S·A·M·I

SOUTHERN APPALACHIAN
MOUNTAINS INITIATIVE

FINAL REPORT

AUGUST 2002

SOUTHERN APPALACHIAN MOUNTAINS INITIATIVE PARTICIPANTS

Governing Body

Director, Alabama Department of Environmental Management
Director, Environmental Protection Division, Georgia Dept. of Natural Resources
Secretary, Kentucky Natural Resources and Environmental Protection Cabinet
Secretary, North Carolina Department of Environment and Natural Resources
Deputy Commissioner, South Carolina Department of Health and Environmental Control
Commissioner, Tennessee Department of Environment and Conservation
Director, Virginia Department of Environmental Quality
Secretary, West Virginia Department of Environmental Protection Regional Administrator
U.S. Environmental Protection Agency – Region III
Regional Administrator, U.S. Environmental Protection Agency – Region IV
Superintendent of Blue Ridge Parkway, National Park Service
U. S. Forest Supervisor, Francis Marion and Sumter National Forests, U.S. Forest Service
Principal Scientist, Southern Company (Industry Representative)
Southeast Air Quality Manager, Environmental Defense (Environmental Representative)

Organizations

State of Alabama
Alabama Audubon Council
Alabama Power
Allegheny Power
American Electric Power
Appalachian State University
Appalachian Voices
Buncombe County, NC Extension Office
Buncombe County Metropolitan Sewerage District
Celanese Acetate, LLC
Center for Entrepreneurship Education and Development
Chevron
Clean Air Conservancy (OH)
Council of Industrial Boiler Owners
Dominion Power
Duke Energy
Duke Power
Eastern Band of the Cherokee Indians
Eastman Chemical Company
Ecusta, a Division of P.H. Glatfelter
Environmental Defense
State of Georgia
Georgia Power
Georgia State University
Great Smoky Mountains National Park
Jackson & Kelly, PLLC
Commonwealth of Kentucky
Land of Sky Regional Council
Mammoth Cave National Park
Mountaineer Chapter of Trout Unlimited
Mountain Air Quality Coalition
National Park Service
National Parks Conservation Association
NC State University
State of North Carolina
Oak Ridge National Labs
Progress Energy
Public Service Company of NC Inc.
Riverlink
Saturn Corporation
SEIF
Southeast States Air Resource Managers (SESARM)
Shenandoah National Park
State of South Carolina
South Carolina Wildlife Federation
Southern Alliance for Clean Energy
Southern Appalachian Man and Biosphere
Southern Company
Southern Environmental Law Center
State of Tennessee
Tennessee Valley Authority
University of North Carolina at Asheville
University of Tennessee
University of Virginia
U.S. Environmental Protection Agency
U.S. Forest Service
Commonwealth of Virginia
Virginia Conservation Network
Virginia Power
Virginia Trout Unlimited
State of West Virginia
West Virginia Citizens Action Group
West Virginia Highlands Conservancy
Western North Carolina Clean Air Campaign
Western North Carolina Air Control Agency

DEDICATION

This report is dedicated to Arthur Smith, who personified the SAMI approach of dedication to values while respecting the viewpoints of others, insistence on good science, and somehow finding the middle ground when it was needed most.

Contractors That Contributed to SAMI Research

ABT Associates, Inc.
Alpine Geophysics
Argonne National Lab
Air Resources Specialists
ASL Associates
BBC Research and Consulting
Boyce Thompson Institute, Cornell University
Duke University
E&S Environmental Chemistry
E. H. Pechan and Associates
Georgia Institute of Technology
ICF Consulting.Inc.
Land of Sky Regional Council
Mathtech, Inc.
Systems Applications International
Tennessee Valley Authority
Tetra Tech, Inc.
University of Alabama, Huntsville
University of Virginia

TABLE OF CONTENTS

Dedication iii
Table of Contents iv
Executive Summary vi

CHAPTER 1 – Introduction to the Southern Appalachian Mountains Initiative 1.1
- SAMI Mission 1.1
- Previous Work 1.1
- SAMI Integrated Assessment 1.2
- Moving From Scientific Analyses to Recommendations 1.3
- SAMI Accomplishments 1.4
- Topics That SAMI Did Not Address 1.4

CHAPTER 2 – Emissions Inventories and Reduction Strategies 2.1
- Introduction 2.1
- Methodologoy 2.2
- Development of Reference Strategies 2.4
- Development of the Control Strategies 2.9
- Uncertainties 2.21
- Lessons Learned 2.22
- Key Findings 2.22

CHAPTER 3 – Atomspheric Modeling And Geographic Sensitivity Analyses 3.1
- Introduction 3.1
- Atmospheric Modeling Methods 3.3
- SAMI Strategy Results 3.9
- Geographic Sensitivities 3.13
- Uncertainties 3.19
- Lessons Learned 3.21
- Key Findings 3.22

CHAPTER 4 – Visibility 4.1
- Introduction 4.1
- Visibility and Fine Particle Trends in SAMI Class I Areas 4.5
- Visibility Responses to SAMI Strategies 4.11
- Link to Socioeconomic Analyses 4.19
- Uncertainties 4.20
- Lessons Learned 4.20
- Key Findings 4.20

CHAPTER 5 – Ozone Effects to Forests 5.1
- Introduction 5.1
- SAMI Ozone Assessment 5.5
- SAMI Strategy Results 5.8
- Regional Forest Analysis 5.11
- Uncertainties 5.15
- Key Findings 5.16

CHAPTER 6 – Acid Deposition and the Effects on Streams and Forests 6.1
Introduction 6.1
Future Changes in Acid Deposition Due to SAMI Strategies 6.8
SAMI Stream Assessment 6.11
Forest Response to SAMI Strategies 6.15
Uncertainties 6.17
Lessons Learned 6.17
Key Findings 6.18

CHAPTER 7 – Direct Cost of Emissions Reductions Strategies 7.1
Introduction 7.1
Methodology 7.1
Total Annualized Costs 7.4
Cost Per Pollutant 7.7
Uncertainties 7.14
Key Findings 7.15

CHAPTER 8 – Socioeconomics 8.1
Introduction 8.1
Fishing 8.2
Visibility 8.5
Sense of Place/Stewardship 8.7
Lifestyles 8.10
Uncertainties 8.12
Key Findings 8.12

CHAPTER 9 – Incentive Programs 9.1
Introduction 9.1
Consumer Incentives 9.1
Incentives for Organizations / Institutions 9.8
Summary of Incentives Potential Effects on Emissions 9.10
Uncertainties 9.11
Key Findings 9.12

CHAPTER 10 – Conclusions and Recommendations 10.1
Developing Recommendations 10.1
SAMI Conclusions 10.1
SAMI Recommendations 10.5
Implementation of SAMI Recommendations 10.6

CHAPTER 11 – Lessons Learned from the SAMI Experience 11.1

List of Figures 1
List of Tables 4
References 5
Additional Data and Resources 8

EXECUTIVE SUMMARY

Background

The Federal Clean Air Act establishes air quality requirements to protect human health and welfare. It also requires that the air quality related values of national parks and wilderness areas be protected. The National Park Service and the United States Forest Service, have an "affirmative responsibility" to review major new air pollution sources for likely impacts on federal Class I parks and wilderness areas. Their comments to permitting authorities on new and expanded facilities have caused concern for economic development interests and also for the industries facing decisions on where to locate or expand plants in the Southern Appalachians. The deteriorating air quality in this region caused concern for the federal land managers, environmental interests, and the public. The air quality issues in the Southern Appalachian Class I areas often generated disagreements among States, land managers, and industry, sometimes leading to air quality permitting delays and uncertainty. In 1990 and 1992 the Department of the Interior published preliminary notices of adverse impacts for Shenandoah and Great Smoky Mountains National Parks, respectively.

The Southern Appalachian Mountains Initiative (SAMI) was founded to develop a better understanding of the complex air quality situation in the southeast and to recommend ways to remedy existing and to prevent future adverse effects on the SAMI Class I areas. It was a voluntary consensus-based partnership of State and Federal environmental agencies, federal land managers, industries, environmental groups, academia, and interested citizens. The eight States of the Southern Appalachians: Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia and West Virginia collectively led the nearly decade-long effort. SAMI intended to identify and recommend reasonable measures to remedy existing and prevent future adverse environmental effects from man-made air pollution.

SAMI Integrated Assessment

SAMI assembled a series of linked computer models to examine some of the more important impacts of aerosols, ozone, and acid deposition in the Southern Appalachian Class I areas. SAMI's Integrated Assessment model tested a series of hypothetical emissions control scenarios and projected the effect of those controls through 2040. SAMI also estimated the cost of those controls and identified some of their social and economic implications. This document reports the highlights of that work.

EMISSIONS INVENTORY

SAMI assembled an inventory of air emissions across the eastern United States at the county level. From lawn mowers to locomotives, emissions were projected from 1990 through 2040. Emissions for two families of strategies ("A" and "B") were developed. Strategies A1 and A2 describe controls currently required under the Clean Air Act, including acid rain controls, the 1-hour ozone standard, highway vehicle and fuel rules, and regional reductions of nitrogen oxides from utilities and large industrial sources. Some provisions of future programs, such as the controls likely to be required under the fine particle standards, 8-hour ozone standard, and the Regional Haze Rules were not included in the "A" strategies because of uncertainty surrounding the nature of the needed controls. The B1, B2 and B3 strategies reflect increasingly stringent additional controls on all sources of emissions. For example, the B1 strategy requires an 80% reduction in industrial sulfur dioxide emissions by 2010 and 90% by 2040. B3 requires a 98% reduction by 2040. On-road mobile sources were projected to meet Tier 2 standards in 50% of the light duty mobile sources fleet under strategy B1 in 2010. For B3 SAMI projected the effect of the entire light duty fleet being converted to zero emission vehicles by 2040. SAMI's confidence in these emission projections varies. The utility growth and emission projections are probably the most certain in the inventory because they are closely monitored and because they come from discrete point sources. There is much less certainty, for example, about ammonia emissions, much of which come from dispersed agricultural operations that are not closely monitored.

ATMOSPHERIC MODELING

SAMI demonstrated three new atmospheric modeling approaches that add credibility to the SAMI results. One is a method for sorting the meteorology from five years of records into categories and then selecting typical episodes to represent each category. This approach made very complex modeling possible within our time and budget constraints. Another new approach is the "one atmosphere" atmospheric chemistry and transport model that allowed SAMI to simultaneously examine acid deposition, ozone, and haze-causing aerosols. Previous efforts focused on one of these topics at a time, ignoring potentially important interactions between pollutants in the atmosphere.

GEOGRAPHIC SENSITIVITY ANALYSIS

In a third area SAMI explored the effect of emission changes in individual States and the impact on Class I areas. This information may be critical for policy decisions. In general, SAMI found that emissions reductions applied in a particular State would generate the most benefit in that State. In every case, Class I areas are also affected by surrounding States and by emissions originating outside the eight SAMI States. This report summarizes the contribution of each SAMI State and the surrounding non-SAMI regions to environmental effects in the ten SAMI Class I areas. These results help answer questions about the sources of emissions that cause environmental effects in Class I ecosystems. Interestingly, the areas contributing emissions that are likely to generate ozone problems are different than the areas that contribute to acid deposition problems or to haze. The emission height of nitrogen oxides is also important. Once required emissions reductions from utilities and large industrial sources are implemented, reducing emissions from ground level sources such as highway vehicles and non-road engines will be increasingly important.

VISIBILITY

SAMI confirmed the widely held impression that sulfate particles account for the greatest portion of the haze affecting our Class I areas. Sulfur dioxide emissions that produce sulfate aerosols come in large part from coal combustion. Most of those emissions now come from electric generating plants. Industrial and area sources contribute a smaller amount. SAMI projects the greatest improvement in visibility when sulfur dioxide emissions are reduced. The greatest improvements are projected to happen on the haziest days. SAMI projected that in 2010 average annual visibility in the SAMI Class I areas will improve less than two miles under the A2 strategy. Up to 15 miles in visibility improvement is expected with the B3 strategy by 2010. As a point of comparison, the National Park Service suggests that the “natural” condition in Great Smoky Mountains National Park is a visibility of 113 miles. Average annual visibility is currently 25 miles in this park.

The first priority to improve visibility is to reduce sulfur dioxide emissions in SAMI States and in surrounding regions. Ammonium nitrate particles are also effective in scattering light. As sulfur dioxide emissions are reduced in the future, controlling ammonia emissions will become increasingly important to improve visibility. The leading ammonia sources are animal feeding operations and agricultural fertilizers. SAMI recommends that the States work with the agricultural community to reduce ammonia emissions for improvement of visibility as well as to reduce nitrogen deposition.

Organic compounds are the second largest contributor to visibility impairment in the SAMI Class I areas. At these sites, organic emissions from natural sources such as trees are greater contributors to organic particles than are emissions from human activities such as highway vehicles. At the SAMI Class I areas, visibility improved very little with reductions in organic emissions from human activities.

OZONE EFFECTS TO FORESTS

The SAMI strategies produced small ozone exposure changes for the forests in the SAMI region. SAMI simulated the effect of those ozone changes on individual trees as well as on forests stands. Some tree species are more sensitive to ozone than others and over time they are at a competitive disadvantage. The shift in forest stand dynamics brought about by this change in competitiveness is the major ozone effect observed in this analysis. SAMI projected no tree death as the result of ozone exposure and the changes in aggregate tree cross-sectional (basal) area were generally small. The largest improvement that SAMI projected was a 22 percent increase in cross section for loblolly pine for the most stringent B3 strategy in 2040. Loblolly pine is an important commercial species but it does not grow in large numbers in most Class I areas. High elevation spruce-fir forests are relatively insensitive to ozone compared to faster growing species such as loblolly pine and tulip-poplar. Tulip-poplar is an important species in some old growth stands, including some stands in Class I areas. The ozone exposure changes that SAMI tested in strategies B1 and B3 were not large, in part because these strategies were applied only to emissions in the SAMI States. Particularly in the north and south of the SAMI region, geographic sensitivity analyses indicate that effects from regions outside the eight SAMI States are important for ozone as well as for other pollutants. Based on the SAMI forest stand simulations, the largest adverse impact on Class I areas from ozone is a shift in natural processes caused by some species being more competitive than others as ozone exposures are changed. SAMI did not assess the effect of foliar injury to plants or health effects for visitors to the parks. SAMI concluded that nitrogen oxide emission reductions are needed to reduce ozone effects on certain tree species in certain Class I areas.

ACID DEPOSITION EFFECTS ON STREAMS AND FORESTS

Current levels of acid deposition do not adversely affect most forests and streams in the SAMI region. The forests and streams that are affected are generally located in areas with base-poor geology and with elevations above 3000 feet. Several of the SAMI Class I areas in Virginia, West Virginia, North Carolina, and Tennessee include

areas that fit this description. The SAMI strategies produce reductions in sulfate deposition in all cases. Those strategies produce small changes in deposition of nitrogen compounds and in deposition of cations such as calcium and magnesium.

SAMI assessed the effect of acid deposition both on forest soils and on streams. Appalachian spruce-fir forests are more susceptible to the soil effects of acid deposition than other forest types. These forests tend to occur at high elevations where cloud deposition regularly adds to wet and dry deposition. Nitrogen deposition is particularly important in spruce-fir forests. In 2010 total nitrogen deposition to the spruce-fir forests in Great Smoky Mountains National Park is projected to decrease by 4% under the A2 strategy and by 11 % under the B3 strategy. SAMI concluded that it is important to reduce emissions of nitrogen oxides and ammonia to reduce nitrogen deposition in order to provide more protection for high elevation spruce-fir forests.

The SAMI acid deposition stream assessment found that in the range of controls evaluated in strategies B1 and B3, few streams changed sensitivity class. For example, few streams moved from being unable to support brook trout to being able to support brook trout. However, reductions in emissions that improve the acid neutralizing capacity of some streams in West Virginia, Virginia, Tennessee and North Carolina will improve fish habitat including some streams in Class I areas. SAMI concluded that it is important to reduce sulfur dioxide, nitrogen oxide and ammonia emissions to reduce adverse affects upon streams in those States. The sources of these emissions are fossil fuel combustion by mobile and stationary sources as well as agricultural animal feeding operations and some agricultural fertilization practices.

DIRECT COST OF CONTROLS

SAMI estimated the direct cost of controls for strategies tested in the Integrated Assessment including installation, operation and maintenance costs over the life of the controls, on an annual basis. For example, the annual cost for sulfur dioxide control in B1 in 2010 for all sectors was $1.9 billion. Emission reductions resulting from those strategies were estimated at 1.6 million tons per year (or $1200 per ton of reduction). In 2040 the B3 annual costs for sulfur dioxide control were $4.6 billion. Emission reductions resulting from those strategies were estimated at 1.8 million tons per year (or $2600 per ton of reduction). For other pollutants, uncertainties about the estimates for mobile and area source categories in particular led to a wide range in direct cost estimates.

SOCIOECONOMIC IMPACTS OF STRATEGIES

SAMI assessed the social and economic implications of the SAMI strategies. Four topics were selected from the numerous topic areas: visibility, sense of place/stewardship, lifestyles, and fishing. The SAMI socioeconomic analysis was not intended to be a comprehensive cost-benefit analysis but instead focused on these four areas. SAMI found that recreational visibility improvements have value both to individuals living in the SAMI region and throughout the United States. Residential visibility benefits have annual dollar values ranging from $224 million in 2010 to $1.5 billion in 2040. Sense of place/stewardship findings showed that residents of the SAMI region are diverse but they are all concerned both about the environment and jobs. They expect the government, at one level or another, to help them protect the environment for themselves and for future generations. A qualitative analysis of lifestyle effects concluded that emission reductions would require changes in consumer behavior. The larger the emission reductions, the larger will be the impacts on individual lifestyles, both positive and negative. Over time, consumers will adapt and find substitutes for higher priced goods and services and job losses.

Incentive Programs

SAMI examined a range of incentive systems as a possible means of implementing air quality management recommendations. In the area of incentives that are likely to affect consumer behavior, the analysis focused on transportation and building energy efficiency. SAMI also examined incentives to affect the behavior of organizations like companies and institutions. While incentives appear capable of generating significant reductions, incentives alone are not likely to produce the full emission reductions described in B1 or B3. Regulatory approaches are also likely to be required to reduce emissions to those levels. The magnitude of incentive-based emission reductions depends on the specific nature of the program employed.

