particles ($\mu g/m^3$).

The extinction coefficient for the scattering of light by coarse particulate matter is obtained from the following equation:

$$b_{CM} = 0.6[CM] \quad \text{(A.13)}$$

in which

0.6 is an empirical constant (m^3 μg^{-1} Mm^{-1}), and
[*CM*] is the concentration of coarse matter ($\mu g/m^3$) obtained from the difference of the PM_{10} and $PM_{2.5}$ gravimetric measurements.

The extinction coefficient for the scattering of light by particles of sea salt is

$$b_{SEASALT} = 1.7 f_{SS}(RH)[SEA\ SALT] \quad \text{(A.14)}$$

in which

2.7 is an empirical constant (m^3 μg^{-1} Mm^{-1}),
$f_{SS}(RH)$ is the relative humidity scatter enhancement factor for sea salt particles (dimensionless), and
[*SEA SALT*] is the calculated concentration of sea salt particles ($\mu g/m^3$).

The concentration of sea salt particles is calculated from the measured chloride concentration

$$[SEA\ SALT] = 1.8[CHLORIDE] \quad \text{(A.15)}$$

in which

1.8 is an empirical constant (m^3 μg^{-1} Mm^{-1}),
[*CHLORIDE*] is the measured chloride concentration ($\mu g/m^3$).

If the chloride concentration measurement is below detection limits, missing, or invalid, then the measured chlorine concentration is used (IMPROVE, 2006).

The three relative humidity scatter enhancement factors $f_S(RH)$, $f_L(RH)$, and $f_{SS}(RH)$ account for water uptake by the hygroscopic ammonium sulfate, ammonium nitrate, organic matter, and sea salt particles, respectively. The hygroscopic particles form solution droplets that increase in size with increasing relative humidity (*RH*). The relationship between light scattering and relative humidity is nonlinear. Also, the relationship between scattering and relative humidity is subject to hysteresis. The relative humidity at which the hygroscopic particles spontaneously form solution droplets with increasing relative humidity (deliquescent relative humidity) is different from the relative humidity at which the particles spontaneously quit being solution droplets and solidify with decreasing relative humidity (crystallization relative humidity) (IMPROVE 2000). The relationships between the each of the three scatter enhancement factors and relative humidity are provided in Figure A.2.

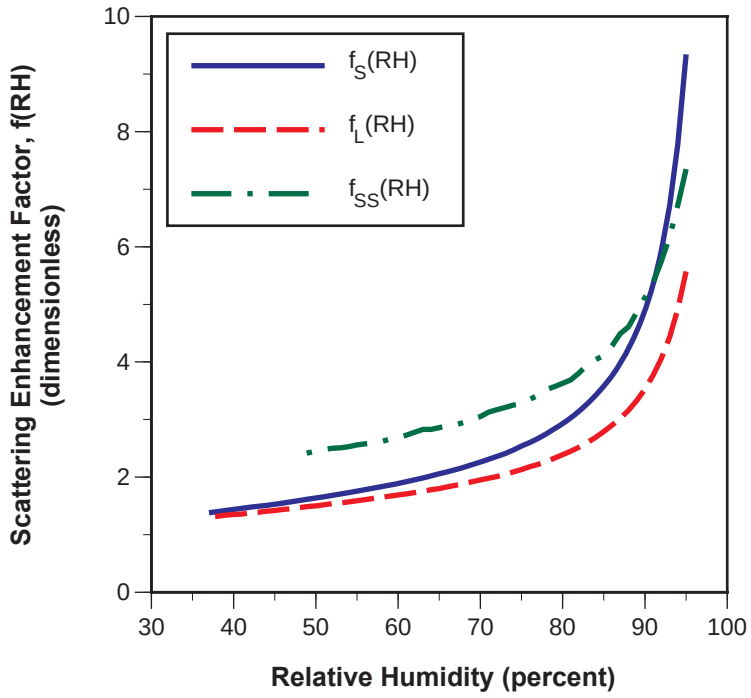


Figure A.2 **Relative-humidity scattering enhancement factors $f_S(RH)$, $f_L(RH)$, and $f_{SS}(RH)$ as a function of relative humidity (IMPROVE, 2006).**

The monthly average $f(RH)$ values for the Boundary Waters monitoring site (BOWA1) are provided on Figure A.3. These monthly $f(RH)$ values were used to reconstruct the BOWA1 aerosol light-extinction coefficients on a daily, monthly, seasonally, quarterly, and annual basis.