Conclusions And Recommendations

SAMI used a systematic process to move from the results of each phase of the Integrated Assessment to observations and then to conclusions that were presented to the SAMI Governing Body. Based on those conclusions, the SAMI recommendations were agreed upon and adopted. SAMI recommendations deal with topics including national multipollutant legislation, ammonia from animal feeding operations, State Implementation Plans, energy efficiency, conserva-

tion, and renewables. The full conclusions text is provided in the Conclusions chapter; summary conclusions and recommendations are listed below:

- To improve visibility, it is most important to reduce SO_2 emissions.
- To improve visibility, it could become necessary, under certain future SO_2 (sulfur dioxide) control strategies, to reduce NH3 (ammonia) emissions.
- To reduce acid deposition affecting streams in the central and northern part of the SAMI region, it is important to reduce SO_2 emissions.
- To reduce acid deposition affecting streams in geographically limited areas, it is important to reduce NOx and NH_3 emissions.
- For high-elevation spruce-fir forests, it is important to reduce NOx and NH_3 emissions.
- Ozone exposure does not produce a region-wide effect on forest basal area, so NO_X or VOC reductions are not needed for this purpose. However, site-specific ozone effects to certain forest species are a concern for Federal Land Managers and other stakeholders. NO_X emission reductions are important to address that concern.
- For SAMI to accomplish its mission, emissions reductions are essential both inside and outside the SAMI region.

Upon consideration of the conclusions presented above, the SAMI Governing Body adopted the following recommendations listed on April 18, 2002 by consensus among the State representatives.

> The SAMI States support and will promote strong national multi-pollutant legislation for electric utility plants to assure significant sulfur dioxide and nitrogen oxides reductions both in and outside the SAMI region. This national multi-pollutant legislation should result in no less than the reductions for sulfur dioxide and for nitrogen oxides represented by the Administration's Clear Skies Initiative. Reductions from other source categories should also be considered in national legislation, and such national legislation should contain sufficient measures to protect Class I areas. Should the national legislation fail to materialize, the States that participated in SAMI will work together to consider regulatory alternatives and to encourage non-SAMI States to participate. Leadership by States ahead of national legislation is encouraged.
>
> Each SAMI State should seek ways to reduce ammonia emissions from animal feeding operations. Also support should be given in future work such as VISTAS to improve the understanding of the sources of ammonia, to develop better inventories, and to seek more effective control approaches.
>
> Where States have control strategy option choices in their eight hour ozone and fine particle State Implementation Plans, that also have co-benefit for the environmentally sensitive Class I areas, they should choose them. Ambient ozone monitoring should be conducted near all Class I areas in the future.
>
> Each SAMI State should encourage energy efficiency, conservation, and use of renewable energy to reduce the emissions from stationary and mobile sources.

Through this report and its recommendations, SAMI has completed its mission and has officially closed its operations. By adoption of the final technical report, the SAMI States recognize the value and importance of our Class I areas and agree to work towards the implementation of SAMI recommendations. Each SAMI State will determine the most appropriate strategy for its own unique circumstances that will lead to successful achievement of SAMI's final recommendations.

Lessons Learned From The SAMI Experience

SAMI participants offer a series of suggestions to others undertaking a similar environmental decision making process and to those undertaking air quality modeling in the future. In general, all stakeholders value the opportunity to understand the perspective of other stakeholders and generally they recommend a participatory process for environmental decisions. If a smaller set of stakeholders or an individual organization were given authority to hear a variety of perspectives but to then make decisions without needing to rely on full consensus, the process would probably move more quickly, and perhaps more effectively, than the process that SAMI used.

Additional Data and Resources

SAMI generated a large volume of results, reports and computer files. These supporting materials will be available electronically to the SAMI participants and other interested parties as described in the Additional Data and Resources Section on page 8 or at www.vistas-sesarm.org. SAMI will close its doors in the fall of 2002. Please direct other inquiries about the SAMI report to your State air quality agency.

INTRODUCTION TO THE SOUTHERN APPALACHIAN MOUNTAINS INITIATIVE

SAMI MISSION

The Southern Appalachian Mountains Initiative (SAMI) is a voluntary public-private regional partnership working to improve air quality. Eight Southeastern States lead SAMI (Figure 1.1). They are Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. Other participants include the U.S. Environmental Protection Agency, U.S. Forest Service, National Park Service, industries, environmental organizations, and interested citizens. The SAMI Mission is:

Through a cooperative effort, identify and recommend reasonable measures to remedy existing – and to prevent future – adverse effects from human-induced air pollution on the air quality related values of the Southern Appalachians, primarily, those of Class I parks and wilderness areas, weighing the environmental and socioeconomic implications of any recommendations.

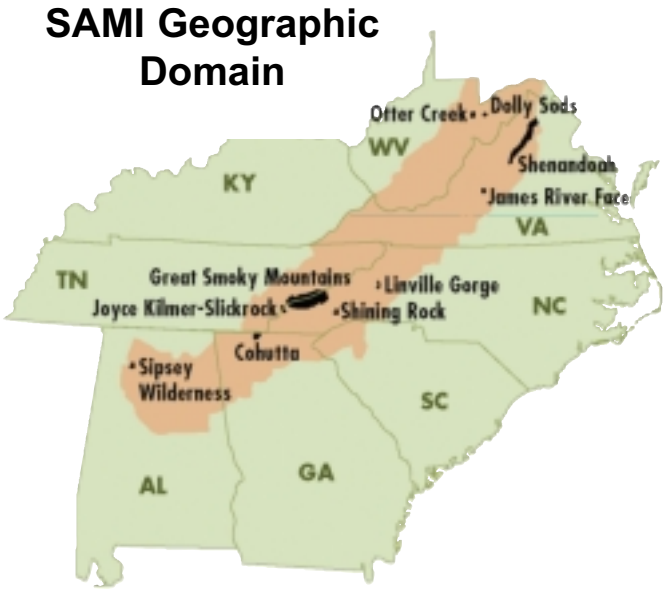


FIGURE 1.1: The Geographic domain of the Southern Appalachian Mountains Initiative and location of Class I Areas.

PREVIOUS WORK

In 1990 and 1992 the Department of the Interior published preliminary notices of adverse impacts for Shenandoah and Great Smoky Mountains National Parks, respectively. These effects included:

- Reduced visibility, particularly in summer months
- Decline in spruce fir forest ecosystem
- Foliar injury to several wildflower, shrub, and tree species
- Increase acidity of streams and reduced stream habitat suitable for supporting trout

In 1995, the Southern Appalachian Assessment described the effects of fine particles, ozone, and acid deposition on environmental resources in the Southern Appalachian Mountains (SAMAB, 1996). This assessment did not include an analysis of how air quality and environmental resources might respond if emissions were reduced.

SAMI was created in 1992 in response to concerns about permitting new emissions sources near Class I parks and wilderness areas in the Southern Appalachian Mountains. (Refer to Figure 1.2 for a description "Class I" Areas). State air quality agencies were receiving conflicting recommendations on permits for new or expanded emissions sources near these Class I areas. SAMI was established to examine the present and future effects of air pollution on these parks and wilderness areas. It was also to recommend ways to deal with any adverse effects that were found.

SAMI used a consensus-based approach to regional strategy development, which provided a forum for stakeholders with diverse viewpoints to work together constructively to conduct the technical and policy assessments necessary for regional solutions.

The Clean Air Act and other regulatory and legislative programs require major reductions in air pollution.

Beginning in 1970, the Clean Air Act established programs to address air quality concerns. For example, under the Prevention of Significant Deterioration provisions of the 1977 Clean Air Amendments (CAAA), national parks that are greater than 6,000 acres and wilderness areas greater than 5,000 acres are designated as "Class I". This designation includes areas such as the Great Smoky Mountains National Park, Shenandoah National Park, and Shining Rock Wilderness Area. Class I areas are afforded special consideration in permitting new and modified facilities.

To improve air quality in the present and future, federal actions have been taken to:

- *Revise the national ambient air quality standards for ozone and fine particulate matter;*
- *Call for revised State Implementation Plans (SIPs) to reduce nitrogen oxides (NO_x) emissions from utilities and industries;*
- *Implement regional haze rules to improve visibility; and*
- *Enact tailpipe emission and automotive standards (i.e., Tier 2) and cleaner gasoline rules to reduce emissions from mobile sources.*

FIGURE 1.2: Federal Legislation & Class I Areas

SAMI INTEGRATED ASSESSMENT

SAMI designed and carried out an Integrated Assessment of air quality in the Southeast with a particular focus on the mountainous areas of the Southern Appalachians. A series of linked computer models predicted future emissions and the response of those emissions to a series of hypothetical emissions control strategies. In contrast to many air quality studies that focus on human health in urban areas, SAMI's focus was ecosystem effects in rural parks and wilderness areas. One goal of this Assessment was to determine if the programs established by the Clean Air Act are adequate to protect the air quality of the Class I areas. A series of new Federal air quality programs were introduced as SAMI developed its Assessment (Figure 1.2). While the full effect of those programs is difficult to predict since they will be implemented over decades, SAMI concluded that additional measures beyond the Clean Air Act are needed as described in the sections on conclusions and recommendations.

The emissions control strategies evaluated in the Integrated Assessment were designed by SAMI's Policy Committee to reflect emissions controls ranging from what might be anticipated in response to Federal regulations, to the most advanced controls for 2010 and prototype controls for 2040. This approach contrasts to previous efforts that have generally considered changes in air quality without linking those changes back to emissions control strategies.

SAMI's Integrated Assessment (Figure1.3) used computer models to: track air emissions from their sources across the Eastern United States; simulate the complex chemical and physical processes that occur in the atmosphere; project air pollutant exposures across the SAMI region; and estimate environmental and socioeconomic responses. The Assessment focused simultaneously on environmental and socioeconomic effects of fine particles, ozone, and acid deposition. Following is a brief description of each of the Assessment areas:

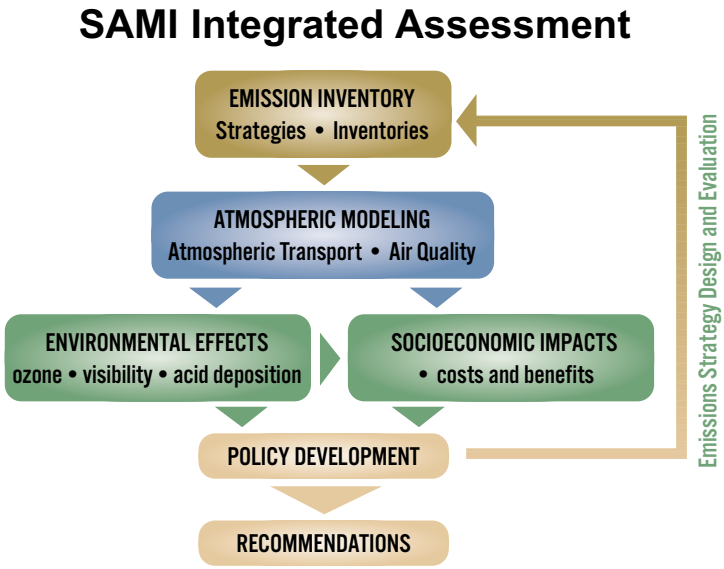


FIGURE 1.3: Flow chart of each level component of the Integrated Assessment

Emissions Inventories characterized pollutants and their sources. SAMI inventories project the emissions that contribute to ozone, fine particles, and acid deposition in the Eastern United States. The projected emissions are based on various emission reduction strategies for current and future years to 2040. See Chapter 2 for more information.

Atmospheric Modeling simulated air quality conditions for nine week-long episodes during 1991-1995. Each episode consisted of contiguous days chosen to represent a range of meteorological, emissions, and atmospheric chemistry conditions that contribute to air quality in the SAMI region. Atmospheric model simulations for the 1991-1995 episodes, 2010, and 2040 generated air quality response information for each emissions reduction strategy. See Chapter 3 for more information.

Environmental Effects Modeling evaluated the response of visibility, forests, and streams to changes in fine particles, ozone levels, and acid deposition. From these projected responses data, SAMI described how air quality and natural resources respond to changes in emissions. See Chapters 4, 5, and 6 for more information.

Direct Costs Of Strategies estimated the direct cost of the emission management strategies in the years 2010 and 2040. These costs were estimated in order to fully evaluate the environmental benefit of expenditures made to reduce pollutant emissions. See Chapter 7 for more information.

Socioeconomics Assessment examined some of the social and economic implications of SAMI emissions reduction strategies. Of the large number of socioeconomic indicators possible, SAMI examined the impacts on: Fishing; Recreational/Residential Visibility; Stewardship/Sense of Place, and Lifestyles. See Chapter 8 for more information.

MOVING FROM SCIENTIFIC ANALYSES TO RECOMMENDATIONS

Over the years of SAMI's work, our three main committees – technical, policy, and public advisory – appointed subcommittees to closely advise staff and contractors in running various parts of the Integrated Assessment model. They were:

- Emissions Inventory
- Atmospheric
- Effects
- Socioeconomic
- Incentives

These subcommittees met weekly over several years to evaluate the early results of the various contractors and to guide them in refining the Integrated Assessment.

As the modeling neared completion, the SAMI Technical and Policy Committees met jointly to guide a systematic process (Figure 1.4) to move from the analyses of the computer models to the recommendations that are intended to guide State and Federal policy makers. Each subcommittee provided a series of observations based on the modeling work that they managed. The joint Policy/Technical Committee drew conclusions based on these observations. The conclusions were presented to the SAMI Governing Body that developed and adopted the recommendations contained in Chapter 10.

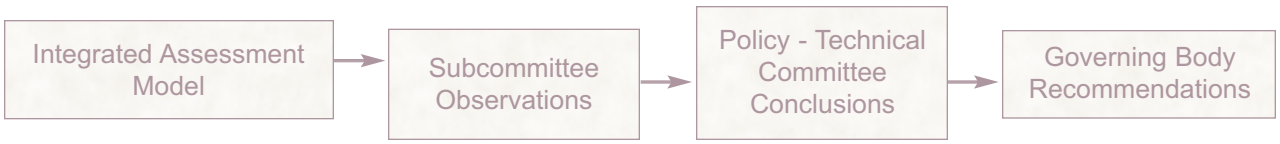


FIGURE 1.4: Recommendation development process

SAMI's goal was for each recommendation to be directly based on sound scientific analysis. With this systematic process, the thousands of model findings were reduced to the four recommendations that the SAMI Governing Body adopted and intends to implement.

Modeling results are found throughout this report but mainly in Chapters 3-7. A summary version of those conclusions, as presented to the SAMI Governing Body, is found in Chapter 10.

SAMI ACCOMPLISHMENTS

Voluntary/Consensus Process – A voluntary, consensus-based organization composed of a variety of stakeholders with diverse interests investigated a complex environmental topic. Using conclusions drawn from this analysis, SAMI recommended actions to address air quality problems in the Southern Appalachian Class I parks and wilderness areas.

Integrated Assessment – In the area of air quality assessments, SAMI is the first to conduct a truly "integrated" assessment linking the outputs from one model to another. SAMI designed unique model linkages to account for temporal, spatial, and episode variability.

"One Atmosphere" Model – SAMI successfully applied a first-generation integrated, one-atmosphere model that addressed fine particles, ozone, and acid deposition simultaneously. Previous studies addressed these topics separately thereby missing potentially important chemical and physical interactions that occur in the atmosphere.

Atmospheric Episode Selection – SAMI successfully demonstrated a method to select episodes that represent all types of emission rates and weather patterns contained in air quality records.

Emissions Contributions – SAMI identified the States and regions contributing to the air quality impacts on Class I national parks and wilderness areas in the Southern Appalachians.

Geographic Sensitivity Analysis. SAMI applied a newly developed tool (Direct Decoupled Method (DDM)) to provide an indication of how exposures would change if emissions were reduced in a particular State (or other area).

Environmental Effects – SAMI projected future changes in air quality and estimated the effect of those changes on streams, forests and visibility.

Visibility Tool – SAMI developed software tools to test the effects of different scientific assumptions used in the calculation of visibility from fine particle mass. SAMI also modified a visualization tool to allow the visibility response to SAMI strategies to be illustrated for each SAMI Class I area.

Visibility Status – SAMI estimated the change in visibility under the SAMI strategies.

Socioeconomic Analysis examined some of the social and economic implications of SAMI emissions reduction strategies.

TOPICS THAT SAMI DID NOT ADDRESS

SAMI did not address carbon emissions, global warming, mercury emissions, mercury effects, human health effects, or attainment of National Ambient Air Quality Standards (NAAQS). While important, these topics were determined to be outside the SAMI mission.

EMISSIONS INVENTORIES AND REDUCTION STRATEGIES

INTRODUCTION

To assess the impacts of ozone, fine particles and acid deposition on the forests, streams and vistas of the Southern Appalachians, SAMI quantified the amount of precursor pollutants being emitted into the atmosphere. Thus, the emission inventory is the starting point of the SAMI analysis. It was designed to estimate several different pollutants from all human activities. Those activities were divided into five source sectors:

- **Utility Sector –** facilities that burn fossil fuels to generate electricity (Hydroelectric, nuclear or other non-fossil fuel sources of electricity were not considered in the inventory);
- **Industrial Point Source Sector –** large industrial facilities that manufacture goods;
- **Highway Vehicle Sector –** includes gasoline powered and diesel powered vehicles designed to operate on the roadways;
- **Nonroad Engine Sector –** includes planes, trains, boats, recreational vehicles, lawn and garden tools, airport service vehicles and construction equipment;
- **Area Source Sector –** includes agricultural ,small industrial, commercial sources, and paved and unpaved roads.

The pollutants inventoried are the chemical precursors to acid deposition, ozone and fine particulates: oxides of nitrogen (NO_X) , volatile organic compounds (VOCs), sulfur dioxide (SO_2) and ammonia (NH_3). Also quantified were other pollutants that are themselves fine particles (particulate matter smaller than 2.5 microns – $PM_{2.5}$) and coarse particles (particulate matter smaller than 10 microns – PM_{10}) or are important to the overall atmospheric chemistry. This chapter discusses the methods used to create the emissions inventory and the resultant inventories for the most significant pollutants. All emissions discussed in this chapter are from human activity. Emissions from vegetation and soils were calculated as part of the emissions modeling and are discussed in Chapter 3.