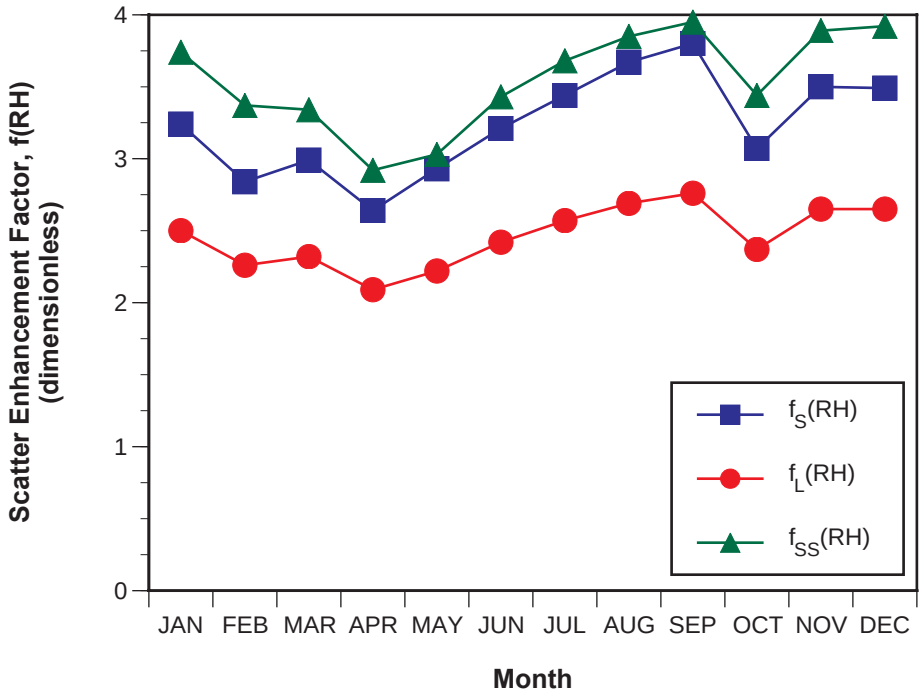


Figure A.3 **Monthly $f(RH)$ values used by the IMPROVE program for the Boundary Waters monitoring station (BOWA1) located in northeast Minnesota.**

Appendix B

Database Completeness

Five-year rolling average Haze Index values are used for tracking progress under the Regional Haze Rule Program. At least 3 complete years of IMPROVE monitoring data are required for calculation of a rolling 5-year average. In order for a year of monitoring data to be considered complete, the following three criteria must be met (EPA 2003a):

- complete data should be available for at least 50 percent of the scheduled sampling days in each quarter of the year,
- complete data should be available for at least 75 percent of all scheduled sampling days in a year, and
- there should be no more than 10 missing scheduled sampling days in a row at any time during the calendar year.

The years of the IMPROVE monitoring data for the BOWA1 site that meet the complete year criteria are provided in Table B.1. The years with calculable 5-year rolling averages are 1992, 1993, 1994, 1995, 1996, and 1999. As of March 2006, 5-year rolling averages cannot be obtained for 1991, 1997, 1998, 2000, 2001, 2002, 2003, and 2004 under the Regional Haze Rule Program completeness criteria. At present, acceptable IMPROVE data is not available to determine the baseline visibility condition (years 2000 through 2004) for the BOWA1 site under the Regional Haze Rule Program.

Because strict application of the annual completeness criteria under the Regional Haze Rule Program only provided 5-year rolling averages for 6 of the 14 monitoring years, a less strict completeness criterion was used in this report. In evaluating the long-term trends in light-extinction coefficients and in the haze index, a monitoring year was considered complete if each quarter of the year had acceptable data for at least 50 percent of the scheduled sampling days. As shown in Table B.1, the relaxed completeness criterion allowed 5-year rolling averages to be calculated for all monitoring years except 1991, 1997, and 1998. With 11 of 14 monitoring years having

calculable 5-year rolling averages, long-term trends in visibility at the BOWA1 site can be evaluated as provided in the report.

Table B.1 Comparison of IMPROVE data for complete years, years with four complete quarters, and years with calculable a five-year rolling averages for the BOWA1 site. [88]

Monitoring Year	Complete Year	Year with Calculable 5-Year Rolling Average	Year with Four Complete Quarters	Year with Calculable 5-Year Rolling Average
1991				
1992	*	*	*	*
1993	*	*	*	*
1994	*	*	*	*
1995	*	*	*	*
1996		*		*
1997	*		*	
1998				
1999		*		*
2000	*		*	*
2001	*		*	*
2002			*	*
2003			*	*
2004			*	*

Table B.2 provides a linear regression analysis of entire IMPROVE data set used in this report, including slopes and regression coefficients (r^2) for the linear least-squares fit of the 5-year rolling average trends (BOWA1). As indicated by the data in Table B.2, there is a strong statistical relationship (r^2) between improved visibility on the 20% worst days over time in the BWCA for the last decade.