This inventory had to meet several objectives. Because SAMI's goals include predicting future air quality given different levels of emission controls, it was essential to develop a Base Year inventory and then vary that inventory according to the year and conditions being projected. SAMI used 1991 to 1995 to represent current conditions in the atmospheric and effects models; therefore the Base Year emission inventory contained emissions for all source sectors in 1990. This year was also chosen because EPA had already developed an inventory for most of the pollutants and activities of interest to SAMI for 1990. While the primary area of interest is the 8 SAMI States and the 10 Class I wilderness areas of the Southern Appalachian Mountains (Figure 1.1), the initial inventory had to be much more extensive, covering essentially the eastern two thirds of the country. Once the Base Year data was accumulated, reference cases were developed based on specific levels of emission control that could be foreseen for 2010 and 2040. The two reference cases are referred to as A1 and A2. These future years were selected to provide both near-term and long-term emission estimates to support SAMI's assessment of visibility, stream, and forest ecosystem response to emission changes. Once this work was completed it was possible to create potential alternative control strategies and calculate emissions assuming the levels of control created for each strategy. These alternative control strategies are collectively referred to as the B-group strategies. This chapter details the controls assumed for each of these strategies and the resultant levels of the most important pollutants. As each phase of the inventory is described, uncertainties inherent to the analysis are discussed.

Objectives

The overarching purpose of the emission inventory, providing the foundational data, can be organized into the following objectives:

- Establish 1990 Base Year emission data from the five source sectors for a variety of pollutants including oxides of nitrogen, sulfur dioxide, ammonia, fine and coarse particles, volatile organic chemicals, and carbon monoxide. From the emission estimates of particles, elemental carbon, organic carbon, primary sulfates, primary nitrates and base cations (calcium, magnesium potassium and sodium) were derived. The emissions were by day and county of origin. This chapter summarizes these results as annual totals (in most cases) at the State and/or region level.
- Provide specific emissions for the nine, 6-10 day periods between 1990 and 1995 that were selected as the episodes to use in the atmospheric model. The inventory was used in the atmospheric model to project concentrations ozone, fine particles, and acid deposition at specific locations (see Chapter 3 for more information on atmospheric modeling).
- Project emission inventories for a reference case for the years 2010 and 2040. Two reference strategies of specific, anticipated regulations were selected and then the inventory was calculated based on those regulations and the growth in population and energy demand in the SAMI States.
- Project emission levels for the B-group strategies representing differing levels of controls in each of the source sectors for the years 2010 and 2040.
- Provide episode-specific emissions for 2010 and 2040 for each SAMI strategy for use in the air quality model.
- Provide the foundation of the cost estimates for various levels of emission reduction efforts in the projected cases (see Chapter 7), and provide the foundation for socioeconomic analysis (see Chapter 8).

METHODOLOGY

1990 Base Year

The 1990 emission inventory used information from several other inventories that had already been completed. The inventory developed by the Ozone Transport Assessment Group (OTAG) was the starting point for the SAMI inventory. The OTAG inventory quantified emissions of ozone precursors for the District of Columbia and the 37 States that form the eastern two-thirds of the United States (Figure 3.1). This same geographic area was used for SAMI's modeling. The OTAG inventory was also chosen because the States themselves provided the data for all the SAMI States, and most of the other States. Additionally, the inventory was developed in 1995 and 1996 providing a good source of data regarding 1990. The OTAG inventory included nitrous oxides, volatile organic compounds and carbon monoxide emissions only; therefore SAMI obtained the remaining pollutant data from EPA's 1990 National Emissions Trends inventory. These two inventories were melded and then enhancements were made specific to the SAMI inventory.

Essential to the SAMI emissions inventory was a rigorous quality assurance process that included both internal and external review. Internally, the inventory was compared with existing inventories to assure that the SAMI estimates were in line with previous studies and to find and include any missing categories of emissions. Once this process was complete, the inventory was made available to States, local governments, utility and, industrial companies and other stakeholders. Three iterations of review and correction were conducted. The resulting inventory was perhaps the best and most comprehensive inventory conducted at the time. However, confidence still varies greatly from area to area in the inventory and many updates to the National Emission Inventories and improvements in methods have occurred since SAMI's Base Year Inventory was developed.

Base Year Uncertainty

Inventorying emissions from all human activities is difficult and the results can often be ambiguous. Emissions from electricity-producing utilities and industrial facilities (often referred to as point source emissions because the pollutant is released from a smokestack at a known, non-moving point) are relatively easy to quantify. Pollutants from a variety of other activities including trucks and automobiles, other combustion engines, farming activities, and commercial activities can be much more difficult to quantify. Emissions calculations require information on the level of emissions that are released by a certain activity and the level of that activity over a fixed period of time. For example, how much air pollution is generated by chainsaws? The answer depends on the emission factors of a chainsaw, how many are in the area, how much they are operated over a fixed period of time and where they are operated. Estimating that number requires making many assumptions. Each assumption leads to uncertainties in the analysis. Table 2.1 provides a qualitative comparison of confidence between certain pollutants in the Base Year inventory by their source sector. This ranking was developed by SAMI as a qualitative aid to understand both the strengths and limitations of the emission inventory, and is consistent with the levels of confidence inherent to all emission inventories developed to date. The assessment of this ranking is supported by a more rigorous analysis (E.H Pechan & Associates, 1997). It is much easier to estimate point source emissions with a high degree of confidence than it is to estimate highway vehicle and nonroad engine emissions. Likewise, it is extremely difficult to estimate area emissions with much confidence. The uncertainties of the 1990 emissions remain throughout the analysis. Estimates of future pollutants are by necessity more uncertain than the 1990 emissions for that pollutant. The SAMI process has highlighted the need for an improved estimate of ammonia emissions that can be used with a higher degree of confidence in this type of analysis.

From Inventory To Model

The 1990 inventory was adapted to the atmospheric model. First, the emission data were adjusted to the appropriate year (1991-1995) in which the particular modeled episode occurred (see Chapter 3). Second, the emissions were calibrated for the actual temperatures and activities that occurred during the time periods in question. The episodes selected were from different seasons representing different atmospheric conditions and required inventories that were very specific in their temporal and spatial distribution of emissions. And third, the data was formatted as model input data.

TABLE 2.1: Relative Confidence Levels in the SAMI 1990 Base Year Inventory (5 pluses is most confident)

SAMI 1990 Base Year Inventory Relative Confidence

	Utility	Industrial	Highway Vehicle	Nonroad Engine	Area
SO_2	+++++	++++	+++	++	++
NO_X	+++++	++++	+++	++	++
VOC	+++	+++	+++	++	++
NH_3	+++	+++	++	+	+
$PM_{2.5}$	+++	+++	++	+	+

DEVELOPMENT OF REFERENCE STRATEGIES

To develop the reference strategies for 2010 and 2040, SAMI projected (from the Base Year) various scenarios with differing levels of future pollutant-producing activities and control programs for the 37 eastern States and the District of Columbia. Population in the eight-State SAMI area is projected to increase from 37.3 million people in 1990 to 45.9 million in 2010 and 57.1 million in 2040 (Figure 2.1). Electricity demand and vehicle miles traveled will increase even more rapidly, assuming current trends. It is anticipated that vehicle miles traveled will increase by 70% from the 1990-level by 2010 and 170% by 2040. Likewise it is anticipated that electricity demand will increase by 50% in 2010 and by 100% by 2040. These projections are for the Eight-State SAMI area as a whole and vary among locales within the region (U.S. Dept. of Commerce, 1995). This growth in the SAMI States drives the inventory projections since population projections are used to estimate growth for a number of area and nonroad sources, vehicle miles projections are used to estimate highway vehicle emissions and electricity demand is used in estimating electric utility emissions.

It was assumed that the current trends in land use and lifestyle will continue into the future. Also, no technology that is not already existing or anticipated was considered. It was assumed that increases in electrical generation would occur at the same location as the increase in demand. Utility plants and industrial coal-fired boilers were generally assumed to retire after 65 years of life. However, large coal-fired utility units that reached 65 years of age were assumed to continue operating after being retrofited with sulfur dioxide and year-round oxides of nitrogen controls. The projected emissions growth developed was used in all the future strategies.

Two potential reference strategies were developed - A1 and A2. The A1 emission inventory assumed that the regulations promulgated prior to 1997 would remain unchanged into the future. This included reductions of volatile organic compounds and oxides of nitrogen emissions to comply with the 1-hour ozone standard, reductions of sulfur dioxide and oxides of nitrogen from utility sources under Title IV of the Clean Air Act Amendments of 1990 and reductions of oxides of nitrogen and volatile organic compounds from mobile sources under Tier I tailpipe standards and fuel rules. The A2 emission inventory included all the controls of the A1 strategy and regulations promulgated in 1997 for

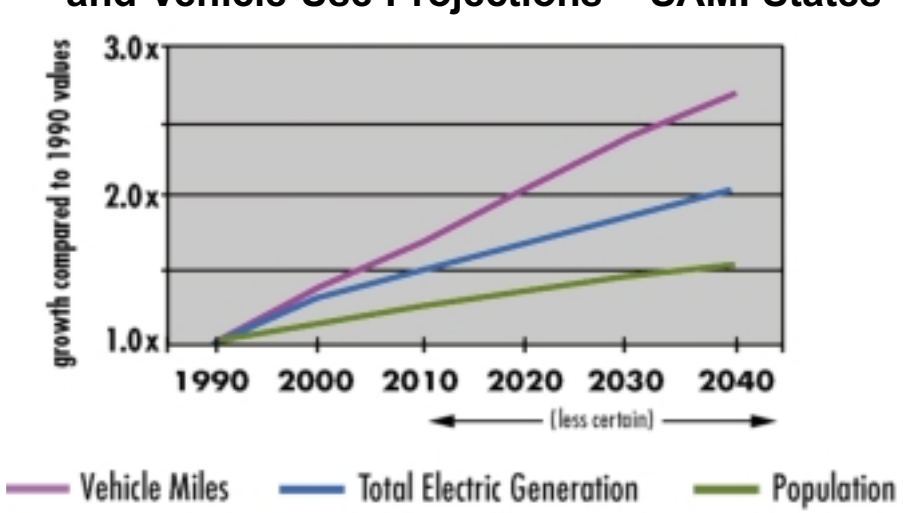


FIGURE 2.1: Projections of population, electricity demand and vehicle miles traveled in the SAMI States from 1990 to 2040.

which there was fair certainty about the controls that would be required for implementation. The A2 strategy more closely predicted the future Baseline conditions, so it became the reference strategy to which other strategies were compared. To the extent possible, SAMI predicted in the A2 strategy the regulations that would be in force in 2010 and 2040 if no further actions were taken. The controls that are assumed to exist in the reference strategy, referred to as A2, are: the acid rain controls (Title IV of the 1990 Clean Air Act Amendments), the Tier II highway vehicle and fuel rules, the 7-10 year Maximum Achievable Control Technologies for the control of volatile organic compounds, and controls included in "State Implementation Plans" to reduce nitrogen oxides (NO_X SIP call). A2 does not include emission reductions that might occur as a result of the regional haze rules, the 8-hour ozone standard, or the national fine particulate standard because the controls required to comply with these regulations were uncertain when the inventory was developed.

Result – Reference Strategies

The regulations assumed by the A2 strategy have the greatest impact on sulfur dioxide and oxides of nitrogen emissions. Despite the increases in activity, the A2 strategies predict decreases in both pollutants. Figure 2.2 compares the Base Year and the reference strategy for 2010 and 2040 for the five key pollutants of oxides of nitrogen, sulfur dioxide, volatile organic compounds, fine particles, and ammonia aggregated over the entire SAMI region. Each bar is segmented into the five source sectors. The utility sector generates the largest quantity of sulfur dioxide and experiences the greatest reduction in sulfur dioxide emissions. For all the SAMI States and sectors, sulfur dioxide is reduced by 23% by 2010 and by 61% by 2040. The utility and highway vehicle sectors generate most of the oxides of nitrogen emissions. Annual oxides of nitrogen emissions are reduced by 24% by 2010 and by 37% by 2040. The volatile organic compounds emissions in the SAMI States decrease between 1990 and 2010, but then increase by 39% between 2010 and 2040. The ammonia and primary fine particle levels increase over time, because the controls assumed do not affect these pollutants and there is an increase in activity.

Table 2.2 provides annual summary data for the eight SAMI States in total (EH Pechan and Associates, 2002a).

Emissions Projections – SAMI States
Strategy A2

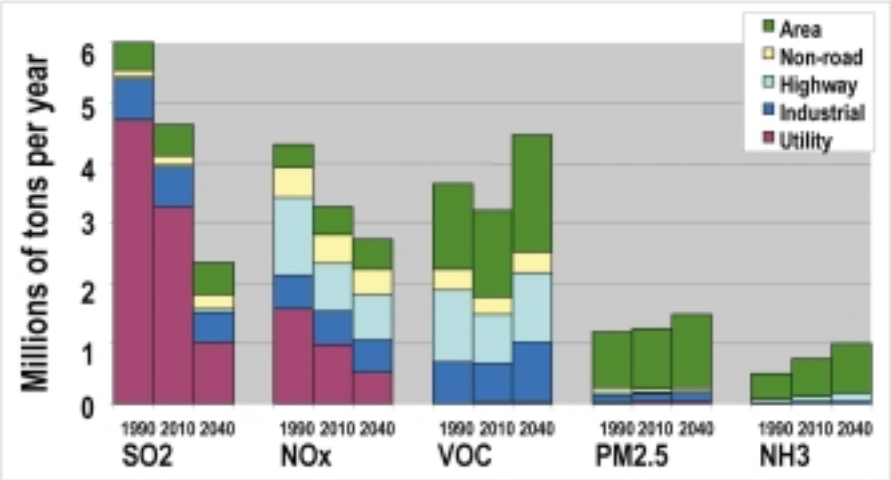


FIGURE 2.2: Comparison of Base Year and reference strategy emissions for five key pollutants in the SAMI States.

TABLE 2.2: Annual summary data for the eight SAMI States in total.

SAMI 8-State Emissions Summary by Sector and Strategy

	2010	2010	2010	2010	2010	2010	2040	2040	2040	2040	2040
Sector	**1990**	**A1**	**A2**	**B1**	**B2**	**B3**	**A1**	**A2**	**B1**	**B2**	**B3**
VOC Emissions (thousand tons per year)											
Utility	6	10	10	10	10	10	20	20	20	22	22
Industrial Point	689	796	668	668	668	668	1,094	1,007	1,007	1,007	1,007
Highway Vehicle	1,183	867	798	759	691	515	1,310	1,153	502	36	15
Nonroad	355	296	296	280	269	220	338	338	285	266	137
Area	1,417	1,443	1,443	1,384	1,232	549	1,952	1,952	1,377	1,107	508
Total	**3,651**	**3,413**	**3,216**	**3,101**	**2,870**	**1,962**	**4,714**	**4,471**	**3,192**	**2,439**	**1,689**
NO_X Emissions (thousand tons per year)											
Utility	1,585	1,367	977	425	293	214	604	524	414	261	84
Industrial Point	550	607	556	453	403	319	591	535	433	401	338
Highway Vehicle	1,285	1,108	792	636	403	284	1,563	744	217	35	14
Nonroad	497	490	490	465	366	265	426	426	302	224	154
Area	383	450	450	399	326	117	496	496	305	239	61
Total	**4,300**	**4,022**	**3,265**	**2,378**	**1,792**	**1,199**	**3,680**	**2,726**	**1,671**	**1,161**	**650**
CO Emissions (thousand tons per year)											
Utility	53	89	89	89	89	89	107	107	107	104	104
Industrial Point	912	1,163	1,163	1,163	1,163	1,163	1,487	1,487	1,487	1,487	1,487
Highway Vehicle	10,437	8,513	8,433	8,247	7,882	5,901	12,934	12,895	5,950	295	118
Nonroad	2,418	3,278	3,278	3,075	2,954	2,354	4,443	4,443	3,695	3,398	1,436
Area	3,263	3,588	3,588	3,396	3,064	1,866	4,028	4,028	3,526	3,340	1,913
Total	**17,082**	**16,631**	**16,552**	**15,971**	**15,153**	**11,374**	**22,999**	**22,960**	**14,766**	**8,624**	**5,057**
SO_2 Emissions (thousand tons per year)											
Utility	4,710	3,270	3,270	2,106	1,848	336	1,013	1,013	617	393	54
Industrial Point	671	662	662	499	434	331	507	507	437	414	370
Highway Vehicle	33	72	29	9	9	6	116	48	8	2	1
Nonroad	121	157	157	76	75	53	233	233	118	116	61
Area	464	524	524	366	230	137	553	553	31	26	17
Total	**5,998**	**4,684**	**4,641**	**3,056**	**2,597**	**863**	**2,422**	**2,354**	**1,211**	**951**	**503**

– Table 2.2 continued on next page –

TABLE 2.2 continued

Sector	2010 1990	2010 A1	2010 A2	2010 B1	2010 B2	2010 B3	2040 A1	2040 A2	2040 B1	2040 B2	2040 B3
PM_{10} Emissions (thousand tons per year)											
Utility	80	97	97	97	97	97	78	78	78	71	71
Industrial Point	132	145	145	145	145	145	148	148	148	148	148
Highway Vehicle	99	38	34	32	25	18	58	51	15	2	1
Nonroad	69	82	82	78	74	59	80	80	69	69	41
Area	3,458	3,682	3,682	3,412	3,238	1,975	4,505	4,505	3,823	3,417	2,283
Total	**3,838**	**4,045**	**4,040**	**3,764**	**3,580**	**2,295**	**4,870**	**4,862**	**4,133**	**3,707**	**2,544**
$PM_{2.5}$ Emissions (thousand tons per year)											
Utility	26	37	37	37	37	37	32	32	32	28	28
Industrial Point	112	129	129	129	129	129	143	143	143	143	143
Highway Vehicle	62	27	22	21	15	11	40	32	8	2	1
Nonroad	60	71	71	67	63	50	67	67	57	58	33
Area	929	986	986	899	826	487	1,211	1,211	989	888	554
Total	**1,189**	**1,249**	**1,244**	**1,152**	**1,069**	**713**	**1,493**	**1,486**	**1,229**	**1,118**	**758**
NH_3 Emissions (thousand tons per year)											
Utility	0	0	0	0	0	0	0	0	0	0	0
Industrial Point	21	30	30	30	30	30	43	43	43	43	43
Highway Vehicle	51	81	81	80	77	58	126	126	60	1	0
Nonroad	0	1	1	1	1	0	1	1	1	1	0
Area	429	634	634	634	501	173	829	829	438	421	104
Total	**501**	**746**	**746**	**744**	**609**	**261**	**998**	**998**	**541**	**465**	**147**
NO_X Ozone Season Day Emissions (tons per day)											
Utility	6,032	3,750	1,194	1,152	811	594	1,660	1,135	1,138	720	236
Industrial Point	1,613	1,690	1,350	1,259	1,122	886	1,650	1,366	1,220	1,132	954
Highway Vehicle	3,529	3,048	2,644	949	1,344	2,124	4,315	2,051	597	97	39
Nonroad	1,661	1,648	1,648	1,553	1,201	853	1,400	1,400	955	684	467
Area	671	815	815	732	579	221	911	911	542	418	127
Total	**13,507**	**10,950**	**7,650**	**6,820**	**5,057**	**3,503**	**9,936**	**6,862**	**4,452**	**3,051**	**1,823**

At the State level (Figure 2.3) between 1990 and 2010, sulfur dioxide emissions are projected to decrease in Kentucky, West Virginia, Tennessee, Georgia and Alabama and to increase in North Carolina, South Carolina, and Virginia. Under Phase I of the Title IV of 1990 Clean Air Act Amendments several utility plants in West Virginia, Alabama, Georgia, Tennessee and Kentucky were required to reduce sulfur dioxide by January 1995. Twenty-one plants in these States added scrubbers and reduced sulfur dioxide emissions. Other utility units complied with Phase II requirements by switching to lower sulfur fuels or purchasing emission credits through the national trading program.

Emissions in all States are projected to fall below 1990 levels by 2040. Utility plans vary State to State in terms of increased production and controls thus accounting for the differences in States' emission trends. Based on information from utility representatives to the SAMI process, it was determined that the eight SAMI States would exceed the sulfur dioxide cap allowed by Title IV by 1 million tons. Utilities in the SAMI States indicated that they would buy allowances under the Title IV trading program. The inventory modeled this behavior by assuming that scrubbers would be installed on 106 sources outside the eight SAMI States.

Annual SO_2 Emissions – SAMI States

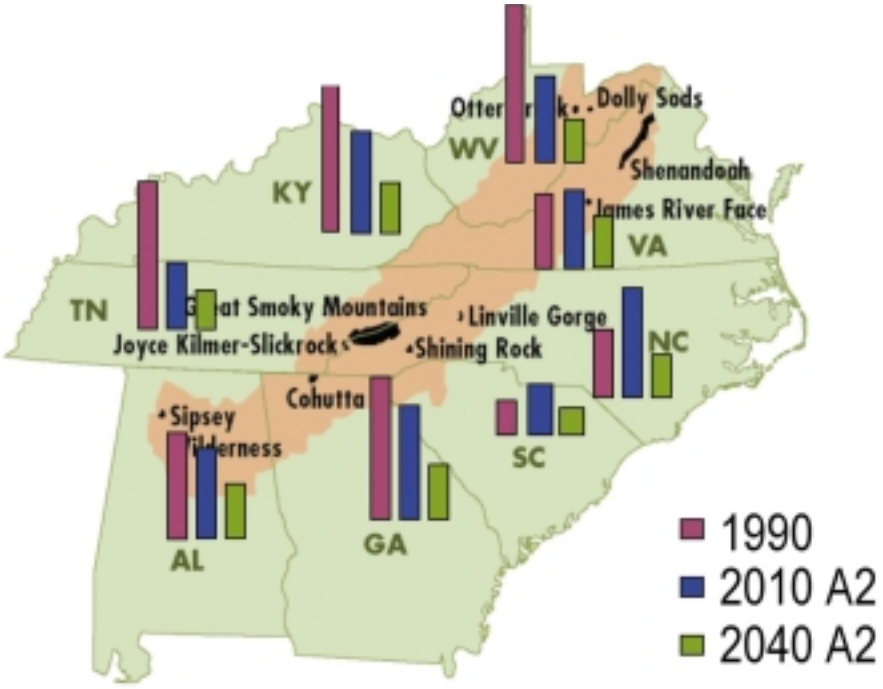


FIGURE 2.3: Relative SO_2 emissions by State, note that SO_2 emissions are projected to rise between 1990 and 2010 in North Carolina, South Carolina and Virginia

DEVELOPMENT OF THE CONTROL STRATEGIES

One of SAMI's tasks was to develop a series of control scenarios. These strategies were not based on existing or anticipated regulations, but were based on a potential course of actions that the SAMI States and the stakeholders could take in the future. These strategies were developed to assess the effects on the environment of different emission levels. Three strategies with increasingly stringent emission controls were developed for both 2010 and 2040, these strategies are referred to as B1, B2 and B3. In general, the SAMI participants designed the three strategies from these conceptual starting points:

- **B1 –** State-of-the-art controls applied to all sources. Logistical and other practical constraints were considered.
- **B2 –** State-of-the-art controls applied to all sources as soon as possible.
- **B3 –** The most advanced controls for 2010 and prototype controls for 2040 applied to all sources as soon as possible. Logistical and other practical constraints were not considered.

The following tables (Tables 2.3-2.7) describe all the B-group strategies by sector (E.H. Pechan & Associates, 2002a). Brief discussions of methods used to approach the strategy concepts outlined above are offered below. In general, any strategy will be more stringent in 2040 than 2010. It is also important to note that these controls and the resulting inventories were calculated for the eight SAMI States only. Working on the assumption that greater controls would only be adopted by the participants in this process, the inventory of emissions for the remaining States were held the same for determining effects of these strategies in the Southern Appalachian mountains.

Utilities

For SO_2 removal for existing units, it was assumed that more efficient scrubbers would be put on more units in each of the more stringent strategies. In 2010 B1, half of the unscrubbed capacity, starting with the largest boilers first, had to meet an emission rate of 0.4 lbs./MBtu. The same approach was used in the B2 case, however the new emission rate for 2010 was 0.2 lbs./Mbtu (90% efficiency). In the B3 case all unscrubbed units of greater than 25MW capacity were assumed to have 95% efficiency scrubbers. In 2040 for the B1 strategy, the emission rate was 0.4 lbs./Mbtu for units less than 65 years old and 0.3 lbs./Mbtu for units over that age. For B2 in 2040, existing units were controlled to an emission rate of 0.2 lbs./Mbtu; and for B3 they were all controlled to 98% efficiency. New power plants added between 2010 and 2040 are assumed to be a weighted average of the following three generation types and fuels: 20% pulverized coal, 40% natural gas combined-cycle, and 40% gasified coal combined-cycle. In the B2 and B3 strategy it was assumed that none of these new units would be pulverized coal and that the units would be split equally between the other two types. This assumption lowers the composite SO_2 rate from 0.025 lbs./MMBtu to 0.0116 lbs./MMBtu.

For NO_X emissions, the assumptions of fuel mixture for new units also apply. For existing units, the following controls apply: In 2010 and 2040 B1 it is assumed that the controls that are in place for the EPA required “State Implementation Plans” would be operated year-round instead of just during the ozone season. All units that are controlled would be controlled to either the emissions achieved for the State Implemenation Plans or 0.15 lbs./MMBtu, whichever is less. Likewise the B2 strategy would be the same except the maximum emission rate would be 0.10 lbs./MMBtu. In the B3 scenario, the emission rate of 0.07 lbs./MMBtu year-round was used for 2010 and 0.05 lbs./MMBtu for 2040.

TABLE 2.3: SAMI emissions inventory assumptions for the utility sector in 2010 and 2040 for B1, B2, and B3 strategies.

Utility Sources

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
Utility - NO_X	lower of A2 2010 NO_X rate or 0.15 lbs/MMBtu year-round	lower of A2 2010 NO_X rate or 0.10 lbs/MMBtu year-round	0.07 lbs/MMBtu year-round	20-40-40 composite NO_X rate (0.0606 lbs/MMBtu) for new and lower of A2 2010 NO_X rate or 0.15 for existing year-round*	0.03 lbs/MMBtu year-round for new and lower of A2 2010 NO_X rate or 0.10 lbs/MMBtu for existing, year-round	0-50-50 composite NO_X rate (0.01 lbs/MMBtu) for new and existing units >65 years; 0.05 lbs/MMBtu for existing units <65 years
Utility - SO_2	0.4 lbs/MMBtu** for half of unscrubbed capacity, year-round ***	0.2 lbs/MMBtu** for half of unscrubbed capacity, year-round ***	95% reduction applied to 2010 A2 unscrubbed emission rate for units >25 MW	20-40-40 composite with SO_2 rate of 0.025 lbs/MMBtu for new generic units 0.4 lbs/MMBtu** for ALL existing units <65 yr, year-round 0.3 lbs/MMBtu**** for ALL existing units >65 yr, year-round ***	0-50-50 composite***** with SO_2 rate of 0.0116 lbs/MMBtu for new generic units 0.2 lb/MMBtu** for ALL existing units (< or > 65 yr), year-round ******	0-50-50 composite SO_2 rate (0.0046 lbs/MMBtu) for new and existing units > 65 yrs; 98% reductions applied to 2040 A2 unscrubbed emission rates for units >25 MW

NOTES: *NO_X emission rate for 20% pulverized coal at 0.10 lbs/MMBtu (pounds per million British Thermal Units of heat output) and 40% combined cycle natural gas plus 40% gasified coal with a composite emission rate from sources of those types. For the remaining existing power plants that have not been retired, an emissions rate of 0.15 lbs/MMBtu will be used.

** Based on an uncontrolled SO_2 emission rate of 4.0 lbs/MMBtu (average coal with 2.5% S content), apply 90% control for B1 and 95% control for B2. For both B1 and B2, use same assumption for unscrubbed capacity.

*** Increase existing scrubbers with control efficiency less than 90% to 90% control for B1. For B2, increase existing scrubbers less than 90% to 95% control, scrubbers with control efficiency from 90% to 94% will not be increased to 95%.

**** SO_2 emission rate of 0.3 lbs/MMBtu same as 2040 A2 for units >65 yr.

***** 50% combined cycle natural gas and 50% gasified coal.

****** Increase existing scrubbers less than 95% to 95% for 2040 B2.

Existing unit controls apply to coal-fired utility boilers only. Oil and gas boilers at utility sites are not assumed to receive additional controls under these strategies.

MW = mega watt, refers to the size measured in power output, of a boiler.

TABLE 2.4: SAMI emissions inventory assumptions for the industrial sector in 2010 and 2040 for B1, B2, and B3 strategies.

Industrial Sources

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
NO_X - Existing Capacity	SIP Call Year Round - 60% Reduction of Uncontrolled Baseline Emissions from coal, oil, and gas-fired boilers; Applies to 250 MMBtu/hr rated capacity and above	Coal, oil, and gas-fired boilers >250 MMBtu/hr: 85% Reduction of Uncontrolled Baseline Emissions. Coal-fired boilers between 100 & 250 MMBtu/hr: 50% Reduction of Uncontrolled Emissions. Controls applied all year	0.07 lbs/MMBtu for all fuels; <100 MMBtu, treat as area sources	60% year round reduction from uncontrolled emissions for old coal, oil, and gas units larger than 250 MMBtu/hr	85% year round reduction from uncontrolled emissions for old coal, oil, and gas units larger than 250 MMBtu/hr and 75% year-round reduction for old coal units between 100 & 250 MMBtu	0.05 lbs/MMBtu for all fuels; <100 MMBtu/hr, treat as area sources.
NO_X - Replacement/ New Capacity	Composite (33-67) mix NO_X rate of 0.16 lbs/MMBtu for all new/replacement capacity from 1990 through 2010. (Assumes coal @ 0.3 and gas @ 0.09 (lbs/MMBtu)	Composite (20-80) mix NO_X rate of 0.12 lbs/MMBtu for all new/replacement capacity from 1990 through 2010. (Assumes coal @ 0.20 and gas @ 0.08 lbs/MMBtu)	0.03 lbs/MMBtu for all fuels	Composite (33-67) mix NO_X rate of 0.09 lbs/MMBtu year-round for all new/replacement capacity from 2011-2040: 33% PC @ 0.15 lbs/MMBtu; 67% gas boilers @ 0.06 lbs/MMBtu	Composite (20-80) mix NO_X rate of 0.044 lbs/MMBtu year-round for all new/replacement capacity from 2011-2040: 20% PC @ 0.10 lbs/MMBtu; 80% gas boilers or GTCC @ 0.03 lbs/MMBtu	0.01 lbs/MMBtu for all fuels
SO_2 - Existing Capacity	80% reduction from uncontrolled emissions for coal-fired boilers greater than 250 MMBtu/hr rated capacity 50% reduction from oil-fired boilers	Same as B1 except 90% reduction from uncontrolled emissions. 50% reduction on coal-fired boilers between 100 & 250 MMBtu/hr 75% reduction from oil-fired boilers	>250 MMBtu/hr 95% reduction 100-250 MMBtu/hr 93% reduction <100 MMBtu, treat as area sources	90% year-round reduction of uncontrolled emissions for old coal units larger than 250 MMBtu/hr 80% reduction from oil-fired boilers	95% year-round reduction of uncontrolled emissions for old coal units larger than 250 MMBtu/hr and 80% year-round reduction for old coal units between 100 & 250 MMBtu/hr 95% reduction from oil-fired boilers	>100 MMBtu/hr 98% reduction

TABLE 2.4 continued

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
SO_2 - New Replacement Capacity	Composite (33-67) mix SO_2 rate of 0.13 lbs/MMBtu for new/ replacement capacity from 1990 through 2010. (Assumes coal @ 0.4 lbs/MMBtu (2.5% S coal & 90% control).)	Composite (20-80) mix SO_2 rate of 0.08 lbs/MMBtu for new/ replacement capacity from 1990 through 2010. (Assumes coal @ 0.4 lbs/MMBtu and 90% control.)	98% control on coal	33-67 - Composite SO_2 rate of 0.10 lbs/MMBtu year-round for all new/replacement capacity from 2011-2040: 33% PC @ 0.3 lbs/MMBtu (assumes 2.5% S coal & 90% control); 67% Gas boilers @ 0.0 lbs/MMBtu	20-80 - Composite SO_2 rate of 0.04 lbs/MMBtu year-round for all new/ replacement capacity from 2011-2040: 20% PC @ 0.2 lbs/MMBtu (assumes 2.5% S coal & 95% control); 80% Gas boilers or GTCC @ 0.0 lbs/MMBtu	20-80 composite, 99% control on coal-fired boiler
Industrial Gas Turbines	60% NO_X control year-round > 250 MMBtu/hr	60% NO_X control year-round >250 MMBtu/hr 20% NO_X control year-round <250 MMBtu/hr	88% NO_X control year-round	60% NO_X control year-round >250MMBtu/hr	60% NO_X control year-round >250 MMBtu/hr 50% NO_X control year-round <250 MMBtu/hr	96% NO_X control year-round
Industrial Internal Combustion Engines	90% NO_X control year-round >1 ton NO_X/OSD	90% NO_X control year-round >1 ton NO_X/OSD 20% NOx control year-round <1 ton NOx/OSD	86% NO_X reduction year-round	90% NO_X control year-round >1 ton NOx/OSD	90% NO_X control year-round >1 ton NOx/OSD 50% NO_X control year-round <1 ton NOx/OSD	93% NO_X reduction year-round
Cement Kilns (>1 ton NO_X/OSD)	30% NO_X control year-round	30% NO_X control year-round	60% NO_X control year-round, 90% SO_2 control year-round	30% NO_X control year-round	30% NO_X control year-round	90% NO_X control year-round, 95% SO_2 control year-round

NOTES: All industrial sources <100 MMBtu/hr to be treated as area sources in B3.

All new boiler capacity is to be fueled with gas equivalents in B3.

All industrial oil is replaced with gas equivalents as of 2010 in B3.

S = Sulfur, 2.5% S coal refers to the sulfur context of the coal.

Composite SO_X + NO_X rates based onmix of pulverised coal and natural gas boilers.

PC = Pulversied Coal

SIP – state implementation plan requires NO_X controls during the ozone season (May- September) only. This strategy calls for the same controls year round.

1 ton NO_X/OSD = industrial unit that emits one ton of NO_X per day during the ozone season (May-September).

TABLE 2.5: SAMI emissions inventory assumptions for the highway vehicle sector in 2010 and 2040 for B1, B2, and B3 strategies.

Highway Vehicle

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
LD Emission Standards	50% Tier 2	100% Tier 2	75% Tier 2; 25% ZEV	50% ZEV; 50%Tier 2	100% ZEV	100% ZEV
LD Reduction in VMT Growth Rate from 2000	10%	25%	25%	10%	25%	25%
HD Diesel Fuel	50 ppm S	50 ppm S	15 ppm S	15 ppm S	5 ppm S	5 ppm S
HD Emission Standards	10% meet 2007 standards	50% meet 2007 standards	10% ZEV; 10% VMT to rail; 50% meet 2007 standards	10% ZEV; 10% VMT to rail; 80% meet 2007 standards	25% ZEV; 25% VMT to rail; 50% meet 2007 standards	50% ZEV; 30% VMT to rail; 20% meet 2007 standards

NOTES: Percentages refer to portion of vehicle miles traveled effected by given control.

LD = Light Duty vehicles (cars, vans, pick-up trucks)

HD = Heavy Duty vehicles (large diesel trucks)

VMT = Vehicle Miles Traveled

ZEV = Zero Emission Vehicle

TABLE 2.6: SAMI emissions inventory assumptions for the nonroad engine sector in 2010 and 2040 for B1, B2, and B3 strategies.

Nonroad Engine

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
Airport Service Equipment	50% ZEV	100% ZEV	100% ZEV	100% ZEV	100% ZEV	100% ZEV
Gasoline Lawn & Garden and Recreational Vehicles	10% ZEV	15% ZEV	30% ZEV	30% ZEV	45% ZEV	90% ZEV
Gasoline S Level for Lawn & Garden, Recreational Vehicles, and Recreational Marine Vessels	30 ppm S	30 ppm S	30 ppm S	30 ppm S	30 ppm S	30 ppm S
Diesel S Level - All Diesel Engines, Diesel Commercial Marine Vessels, Diesel Recreational Marine Vessels, and Diesel Locomotives	50 ppm S	50 ppm S	15 ppm S	15 ppm S	5 ppm S	5 ppm S
2007 Highway Vehicle Engine Standards (0.2 g/bhp-hr) to Diesel Construction, Farm, Logging, Industrial Equipment, and Commercial Marine Engines	0%	30%	50%	50%	100%	100%
ZEV for SI, CI, Marine, and Locomotive Engines			25% ZEV			50% ZEV
Clean Aircraft Engines		10%	50%		75%	100%

NOTES: Percentages refer to portion of emissions from given source effected by given control.