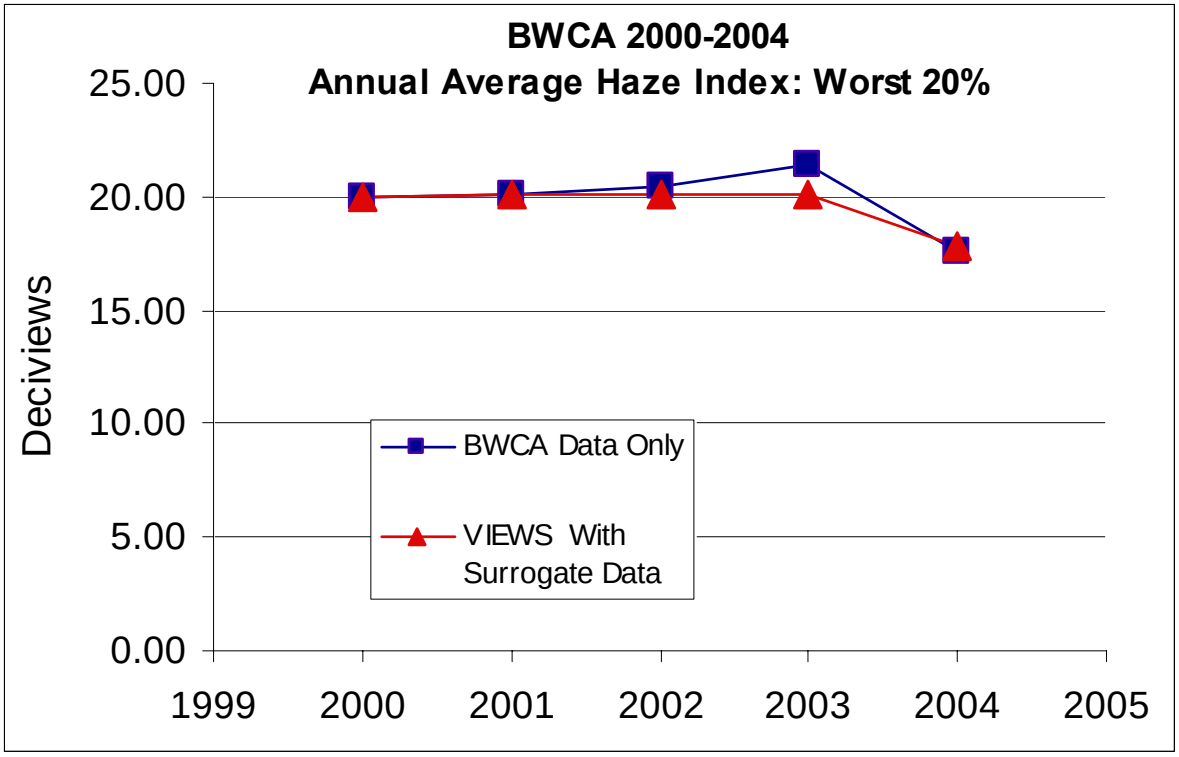
[88] (http://vista.cira.colostate.edu/view/web/improve/summarydata.aspx)

Table B.2. Linear Regression statistics of IMPROVE 5-year rolling average haze index for BWCA (BOWA1) for all years shown in Table 1, including slopes and regression coefficients (r^2) for the linear least-squares fit.

		Slope	20% Worst Visibility Days		Median Visibility Days	
		Units	slope	r^2	slope	r^2
Extinction Coefficient	AEROSOL	Mm^{-1}/year	-0.99	0.85	-0.14	0.36
	SULFATE	Mm^{-1}/year	-0.71	0.78	-0.23	0.74
	NITRATE	Mm^{-1}/year	-0.14	0.25	0.00	0.01
	OMC	Mm^{-1}/year	-0.08	0.04	0.13	0.69
Haze Index	HI	deciview/year	-0.11	0.86	-0.04	0.39
PM_{10} Concentration	PM10	$(\mu g/m^3)$/year	-0.21	0.92	-0.10	0.88

Finally, the Visibility Information Exchange Web Site (VIEWS) recently posted a surrogate data set for the BWCA for the years 2000 through 2004, based on linear regression analysis of data from Voyageurs.[89] Figure B.1 compares the unadjusted *annual* (not 5-year rolling) average haze-index for the BWCA for 2000-2004 as calculated for this report to the VIEWS surrogate data set. This comparison shows that the two methods provide nearly identical annual average values (deciviews) for the 20% worst days for all years except 2003, when the uncorrected data is slightly higher. The resulting 5-year (20% worst day) average for 2000-2004 using the VIEWS surrogate data (as posted November, 2006) is 19.59. The 5-year average for the worst 20% days using the uncorrected BWCA data, omitting days with missing data, is 19.89 deciviews. At both the BWCA and Voyageurs, the annual average improved by over 1.5 deciviews in 2004 compared to 2003 due to reductions in sulfate, nitrate and organic carbon.

[89] Visibility Information Exchange Web System (VIEWS) http://vista.cira.colostate.edu/views).



VIEWS DATA: Site: BOWA1. **Series** - Parameter: dv. **Metadata** - Program: IRHR2, Poc: 1, Parameter: dv, Aggregation: Worst 20%, Method: Substituted dataset

Figure B.1 Annual average Haze Index on 20% worst days in the BWCA for 2000-2004 (non-corrected data BOWA1; days with missing data omitted) compared to VIEWS surrogate estimate using Voyageurs data. VIEWS surrogate data downloaded 10-09-06. (http://vista.cira.colostate.edu/views). Baseline 5-year rolling annual average for BOWA1 data for 2000-2004 is 19.89; 5-year baseline using surrogate data from VIEWS is 19.59.