S = Sulfur

ZEV = Zero Emission Vehicle (or equipment)

TABLE 2.7: SAMI emissions inventory assumptions for the area sources sector in 2010 and 2040 for B1, B2, and B3 strategies.

Area Sources

Emission Category	2010 B1	2010 B2	2010 B3	2040 B1	2040 B2	2040 B3
NO_x						
Industrial Natural Gas Combustion	0%	20%	75%	30%	50%	90%
Industrial Coal Combustion	10%	20%	75%	30%	50%	90%
Miscellaneous Burning	0%	10%	75%	20%	30%	90%
Residential Natural Gas	10%	20%	75%	30%	50%	90%
Commercial/Institutional Natural Gas	10%	20%	75%	30%	50%	90%
Open Burning	50%	90%	90%	90%	90%	90%
Commercial/Institutional Oil	15%	25%	75%	35%	55%	90%
Residential Wood	10%	20%	75%	30%	50%	90%
SO_2						
Industrial Coal	25%	50%	75%	98%	98%	98%
Commercial/Institutional Oil	25%	50%	75%	98%	98%	98%
Residential Distillate Oil	25%	50%	75%	98%	98%	98%
Industrial Distillate Oil	25%	50%	75%	98%	98%	98%
Commercial/Institutional Coal	25%	50%	75%	98%	98%	98%
Other Industrial Fuel Combustion	25%	50%	75%	98%	98%	98%
Residential Coal	25%	50%	75%	98%	98%	98%
PM_{10}						
Unpaved Road Dust	10%	20%	75%	30%	50%	90%
Fugitive Dust	10%	20%	75%	30%	50%	90%
Agricultural Crops	0%	5%	75%	10%	20%	90%
Agricultural Livestock	10%	20%	75%	30%	50%	90%
Managed Burning	0%	10%	75%	0%	10%	90%
$PM_{2.5}$						
Unpaved Road Dust	10%	20%	75%	30%	50%	90%
Fugitive Dust	10%	20%	75%	30%	50%	90%
Managed Burning	0%	10%	75%	0%	10%	90%
Residential Wood	10%	20%	75%	30%	50%	90%
Agricultural Crops	0%	5%	75%	10%	20%	90%
Open Burning	50%	90%	90%	90%	90%	90%
Ammonia						
Livestock	30%	40%	75%	50%	60%	90%
Fertilizers	10%	20%	75%	30%	50%	90%
VOC						
All Chemical and Allied Products (>90%)	0%	10%	75%	30%	50%	90%
All Solvent Use (>90%)	0%	10%	75%	30%	50%	90%
All Storage and Transport (>90%)	0%	10%	75%	30%	50%	90%

NOTES: Percentages represent assumed reductions of emissions without consideration of methods used to achieve those reductions.

Industrial Sector

SAMI strategies focused on controls on coal, oil and gas-fired industrial boilers, industrial gas turbines, industrial internal combustion engines and cement kilns. The approach was similar to that used in the utility sector. In general, increasing levels of controls were added to a greater number of units as the strategies became more stringent (Table 2.4).

Highway Vehicle

Additional emission reductions from highway vehicles were achieved for each strategy by increasingly more aggressive implementation of several strategies. First in developing the B strategies from the A2 strategy, it was assumed that fleet turnover would occur at a faster pace and that a greater percentage of the fleet would achieve the 2004 Tier II controls in the year 2010. It was also assumed that a percentage of the fleet would convert to zero emission vehicles - in the 2010 B3 case 25% of the light duty vehicles are assumed to be zero emitting. This percentage increases through the strategies in 2040. In the 2040 B3 case 100% of the light duty vehicles are assumed to be zero emission vehicles. The other control assumed is reduction in the growth rate of vehicle miles traveled. Similarly, a fleet of heavy-duty vehicles, which would be predominately trucks and exclusively diesel-powered vehicles, is assumed to turnover more rapidly resulting in greater percentages of the fleet meeting the 2007 emission guidelines in 2010. In 2040 there are significant portions of the fleet that are assumed to have converted to zero emission vehicles and there is the assumption that up to 30% of the vehicle miles traveled can be converted to rail traffic. There are also increasingly stringent reductions in the amount of sulfur in diesel fuel.

Nonroad Engine

The nonroad engine sector includes a variety of motors and engines used for all other activities besides passenger cars and trucks. Examples include: airport service equipment, gasoline powered lawn and garden equipment and recreational vehicles, all diesel engines except trucks, construction equipment, and aircraft engines. The different strategies involved increased reliance on zero emission vehicles in many of these categories. Strategies also included decreasing the level of sulfur in diesel fuel, applying the 2007 diesel engine standards to additional types of engines, and increased penetration of the clean aircraft rules (E.H. Pechan and Associates, 2002).

Area Sources

The area source sector is considered by pollutant type. Thus there are five categories of pollutants for which there are area sources and then specific sources that generate each of those pollutants. There is significant overlap in the sources that generate sulfur dioxide and oxides of nitrogen with all of these sources being some type of combustion. There are also sources for particulate matter smaller than 10 microns, particulate matter smaller than 2.5 microns, ammonia and volatile organic compounds. Instead of identifying specific types of controls, as was done for the other source sectors, for area sources a level of reduction was assigned to each source in each strategy. See Table 2.7 for the specific reduction percentages.

Results: Application of Emissions Reduction Strategies

This section emphasizes the emission results for the three pollutants that are most significant to the SAMI analysis: nitrogen oxides, sulfur dioxide and ammonia. These pollutants are contributors to the formation of ozone, acid deposition and fine particle haze in the Southern Appalachia's Class I wilderness areas. Graphics in this section will compare the 1990 Baseline to the A2 reference strategy and to the B strategies. Volatile organic compounds are a significant contributor to the chemistry of ozone formation and are emitted from both natural sources and human activities. Modeled natural emissions of volatile organic compounds are substantially larger than emissions for human activity (Odoran et. al, 2002). This section only discusses volatile organic compounds from human activity that were calculated as part of the inventories. The pattern of volatile organic compounds emissions over the study years and under various strategies can be seen in Figure 2.4. Volatile organic compounds and primary particles will also be discussed briefly. Other pollutants including carbon monoxide are in the annual inventory as

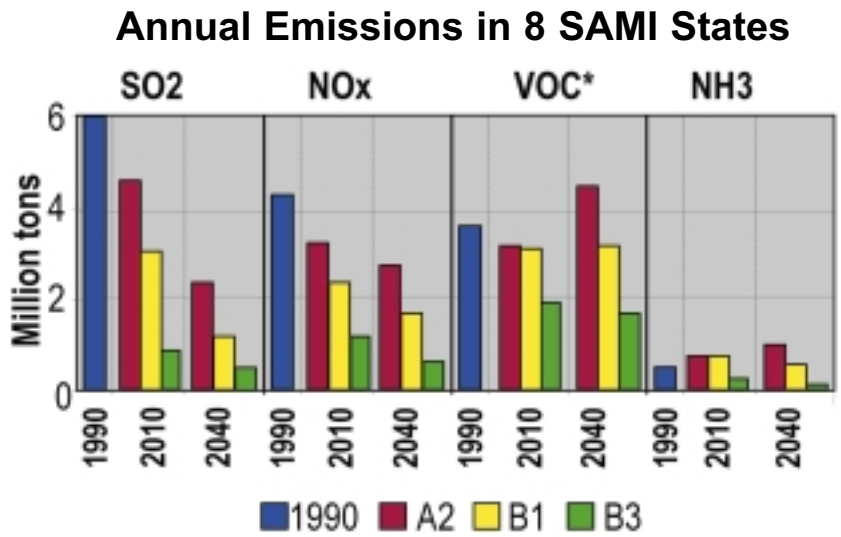
summarized in Table 2.2, (E.H. Pechan and Associates, 2002a) but are not discussed in the text.

SULFUR DIOXIDE

The A2 reference case, as discussed previously, would reduce SO_2 levels from the 1990 baseline by 23% in 2010 and by 61% in 2040.

Total reductions from each B-group strategy compared to A2 are (Figure 2.5):

- In 2010, B1 - 34%, B2 - 44%, B3 - 81%
- 2040 A2 strategy is 51% of 2010 A2
- In 2040, B1 - 48%, B-2 - 60%, B3 - 79% (relative to 2040 A2)



*Human sources of VOC only, not included natural sources of VOC

FIGURE 2.4: Four-pollutant comparison of emission levels between 1990, 2010 and 2040 selected strategies in the SAMI States

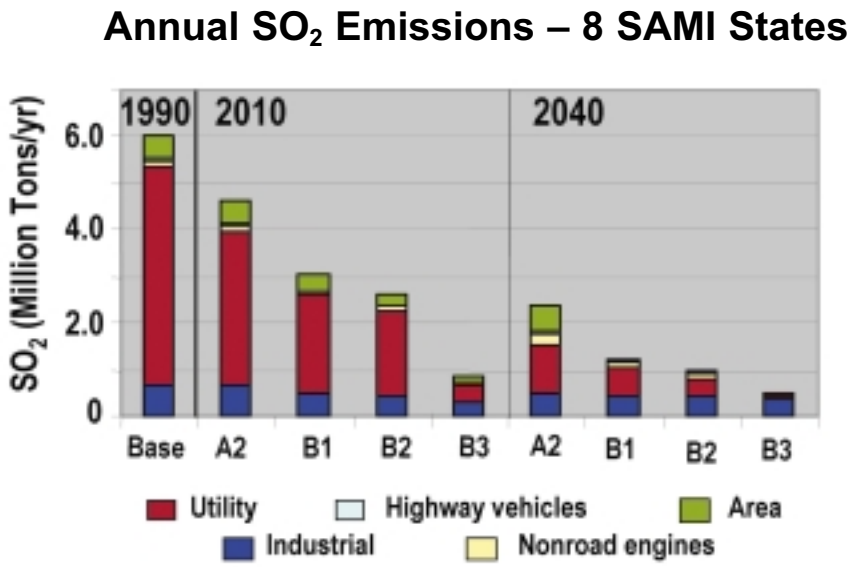


FIGURE 2.5: Comparison of annual SO_2 emissions by source sectors.

The utility sector contributes most to SO_2 emissions. This sector also experiences the greatest emission reductions, through increasingly tighter controls on more and more units and switching from pulverized coal to cleaner emitting coal technology and other fuel types. In the utility sector in 2010, the B1 and B2 strategies require scrubbers of 90% and 95% efficiency, respectively, on 50% of the capacity that still did not have scrubbers. The B3 strategy required scrubbers of 98% efficient on 100% of the unscrubbed capacity.

It was recognized that by 2040 there would be new plants to meet increasing demand and many utility plants would be retired (an active life of 65 years was assumed for power generating facilities). These new facilities were assumed to consist of a weighted average of the following generation technology and fuel types: 20% pulverized coal, 40% integrated gasification combined-cycle and 40% natural gas combined-cycle in the A2 reference case and the B1 strategy. In the B2 and B3 strategies the percentage of pulverized coal was dropped to 0% and the other two were each raised to 50%.

In addition to the significant reductions in the utility sector, there are small reductions in the area and nonroad vehicle sectors through fuel switching. There is very little sulfur dioxide emission reduction from the industrial source sector because there are so many small sources that none of the approaches assumed the depth of controls that would significantly change this sector. Note that the B1 and B2 strategies implemented in the year 2010 would accelerate annual emissions reductions that would be achieved through the A2 reference strategy alone by 2040. The 2010 B3 strategy would create emission reductions greater than the A2 reference strategy in the year 2040.

Although there are significant uncertainties, confidence in the SO_2 inventory is the highest of all the pollutant inventories developed.

NITROGEN OXIDES

The largest sources of nitrogen oxides are the utility and highway vehicle sectors and the greatest reductions are also in these sectors (Figure 2.6). Nitrogen oxides reductions in the utility sector are achieved by increasingly stringent controls. Nitrogen oxides control on utility boilers is achieved by use of selective catalytic reduction (SCR). New units and replacement units are also assumed to have tighter controls. In the highway vehicle sector the strategies presume increasing penetration of the TIER II rules which take effect in 2007 and greater conversion to zero emission vehicles. It was assumed that zero emission vehicles did not cause an increase in electricity demand.

Total reductions in annual average NO_X emissions from each B-group strategy compared to A2 is: (Figure 3.8)

- In 2010, B1 - 27%, B2 - 45%, B3 - 63%.
- 2040 A2 is 83% of 2010 A2.
- In 2040, B1 - 39%, B2 - 57%, B3 - 76% (relative to 2040 A2).

The 2010 A2 strategy requires NO_X reductions in the summer months only, since NO_X is a precursor to ozone formation and ozone is a summertime pollution problem (Figure 2.7). Both sunshine and warm temperature promote the chemical reactions that generate and accumulate ozone. All of the B-group strategies require year round control.

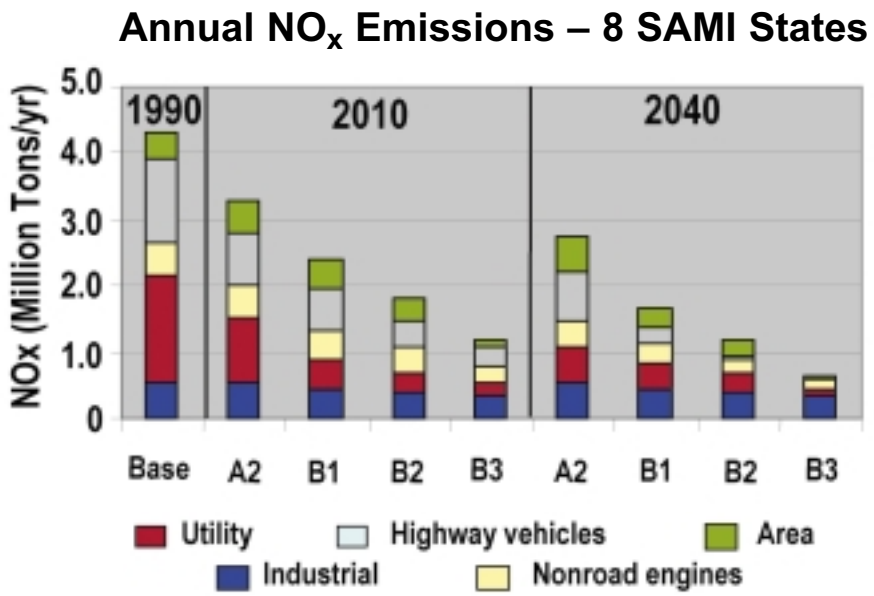


FIGURE 2.6: Comparison of annual oxides of nitrogen emissions by source sectors.

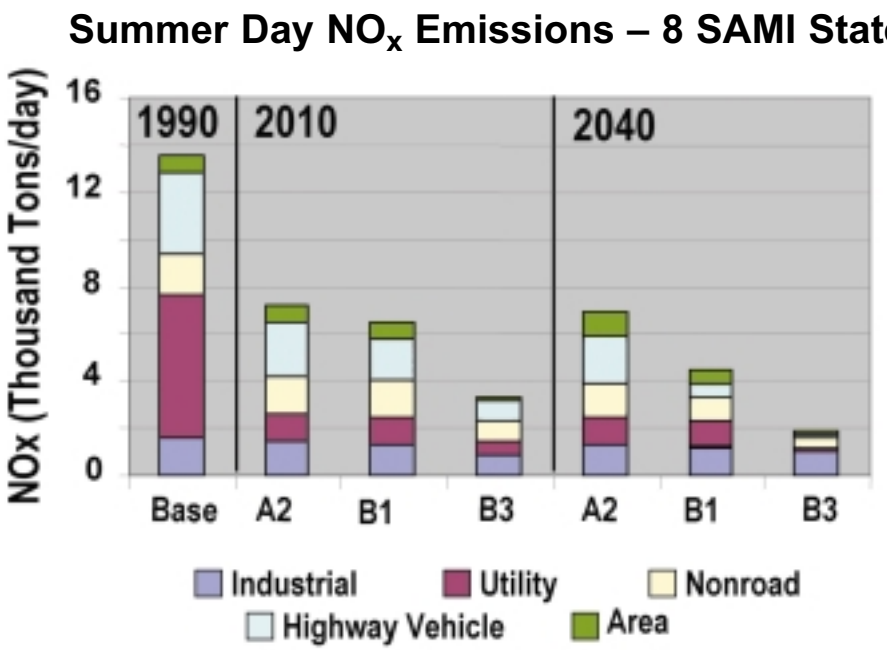


FIGURE 2.7: Projections of daily NO_X levels in the SAMI States during the summer months (May through September)

AMMONIA

Greater than 80% of ammonia emissions are from agricultural sources such as animal waste products from concentrated animal feedlots, and fertilizer production and application. In the reference strategy, ammonia emissions increase with activity since there are no significant controls for these ammonia sources. The SAMI strategies assume 10% to 75% reductions in ammonia are achieved in the B strategies but do not specify methods for achieving these reductions. As greater controls are envisioned in the different strategies, reductions are accomplished, but it is not until the B3 strategy that emission levels are significantly less than 1990 levels (Figure 2.8). Ammonia emissions are more significant in the area of fine particulate development and acid deposition than was recognized at the beginning of the SAMI Assessment. The level of confidence in the Baseline ammonia inventory is very low because it is difficult to assess emissions from area sources. For example, estimating agricultural emissions from animal operations requires estimating the emission from each animal and then estimating the level of activity. The development of reference strategies required assessing the growth in the number of animals. This inventory was developed using economic growth of the agricultural sector as a surrogate for the number of animals.

Ammonia is a significant contributor to the deposition of nitrogen. To begin to understand this contribution, SAMI calculated the total nitrogen emissions, as nitrogen from both the nitrogen oxides sources and the ammonia sources (Figure 2.9).

OTHER POLLUTANTS

Volatile organic compounds emissions from human activity come primarily from area, highway vehicle and industrial source sectors. In the A2 strategy reductions in the highway vehicles sector reduce volatile organic compounds emissions in 2010 as compared to 1990. By 2040, these reductions are more than overwhelmed by the growth in activity in several sectors, including the industrial sector. In the B-group strategies, the most significant reductions are seen in the highway vehicle sector as the strategies call for lower emission vehicles in 2010 and more zero emission vehicles in 2040. Also the B3 strategy calls for significant reduction in volatile organic compounds emissions from area sources.

Emissions of primary particulate matter smaller than 2.5 microns come mostly from area sources (80%), including combustion sources (e.g., uncontrolled burning like agricultural burning, residential heating, and forest fires) and unpaved road dust. These sources actually contribute little to the visibility problem, which is predominately the result of secondary fine particles that form in the atmosphere from sulfur dioxide, nitrogen oxides, ammonia and organic emissions. The A2 reference strategy assumes no controls for primary fine particulate. Therefore, these emissions increase with increased activity from 1990 to 2010 and 2040. Only the B3 strategy requires controls that would significantly reduce the levels of primary fine particles.

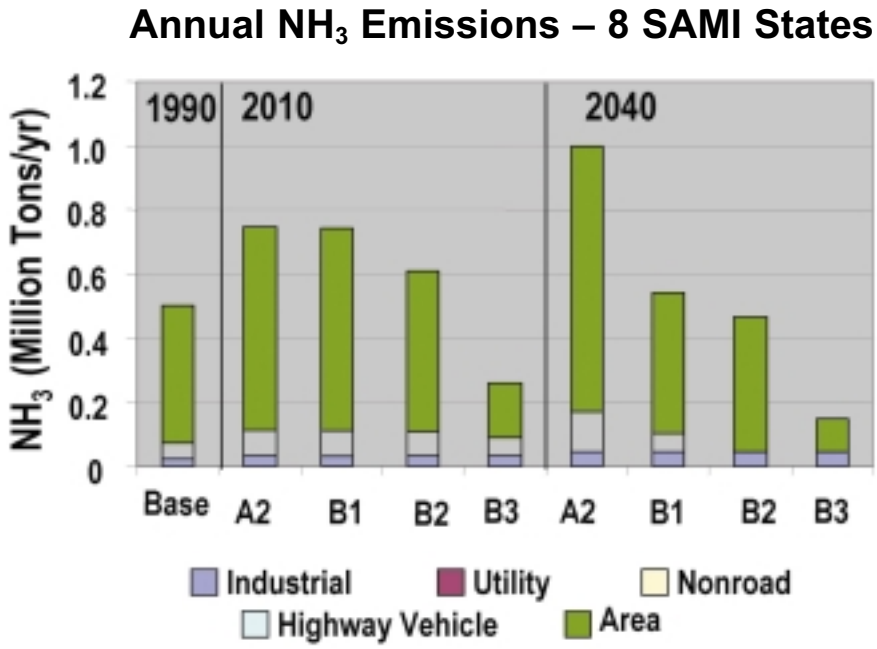


FIGURE 2.8: Comparison of annual ammonia emissions, broken out by source sectors.

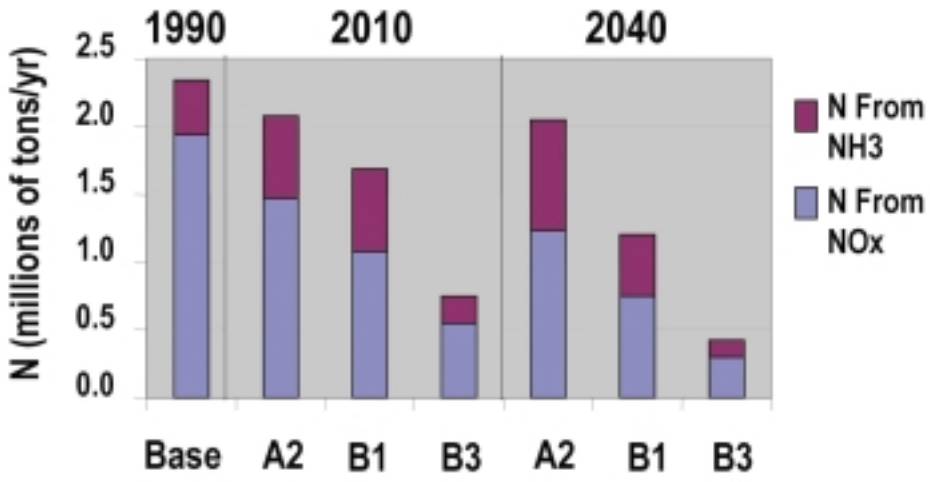


FIGURE 2.9: Comparison of annual Nitrogen emissions, calculated from the oxides of nitrogen and ammonia emissions as Nitrogen.

UNCERTAINTIES

Uncertainties associated with the 1990 Inventory have already been discussed. This section discusses uncertainty associated with the development of the reference strategies (A1 and A2) for 2010 and 2040. Tables 2.8 and 2.9 illustrate the relative uncertainty associated with the emission projections and factors leading to these projections for 2010 and 2040, respectively. Blocks in the matrices labeled with NS (not significant) account for less than 8% of the emissions of that pollutant. This system includes half pluses in order to distinguish between levels of uncertainty. Thus (++-) equals 2.5 pluses. The results for 2040 are, of course, less certain that the results for 2010. In many cases projections of activities were not available that far in the future. Some activity projections for 2040 were done by linear extrapolation from existing projections.

TABLE 2.8: Relative Confidence Levels in SAMI 2010 Base Case Emission Inventories (A1/A2)

SAMI 2010 Base Year (A2) Emission Inventory Relative Confidence

(5 pluses = most certain)

	Utility	Industrial	Highway Vehicle	Nonroad Engine	Area
Growth/Activity	+++++	+++-	+++-	++++	++-
Emission Location	+++-	+++	++++	++-	++
SO_2	+++-	++-	NS	NS	++
NO_X	++++-	+++-	+++	++-	++
VOC	NS	++-	+++	++-	++-
NH_3	NS	++-	NS	NS	+
$PM_{2.5}$	+-	+-	++	NS	+

TABLE 2.9: Relative Confidence Levels in SAMI 2040 Base Case Emission Inventories (A1/A2)

SAMI 2040 Base Year (A2) Emission Inventory Relative Confidence

(5 pluses = most certain)

	Utility	Industrial	Highway Vehicle	Nonroad Engine	Area
Growth/Activity	++-	+-	++	+-	+
Emission Location	++	+-	+-	+	-
SO_2	++	NS	NS	NS	+
NO_X	++	+-	+	+	+
VOC	NS	+	+	+	-
NH_3	NS	+	NS	NS	-
$PM_{2.5}$	-	-	-	NS	-

NS= not significant (less than 8% of the inventory)

Uncertainty in the utility growth and activity factors is driven by uncertainty in the projection of electrical need and generation, assumptions regarding capacity factors and retirement age. In 2040 the assumption concerning generation mix also adds uncertainty. In the highway vehicle sector uncertainty is driven by vehicle mile projections and fleet turnover projections. In the nonroad engine sector uncertainty is driven by even greater uncertainty about equipment turnover and by the fact that population and economic surrogates were used for projections of types of equipment.

The area sources are, as a sector, the most uncertain. Uncertainty in this sector is associated with the use of population and economic growth surrogates to determine growth of emissions and the numerous and wide-ranging sources of pollutants that have not traditionally been controlled or even quantified. The least certain pollutant is ammonia. Both the 1990 Base Year inventory and the growth projections (based on projections of economic growth in agriculture) are highly uncertain in this area (E.H. Pechan and Associates, July 2002).

The uncertainty of the reference case carries through to the B-group of control strategies. Since these controls were determined by SAMI, it is not possible to assess uncertainty in the traditional sense. However, the B3 strategies were developed without consideration of technical or other feasibility. Thus, for the B3 strategies and in some cases the B2 strategies, there is uncertainty as to whether the emission reductions proposed by the strategy are actually achievable.

LESSONS LEARNED

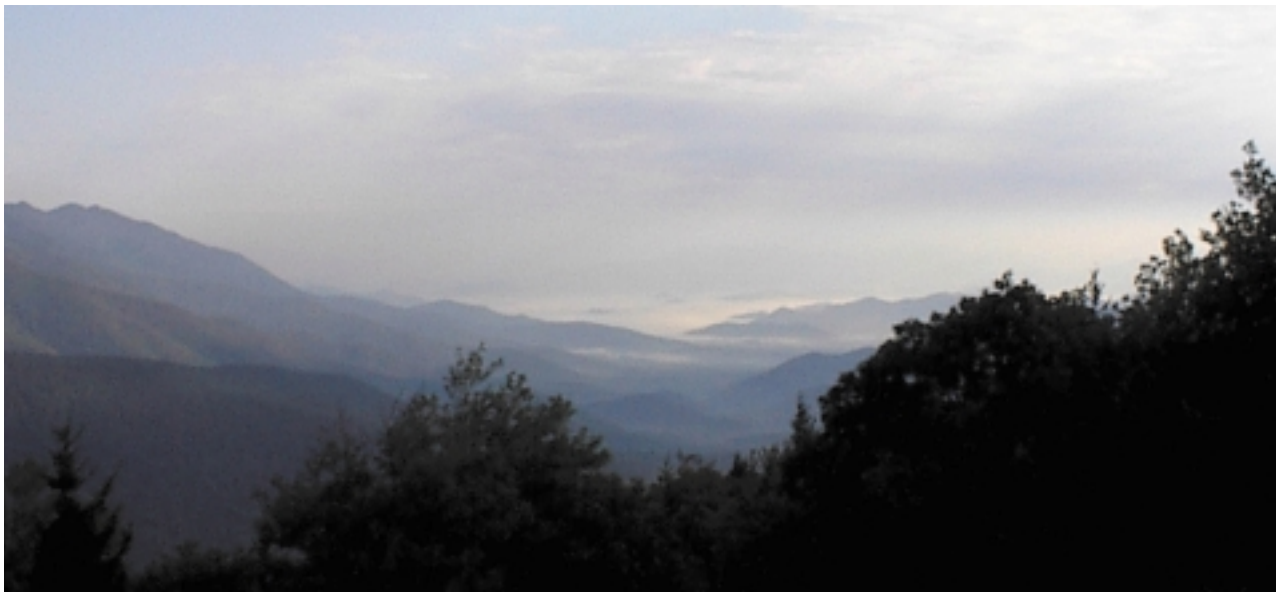
- Emissions activity and growth assumptions are as important as emission factors in projecting future emission levels.
- Improvements in ammonia assumptions and organic speciation are important for future inventories addressing fine particles, ozone, and acid deposition.

KEY FINDINGS

1. The SAMI emission inventory quantifies emissions for a 1990 Base Year, a 2010 and 2040 reference case, and a series of hypothetical control strategies for the years 2010 and 2040 to be used in the SAMI air quality and effects models to determine what the effect could be on the Class I wilderness areas in the eight State SAMI region.
2. Base Year and reference inventories (A1 and A2) for 2010 and 2040 were developed for the eastern two-thirds of the United States. Inventories for the hypothetical, B-group strategies, were developed for the SAMI States only.
3. The utility sector is the largest source of SO_2 and has the greatest reductions in SO_2.
4. SO_2 emissions are 23% less in 2010 A2 than in the 1990 Base year across all SAMI states, however there are increases in emissions projected in North Carolina, South Carolina and Virginia.
5. Utility and highway vehicle sectors are the largest sources of NO_X and have the greatest reductions.
6. Under the A2 strategy, VOC emissions increase between 2010 and 2040 by 39% and NH_3 by 34% compared to 1990.
7. 2010 B1 & B2 strategies accelerate SO_2 emission reductions that are achieved in 2040 A2. 2010 B3 provides greater reductions than 2040 A2.
8. The inventory provides the foundation for the SAMI Integrated Assessment, from which further conclusions can be drawn.

CHAPTER 3

ATMOSPHERIC MODELING AND GEOGRAPHIC SENSITIVITY ANALYSES



INTRODUCTION

SAMI successfully completed the first application of an integrated, one-atmosphere model to simultaneously evaluate fine particles, ozone, and acid deposition in the Southern Appalachian Mountains (GIT, 2001; Odman, et al., 2002a; Boylan, et al., 2002). The model accounts for the complex chemical and physical processes that affect the emissions, formation, transport, and removal of gases and fine particles. Previous regional or national modeling efforts have used separate modeling systems to address ozone (Russell and Dennis, 2000), fine particles (Seigneur, 2001), or wet deposition (Dennis et al., 1990). These previous efforts simplified or eliminated some chemical or physical processes, such as interactions among pollutants, that can be important to accurate modeling.

SAMI's atmospheric modeling is unique in that it focused on air quality in Class I parks and Wilderness areas rather than the urban population centers. SAMI's atmospheric modeling is also unique in supporting assessments of the environmental effects of fine particles, ozone, and acid deposition, rather than health effects assessments. Seasonal and annual air quality measures are most relevant to SAMI's assessments of environmental effects. SAMI used an episodic modeling approach to evaluate a range of air quality and meteorological conditions across a five-year period 1991-1995. The classification technique allowed episodes to be aggregated into the seasonal and annual measures with an estimate of uncertainty. This approach contrasts with those of previous regulatory modeling applications that generally focused on episodes with the highest pollutant exposures.

SAMI's atmospheric modeling methods and results are briefly highlighted in this report. For more information and illustrations of model performance and results see the websites maintained by SAMI (www.vistas-sesarm.org) and by Georgia Institute of Technology (www.environmental.gatech.edu/SAMI), and project reports (Odman, et al., 2002a) and publications (Boylan, et al. 2002).

Atmospheric Modeling Objectives

- Use an integrated one-atmosphere model to represent gaseous, aerosol, and deposition processes
- Focus greatest accuracy on air pollutant dynamics in the Southern Appalachian Mountains, an area that has generally not been addressed in other modeling exercises

- Select episodes to represent seasonal and annual air quality exposures that are most relevant for environmental effects
- Demonstrate model performance for selected episodes by comparing modeled air quality to available air quality measurements
- Project future air quality in response to SAMI emissions strategies and provide changes in air quality for effects and socioeconomic analyses
- Evaluate changes in air quality at specific receptors in response to emissions changes in specific geographic areas

Air Pollution Primer

Most fine particles, ozone, and acids are not emitted directly into the atmosphere, but rather are secondary by-products formed by chemical reactions of primary gaseous emissions. Examples of primary emissions are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), ammonia (NH_3), volatile organic compounds (VOCs), particles less than 2.5 microns in diameter ($PM_{2.5}$), and particles less than 10 microns in diameter (PM_{10}; see Emissions Inventory Chapter 2). Coal-fired electric utility plants are the largest source of sulfur dioxide. Highway vehicles and utilities are the largest sources of nitrogen oxides, highway vehicles are the largest sources of volatile organic compounds, and agricultural sources are the largest contributors to ammonia gas. Natural sources such as vegetation also contribute to organic carbon compounds.

Ozone (O_3) is a secondary pollutant formed from the reactions of nitrogen oxides and volatile organic compounds in the presence of sunlight. Fine particles are comprised of a mixture of several components including sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), organic carbon (OC), elemental carbon (EC), and soil particles. Organic aerosols are either emitted directly (for example. wood smoke) or formed by reaction and/or condensation of organic gases. Sulfate fine particles are formed by the oxidation of sulfur dioxide gas by hydroxyl radicals, ozone, or hydrogen peroxide. Sulfate particles typically exist as sulfuric acid, ammonium bisulfate, or ammonium sulfate. Ammonia gas reacts with nitrate acid to form ammonium nitrate particles. These particles can be deposited dry to surfaces or washed out of the atmosphere in precipitation. The atmospheric model accounts for these interacting chemical, transport, and deposition processes.

Meteorology influences the rate of formation and transport of air pollutants. For example, ozone formation is greater on days with higher temperatures and full sunlight than on cooler, cloudy days. Emissions of volatile organic compounds from highway vehicles, nonroad engines, vegetation, and the release of ammonia gas from animal waste increases at a higher temperature.

Particularly during strong storm systems, winds can transport primary emissions and secondary pollutants hundreds of miles from the emissions sources. In contrast, the Southern Appalachian Mountains area may experience many consecutive days with low or stagnant winds (called an air stagnation event). During these periods, dispersion of emissions is low and pollutants can build up in the atmosphere. The complex terrain in mountainous areas also influences winds, temperature, clouds, and precipitation.

Ozone = nitrogen oxide + volatile organic compounds + sunlight

Ozone is a colorless gas. At elevated levels it affects breathing in humans, particularly for children, elderly, and those with respiratory problems.

Acid Rain = sulfur dioxide + nitrogen oxide + water = sulfuric acid + nitric acid

Acid Deposition can occur as rain, cloudwater, or dry deposition of particles. Acid rain can acidify sensitive streams and forests.

Fine Particles = sulfate + nitrate + ammonia + organics + soil dust

Fine particles in the air scatter light and impair visibility. They can also affect breathing in humans.

ATMOSPHERIC MODELING METHODS

Episode Selection

The air quality and meteorological records for 1991 through 1995 at Great Smoky Mountain National Park (Look Rock, Cove Mountain, and Elkmont monitoring sites) and Shenandoah National Park (Big Meadows monitoring site) were used for episode selection. Days with valid monitoring data in 1991 – 1995 were classified based on air quality and associated meteorological conditions using the Classification and Regression Trees (CART) analysis technique (Deuel and Douglas, 1998). Days were classified according to their contribution to each of three air quality measures listed below. Days were also sorted by meteorological conditions such as wind speed, wind direction, temperature, precipitation, relative humidity, and air quality on previous days in surrounding urban areas.

- **Ozone –** Growing season (April-October), 24-hr cumulative ozone exposures were based on the W126 ozone metric, (where all hourly ozone values are accumulated and higher values are weighted more than low values). Cumulative growing season ozone exposures are most appropriate for evaluating effects of ozone on forests (Lefohn and Runeckles, 1987).
- **Visibility –** Fine particle mass was used as a surrogate for visibility for the purposes of episode selection. Annual and summer averages for daily fine particle mass (sulfate, nitrate, organics, and soil) were based on measurements made twice a week at Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites. Visibility measures were not used for episode selection because relative humidity greatly affects visibility in the Southeastern United States. By removing variability due to relative humidity, the episode selection methods focused on the component of visibility (fine particle mass) that is most responsive to emissions changes.
- **Acid Deposition –** Annual cumulative wet deposition of sulfate, nitrate, calcium, and magnesium were based on weekly measurements at National Atmospheric Deposition Program (NADP) monitoring sites. Annual average deposition is most appropriate for evaluating effects to streams and forests.

Each day (or week in the case of acid deposition) was assigned to a category or class based on observed pollutant levels (Table 3.1). Days or weeks in the higher classes have higher pollutant levels.

TABLE 3.1: Percent of days (or weeks in the case of wet and dry deposition) falling into each Class based on the severity of pollutant levels at Great Smoky Mountains and Shenandoah National Parks (Deuel and Douglas, 1998, Odman, et al., 2002a).

Species	Class 1	Class 2	Class 3	Class 4	Class 5
Ozone	70%	20%	7%	3%	N/A
Fine Particles	20%	30%	30%	17%	3%
Wet Deposition	70%	20%	7%	3%	N/A
Dry Deposition	70%	20%	7%	3%	N/A

Sixty-nine days in nine episodes (each episode of 6-9 days in length) were selected to minimize error in recreating growing season ozone, annual and summer fine particle mass, and annual wet deposition for the Great Smoky Mountains and Shenandoah National Parks (Table 3.2, see also Timin, 2002). The selected episode days were weighted to account for the frequency of occurrence of similar meteorological conditions during the five-year period. Episodes were not initially selected to represent the annual average dry deposition. Instead dry deposition classes were assigned after the episodes were selected. As a result, the selected episodes under estimated annual average dry deposition (Timin, 2002) at these two parks. Error in calculating summer average visibility at Shenandoah National Park was judged to be unacceptable and therefore was not reported as part of SAMI's visibility analyses (see Chapter 4).

The range of meteorological conditions represented by the nine selected episodes is described in Table 3.3. The wintertime event in February 1994 represents clean air conditions over the Southern Appalachian Mountains with snow in the Ohio River Valley and rain in the Southeastern U.S. In contrast the July 1995 episode represents an air stagnation event with little precipitation that resulted in elevated ozone and fine particle levels over much of the Southeastern US.

Table 3.2: Error in using modeled days and episode weightings to recreate annual and season air quality averages for Great Smoky Mountains and Shenandoah National Parks for the period 1991-1995

	Growing Season Ozone	Annual Average Fine Particle Mass	Summer Average Fine Particle Mass	Wet Deposition	Dry Deposition
	Error (%)				
Great Smoky Mountains National Park	-0.5	-1.2	1.9	4.5	-15.0
Shenandoah National Park	0.1	-1.9	23.9	-1.0	-9.2

Table 3.3: Nine episodes selected for air quality modeling and description of meteorological characteristics (Doty, et al., 2002; Odman, et al., 2002a)

SAMI Modeling Episode	Season	Meteorological and air quality conditions
February 8-13, 1994	winter	Clean air conditions over the Southern Appalachian Mountains with snow in the Ohio River Valley and rain in the Southeastern U.S.
March 23-31, 1993	early spring	Rain across Tennessee, Alabama, Georgia, North Carolina, South Carolina, low particle mass
April 26-May 3, 1995	spring	Clean episode with several weather systems moving rapidly through Eastern U.S.
May 11-17, 1993	spring	Several rain storms across Eastern U.S. with high deposition, low ozone and moderate fine particle mass
May 24-29, 1995	spring	Several rain storms across Eastern U.S., moderate deposition, ozone, and fine particle mass
June 24-29, 1992	summer	Two high pressure systems and two stationary fronts, little precipitation, low ozone, and moderate fine particle mass
July 23-31, 1991	summer	Several rain storms, heavy deposition, also air stagnation period with high fine particle mass but not high ozone
July 11-19, 1995	summer	Stagnation event with light winds, high temperatures, and little precipitation. High ozone and high fine particle mass.
August 3-11, 1993	summer	Several days with stationary front, localized heavy rain along frontal system, low ozone and moderate fine particle mass

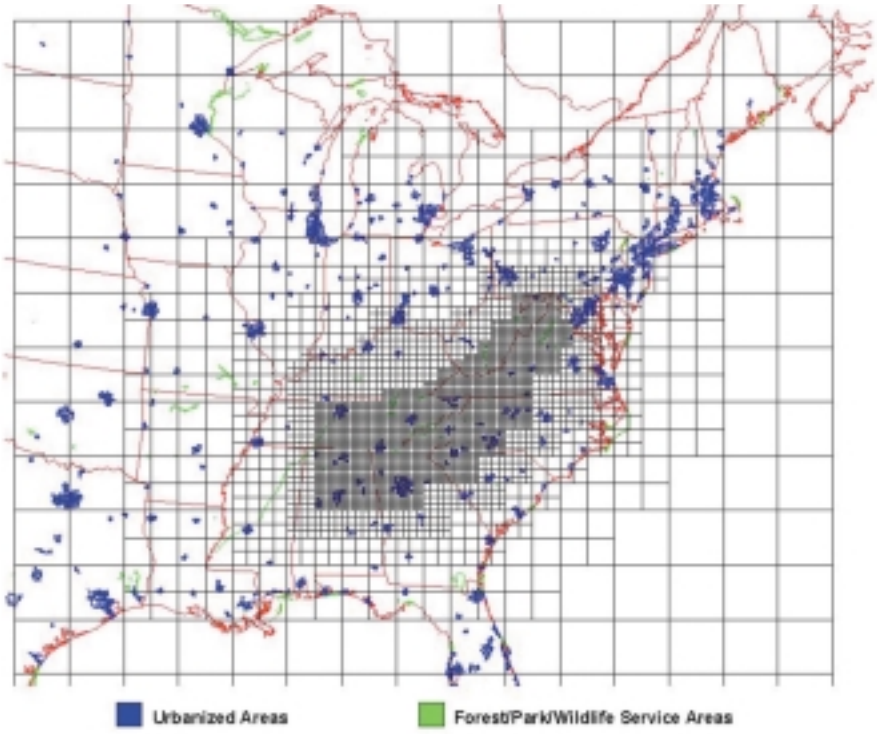
Atmospheric Modeling System

A meteorological model, the Regional Atmospheric Modeling System version 3b (RAMS 3b), was used to simulate the winds, temperature, clouds, and precipitation across the Southeastern U.S. for the selected nine episodes (Doty, et al., 2002). Two "ramp up" days were also modeled at the beginning of each episode to minimize the effects of assumptions for initial atmospheric conditions. Accurately simulating temperature, winds, sunlight, clouds, and precipitation is important to accurately model ozone, particles, and deposition at specific locations.

The Emissions Modeling System (EMS) was used with appropriate seasonal emissions inventories and outputs of the meteorological model to calculate emissions that are specific to the weather conditions on each of the modeled days (Odman, et al., 2002a). Natural emissions are calculated using the Biogenic Emissions Inventory System (BEIS-2) model. Natural emissions calculated for the 1991-1995 episodes were held constant in all future year SAMI strategies. The emissions model also accounts for the height of emissions into the atmosphere. Highway vehicles, nonroad engines, and area source emissions are released into the atmosphere at ground level, while emissions from utility or industrial stacks are released into the higher layers of the modeled atmosphere.

A three-dimensional photochemical model, the Urban-to-Regional Multiscale – One Atmosphere (URM-1ATM) model was used with meteorology and emissions for the 69 modeled days to project ozone, fine particle, and deposition levels across the modeling domain (Odman, et al., 2002a). The atmospheric modeling domain covered the eastern half of the U.S. and Southeastern Canada (Figure 3.1). The model used a variable grid, with the greatest resolu-

SAMI Atmospheric Modeling Domain



Georgia Institute of Technology

FIGURE 3.1: Atmospheric modeling domain for the urban-to-regional multiscale – one atmosphere (URM-1-ATM) model

tion of detail (12x12-km square) centered over the Southern Appalachian Mountains and the surrounding urban areas that were expected to most directly influence air quality in the region. Grid sizes were progressively coarser (12-km, 24-km 48-km, 96-km and 192-km) at greater distances from the Southern Appalachian Mountains. Because air quality values were averaged across the area within each 12 x 12 km grid cell, differences between ridge-top and valley exposures can not be distinguished. Seven vertical layers were used to simulate the atmosphere up to 13 km in altitude with the layers closest to the surface shallower than those for the upper layers.

The modeling system was first run to evaluate the model's ability to reproduce the air quality conditions for the modeled days in the 1991-1995 episodes. These simulations represent the Base year model runs. The meteorological conditions for each episode day from the Base year simulations were then run with emissions projected for the 2010 and 2040 SAMI emissions control strategies (E. H. Pechan & Associates, 2002). Modeled responses to SAMI strategies were evaluated for specific locations of interest in the environmental effects modeling and for the SAMI region. The percentage changes in modeled air quality between the Base year and future year simulations in response to SAMI strategies were used to adjust measured air quality values in the environmental effects assessments. The Decoupled Direct Method (DDM) is a sensitivity analysis tool used with the URM-1ATM photochemical model (Odman, et al., 2002a). The tool was used in the SAMI application to evaluate the air quality responses in the SAMI region to emissions changes in specific geographic locations. These results are discussed in more detail in the following sections.

Model Performance

The URM-1ATM air quality model calculates hourly ozone, aerosol, and deposition values for each grid cell in the modeling domain for each episode day. Model performance is evaluated by comparing model outcomes to observational data across the Southeastern U.S., with particular focus on performance within the fine grid of the SAMI modeling domain. Limited monitoring data is available for regional model performance evaluation for the nine episodes (Table 3.4). SAMI developed model performance criteria because there were no established performance criteria for regional models for ozone, fine particles, and acid deposition at the start of the SAMI modeling project. The URM-1ATM model performance was best in the 12-km grid and was accepted as comparable to or better than previous modeling efforts (Odman, et al., 2002a; USEPA, 1991; Seigneur, 2001; USEPA, 2001a).

The URM-1ATM model met SAMI's ozone performance criteria for 6 of 7 ozone episodes. The daily variation in ozone and the timing of the modeled ozone peaks were generally in good agreement with observations in both urban and rural locations. The model underestimated peak hourly ozone on many days and likely also underestimated the magnitude of change in peak ozone values in response to SAMI strategies.

The URM-1ATM model met SAMI performance criteria for fine particle mass (PM2.5) and mass of sulfate, organic carbon, and elemental carbon (Table 3.4). Because sulfate and organic carbon are the largest two components of fine particle mass, we have confidence using model results to calculate visibility and changes in visibility in the SAMI analyses. There are greater uncertainties associated with our ability to measure organic carbon compounds (both emissions and concentrations in ambient air) than for sulfate, so our confidence in organic carbon performance is somewhat lower than for sulfate. The model frequently over predicted nitrate and fine soil particles. These components are small fractions of total fine particle mass on most days (generally less than 0.5 micrograms per cubic meter) and errors in these values (while large on a percentage basis) have small impact on total fine particle mass and visibility. The model also over predicted coarse particles, but since coarse particles have low contribution to haze (see Chapter 4 - Visibility), these errors had small impact on visibility calculations. Because the IMPROVE network does not measure ammonium directly but estimates ammonium mass based on measured sulfate and nitrate mass, modeled ammonium levels were not compared directly to IMPROVE estimates of ammonia.

Precipitation is difficult to accurately model because precipitation volumes can vary greatly over short distances. For this reason, model performance was evaluated using the best match between observed and modeled deposition within a 30-km radius of the monitoring site. Sulfate, nitrate, and calcium wet deposition met SAMI performance criteria (Table 3.4). Ammonium wet deposition was overestimated. Dry deposition measurements are sparse but in general indicate that, sulfur dioxide and nitric acid were overestimated for the modeled episodes. Because the nine episodes were selected to represent annual wet deposition and do not represent events with high dry deposition levels, total annual dry deposition was underestimated by the modeled episodes.

The modeled days were not selected to represent air quality in urban areas. However ozone monitoring data for urban areas in the 12-km grid on the modeled days indicate that model performance for ozone in urban areas is as good as or better than that for rural areas (GIT, 2001). Measurements of fine particle mass are not available in urban areas for the modeled days in 1991-1995. Comparing modeled fine particle components to those measured in urban areas since 1997 indicates that the atmospheric model appropriately represents fine particle mass and sulfate levels in urban areas and that organic carbon and nitrate levels are higher in urban areas than at the rural IMPROVE sites (Search, 2002).

Overall, there was higher confidence in model performance for sulfur species (sulfur dioxide, sulfate fine particle mass, sulfate wet and dry deposition) than for nitrogen species (nitrogen oxides, nitrate fine particle mass, nitrogen wet and dry deposition) and ozone. Initial conditions for some nitrogen components (peroxy acetyl nitrate, PAN) in the upper layers

TABLE 3.4: Data used for performance evaluation of the Urban-to-Regional One-Atmosphere (URM-1ATM) model and performance results (Odman, et al., 2002a).

Air Quality Measure	Number of Monitors in SAMI 12-km modeling grid	Frequency of Monitoring record	SAMI Performance Evaluation Criteria	Achieved Criteria > 75% of record?
Ozone	74 monitors[a]	hourly	35% normalized error and +/-15% normalized bias for daily ozone[e]	Yes, but under estimates peak hourly values
Particle Mass	6 monitors[b]	2 days per week	+/- 50% normalized error [f]	Yes for fine particle mass, sulfate, organic carbon, elemental carbon, and ammonium over predicts nitrate, fine soil particles, and coarse mass
Wet Deposition	14 monitors[c]	weekly	+/- 50% normalized error (using best match within 30-km of monitor)	Yes for sulfate, nitrate, and calcium. Over predicts ammonium
Dry Deposition	2 monitors[d]	weekly	Insufficient data to establish criteria	Generally over predicts dry deposition of sulfur dioxide, nitric acid, and ammonia for modeled episodes

[a]Aerometric Information Retrieval System (AIRS) monitoring network(USEPA, 2001b)

[b]Interagency Monitoring of Protected Visual Environments (IMPROVE) network (NPS, 2000)

[c]National Atmospheric Deposition Program (NADP) network (NADP, 2000)

[d]Atmospheric Integrated Research Monitoring Network (AIRMoN, 2000)

[e]SAMI adopted the Environmental Protection Agencys' criteria for model performance for regulatory modeling of maximum hourly ozone in urban areas (USEPA, 1991)

[f]Environmental Protection Agency's guidance for demonstrating attainment of air quality goals for PM2.5 and regional haze (USEPA, 2001a) recommends that for particle components that are at least 30% of measured PM2.5, the relative proportions of fine particle mass that are modeled for each component should agree within 20% of average observed proportions of fine particle mass. SAMI's modeling meets these criteria for annual average mass of particle components.

of the atmosphere may have been overestimated (although there are few measurements available to evaluate model assumptions). As a result, modeled responses to reductions in nitrogen oxides in the SAMI States are uncertain. Ammonia emissions levels in 1991-1995 and growth in ammonia emissions between 1990, 2010, and 2040 are highly uncertain (see Chapter 2 - Emissions Inventory). Thus projected increases in wet deposition of ammonium and dry deposition of ammonia gas in future years are also uncertain. These uncertainties represent areas where further study is needed.

Linking SAMI Atmospheric And Effects Models

A unique feature of the SAMI Assessment were the methods developed to use the air quality changes projected by the atmospheric model to define the air quality changes used in the acid deposition, ozone, and visibility effects models. Growing season ozone, annual and summer fine particle mass, and annual wet and dry deposition were derived by weighting the air quality contribution of each modeled day by the frequency of occurrence of those meteorological conditions over the 1991-1995 period.

Because we have greater confidence in the relative change in ozone, fine particles, and deposition in response to SAMI strategies than in the absolute magnitude of modeled air quality values, modeled air quality values were not used in the environmental effects models. Instead, measured hourly ozone for 13 forested sites, daily average particle mass at Class I areas, and weekly total deposition at 170 stream and forest sites were used to define Base year air quality measures for the ozone, visibility, stream and forest effects models, respectively (Weinstein, 2002; Air Resource Specialists, 2002; and Sullivan, et al., 2002a). The percentage changes in modeled air quality between the Base year and future year simulations in response to SAMI strategies were used to adjust measured air quality values for effects modeling (Odman, et al, 2002b; Imhoff and Jackson, 2001; Air Resource Specialists, 2002).

Days selected for atmospheric modeling represent all other days in the 1991-1995 record for Great Smoky Mountains National Park and Shenandoah National Park. The weights assigned to hourly ozone and daily fine particle mass for Great Smoky Mountains National Park were also used for Class I areas in Alabama, Georgia, and North Carolina. The weights used for Shenandoah National Park were also used for Class I areas in Virginia and West Virginia. Distances from Great Smoky Mountains and Shenandoah National Parks were used in calculating weights for weekly wet and dry deposition for 170 modeled stream and forest sites.

Influence Of Meteorology On Air Quality

The influence of meteorology on air quality was evaluated as part of episode selection (Deuel and Douglas, 1998). At Look Rock, a ridge top site in Great Smoky Mountains National Park in eastern Tennessee, and at Big Meadows, a ridge top site in Shenandoah National Park, Virginia, days with the highest fine particle mass tended to be days with low wind speeds and high temperatures. Days with the highest ozone levels tended to be days with high solar incidence, high temperatures and either high or low wind speeds. These results suggest that, for these sites, local sources are likely to have a greater contribution to fine particle mass than distant sources and that both local and distant sources are likely to contribute to elevated ozone levels. Rainfall volume was the best predictor of deposition amount. At Shenandoah National Park, the highest deposition was associated with winds from the west.

Meteorological influences on air quality can also be interpreted from URM-1ATM model results. As an example, the four maps in Figure 3.2 illustrate modeled maximum hourly ozone values for four consecutive days during the week of July 11-19, 1995. Air quality changes on these days in response to SAMI strategies and to changes in emissions from specific States and geographic regions are illustrated later in this chapter. An air stagnation episode with elevated temperatures and low wind speeds was centered over the Southeastern United States during this week. As the high pressure system moved slowly east, the light winds circled slowly clock-wise across the Southeastern U.S. On July 12, 1995, ozone levels were highest over Atlanta, Georgia, and Birmingham, Alabama. On subsequent days the highest ozone levels followed the high-pressure system, with highest levels over Nashville, Tennessee, on July 13, over central Kentucky on July 14, and over West Virginia and Virginia on July 15. Elevated fine particle levels followed similar patterns over this week.

SAMI STRATEGY RESULTS

Generally, the largest air quality changes in response to SAMI emissions strategies occurred on the days with the poorest air quality. For brevity, SAMI air quality results are illustrated here for the Great Smoky Mountains and Shenandoah National Parks. These results are representative of those for the other SAMI Class I areas.

Ozone Responses To SAMI Strategies

Ozone levels are projected to decrease in 2010 and 2040 under all three SAMI strategies. The largest reductions in ozone occur for the hours and days with the highest ozone values. As an example of responses on days with high ozone values, Figure 3.3A and 3.3B show modeled changes in hourly ozone values for July 11-19, 1995 at Look Rock in the Great Smoky Mountains National Park and Big Meadows in the Shenandoah National Park in response to SAMI strategies. The black line represents the modeled ozone values for each hour of the 9 days. The red, turquoise, and blue lines represent hourly ozone levels in 2010 under the SAMI A2, B1, and B3 strategies, respectively. Ozone reductions from peak hourly values for the A2 strategy ranged from 10 to 18% compared to 1995. Ozone reductions

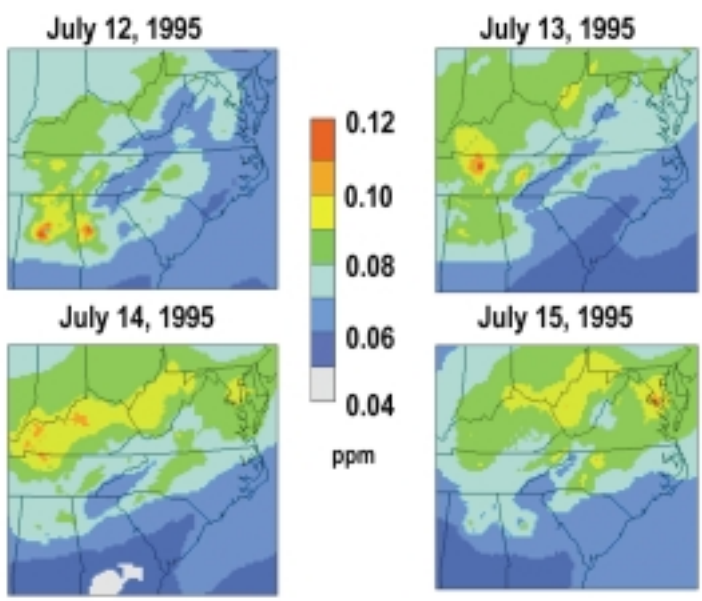


FIGURE 3.2: Modeled maximum hourly ozone values in SAMI region for July 12-15, 1985

Example Responses to 2010 SAMI Strategies for Hourly Ozone July 11-19, 1995

Look Rock (Great Smoky Mtn., TN)

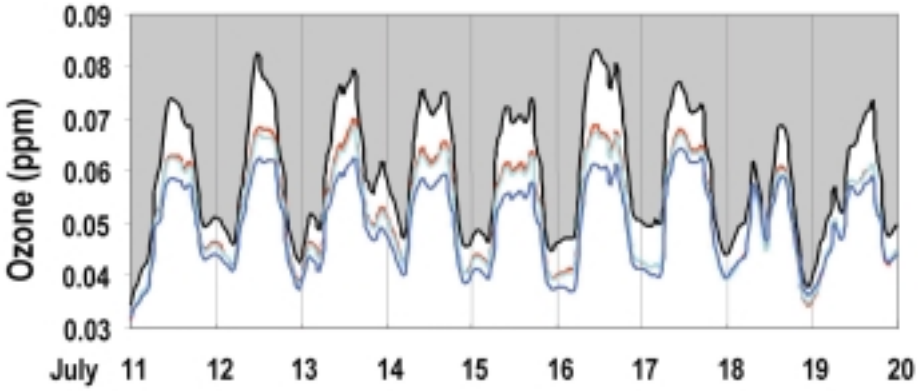


FIGURE 3.3A: Hourly ozone values at Look Rock, Great Smoky Mountains National Park for July 11-19 1995 and modeled changes in hourly ozone values in response to SAMI strategies

Example Responses to 2010 SAMI Strategies for Hourly Ozone July 11-19, 1995

Big Meadows (Shenandoah, VA)

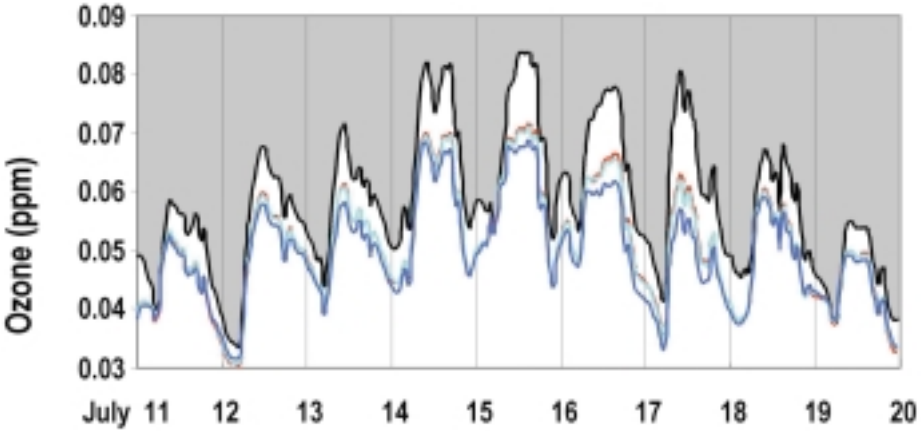


FIGURE 3.3B: Hourly ozone values at Big Meadows, Shenandoah National Park for July 11-19, 1995 and modeled changes in hourly ozone values in response to SAMI strategies

under the B1 strategy are similar to those under the A2 strategy. The B3 strategy shows reductions of 20 to 25% compared to 1995. These reductions in ozone values are smaller than the reductions in summer-day nitrogen dioxide emissions (44% reduction for the A2 strategy in 2010, see Chapter 2 - Emissions Inventories). Changes in growing season ozone are discussed in Chapter 5.

Fine Particle To SAMI Strategies

Changes in fine particle mass in response to SAMI strategies are consistent with emissions changes (see Chapter 2), but have a less than linear response to emissions changes. The largest changes in fine particle mass occurred on the days with highest mass. In Figure 3.4, the map on the upper left illustrates modeled fine particle mass for July 15, 1995. The highest fine particle concentrations on July 15, 1995, occur over West Virginia and over urban areas in Georgia, Tennessee, Kentucky, and North Carolina. The map on the upper right illustrates modeled fine particle mass using the same meteorological conditions as occurred on July 15, 1995, and using emissions for the 2010 A2 reference strategy. Fine particle mass is reduced 10 to 40% across the Southern Appalachian Mountains under the 2010 A2 strategy compared to July 15, 1995. The maps on the lower left and lower right illustrate fine particle mass on July 15 assuming emissions under the 2010 B1 and B3 strategies, respectively. The spatial areas with fine particle mass above 32 mg/m3 are progressively smaller under the A2, B1, and B3 strategies.

Most of the reductions in daily average fine particle mass are due to reductions in sulfate particles. This is illustrated for example modeled days with concentrations ranging from low to high particle mass at Great Smoky Mountains in Figure 3.5. Across the modeled days, daily-average sulfate particle mass is projected to decrease between 6% (for the 2010 A2 strategy) to 60% (for the 2040 B3 strategy) at Great Smoky Mountains National Park and between 16% (2010 A2 strategy) to 58% (2040 B3 strategy) at Shenandoah National Park. Sulfate particle mass was reduced more in response to the A2 strategy in the Class I areas in West Virginia and Virginia than

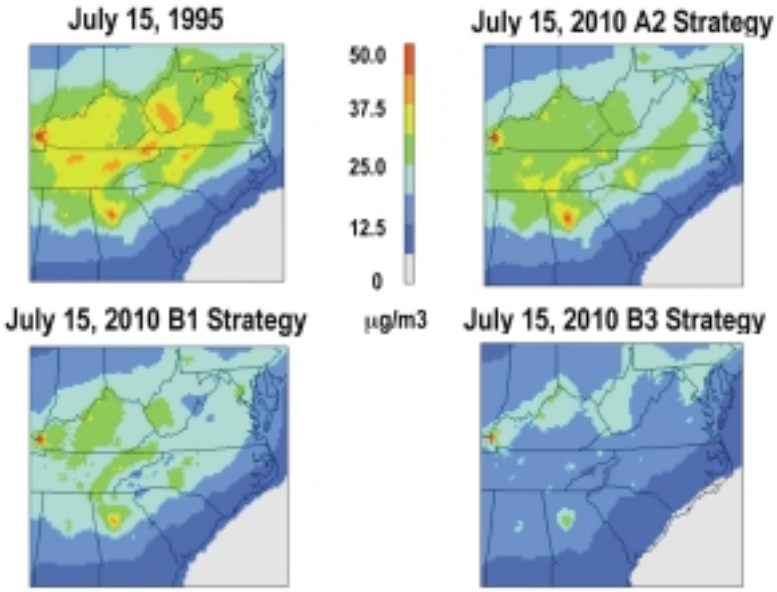


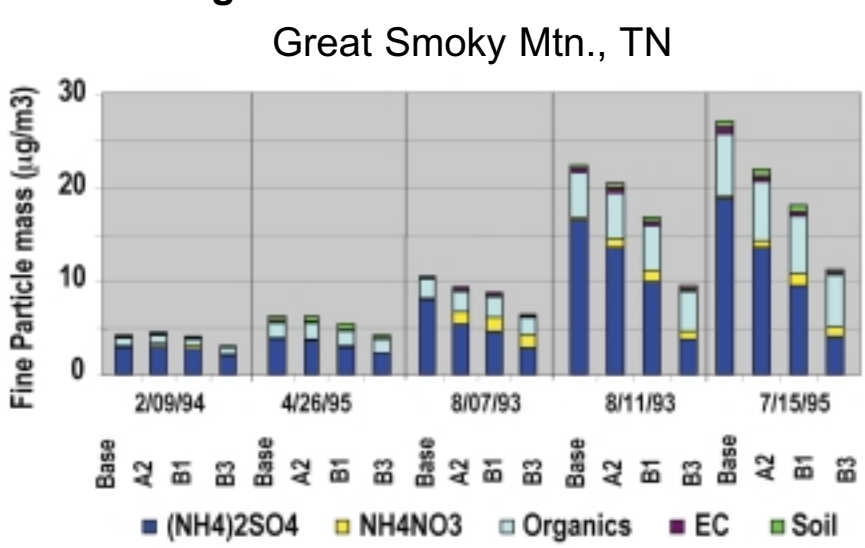
FIGURE 3.4: Change in fine particle mass on July 15, 1995, In response to SAMI strategies.

in the Class I areas in Alabama, Georgia, Tennessee, and North Carolina. The Class I areas in West Virginia and Virginia are influenced by sulfur dioxide emissions from these States and Midwestern States. Emissions in the Midwestern States were reduced more in the 2010 A2 strategy than emissions in the southern States (E. H. Pechan & Associates, 2002). Sulfur dioxide emissions for States outside the SAMI States remained the same for the B1 and B3 strategies as for the A2 strategy. Therefore, changes in sulfate mass at the Class I areas in West Virginia and Virginia in response to the B1 and B3 strategies were smaller than changes at the other SAMI Class I areas.

On days with low sulfate particle mass (Class 1 and 2 days in Figure 3.5), changes in daily-average sulfate mass due to SAMI strategies are small. On some low mass days and in some locations, sulfate mass is projected to increase slightly in 2010 under the A2 strategy. This result may be due to increases in sulfur dioxide emissions at some utility units between the modeled days in 1991-1995 and in the 2010 A2 strategy (E. H. Pechan and Associates, 2002). These increases may also indicate an increase in sulfate formation due to changes in cloud chemistry.

Nitrate particle mass is projected to increase in response to the A2 and B1 strategies and to decrease for the B3 strategy at the Great Smoky Mountains National Park. At Shenandoah National Park nitrate particle mass is projected to decrease under all strategies. Difference between nitrate responses at the two sites are likely due to larger reductions in sulfur dioxide and nitrogen oxides emissions and smaller increases in ammonia emissions in the areas influencing Shenandoah National Park.

Modeled changes in organic carbon mass in the SAMI Class I areas in response to SAMI strategies were generally small. The emissions model projected that natural sources are much larger contributors to organic carbon emissions than are human sources (GIT, 2001). Natural emissions of organic carbon were assumed to be unchanged by the SAMI strategies. At the Class I areas the modeled change in organic carbon mass due to controls on human sources were small compared to the modeled organic carbon levels due to natural sources. In urban areas, the model did project reductions in organic carbon mass in response to emission reductions from human activities such as highway vehicles. Current research on the relative contributions of natural



*based on IMPROVE aerosol data and URM modeled change

FIGURE 3.5: Changes in Fine Particle Mass on Example Modeled Days at Great Smoky Mountains National Park in Response to SAMI Strategies in 2010

and human sources of organic carbon and improvements in measurement techniques will allow these assumptions to be better evaluated.

Changes to soils, elemental carbon, and coarse particle mass in response to SAMI strategies were sometimes large (>50%) on a percentage basis but were generally small in terms of total particle mass.

Changes in annual average, summer average, and class average fine particle mass in response to SAMI strategies in 2010 and 2040 are discussed in Chapter 4 on Visibility.

Deposition Responses To SAMI Strategies

Sulfate deposition is reduced in response to all SAMI strategies in 2010 and 2040. Model results for sulfate deposition for the week of July 23-31, 1991, which is a high deposition event, are illustrated in Figure 3.6. The map on the upper left illustrates modeled wet sulfate deposition for the week of July 23-31, 1991. Precipitation volume and deposition were heaviest along and east of the Southern Appalachian Mountains. The map on the upper right illustrates modeled wet sulfate deposition for this episode using the same meteorological conditions as occurred during July 23-31, 1991, and using emissions for the 2010 A2 reference strategy. The maps on the lower left and lower right illustrate sulfate wet deposition for the 2010 B1 and B3 strategies, respectively. These maps illustrate that reductions in sulfate wet deposition levels in the July 1991 event were greatest in those areas with the highest sulfate wet deposition and that sulfate reductions were progressively larger across the SAMI strategies.

GEOGRAPHIC SENSITIVITIES

DDM sensitivity analysis was used in the URM-1ATM photochemical model to evaluate the responses of air quality at specific locations to changes in emissions in specific geographic areas. The approach considers changes in a single pollutant at a time and cannot simulate the effects of changing multiple pol-

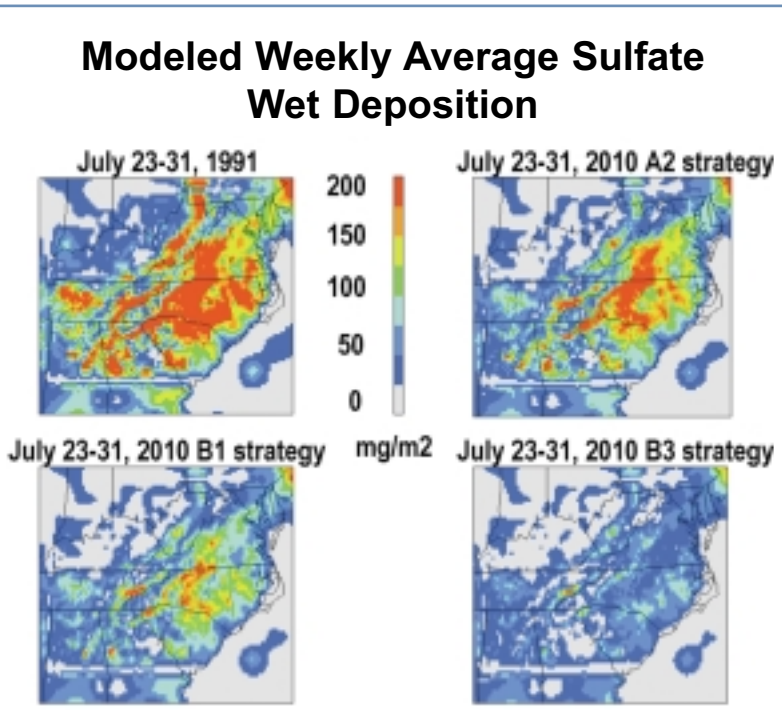


FIGURE 3.6: Changes in Sulfate Wet Deposition during the week of July 23-31, 1991, in Response to SAMI Strategies in 2010

lutants simultaneously. The 2010 A2 reference strategy is used as the basis for these geographic sensitivity analyses. In 2010 the A2 strategy represents those Federally required emissions controls for which we have the greatest confidence in the methods of implementation (E.H. Pechan & Associates, 2002). These include:

- One-hour ozone standard,
- Acid rain rules,
- State Implementation Plans for reducing nitrogen oxide emissions from utilities and large industries (NOx SIP call),
- Highway vehicle Tier I and Tier II standards,
- Low-sulfur fuel rules, and

  Industrial controls of volatile organic compounds.

The SAMI geographic sensitivity analyses can be used to interpret the benefits of emissions reductions of single pollutants in specific geographic areas beyond those in the 2010 A2 strategy. Emissions reductions beyond those included in the 2010 A2 strategy will likely be required to comply with the 8-hour ozone standard, the PM2.5 standard, and the regional haze rules, but the specific implementation strategies have not yet been determined. By adjusting emissions from the 2010 A2 reference strategy, we can evaluate the benefits expected from the next incremental set of controls. All results reported here are for 10% changes in single pollutant emissions from the 2010 A2 strategy. These results can be extrapolated to emissions changes up to 30% from the 2010 A2 strategy.

For these analyses, the SAMI modeling domain was subdivided into 12 geographic areas of interest (Figure 3.7). These geographic areas correspond to the regional planning organizations established as part of the regional haze rule. In addition to each of the eight SAMI States, the collective contributions of States in the Midwest, Northeast, and Central regions and the combined effect of Florida and Mississippi (States in regional planning organization for the Southeastern US that are not also SAMI States) are considered. Any areas of the modeling domain not covered in these 12 geographic areas are assigned to an “all other” category.

Overall, we have greatest confidence in the relative contributions of the SAMI States to air quality at specific receptor locations. We have less confidence in the absolute magnitude of the air quality responses to emissions reductions. Confidence in geographic sensitivity results is greatest where both source areas and receptors are within the SAMI region (12-km and 24-km grids). Confidence is somewhat lower for those cases where emissions sources are in the SAMI region and receptors are in coarser grids (representing the influence of SAMI States on other regions). Confidence is lower for those cases where emissions sources are in the coarse (48-km and larger) grids (representing influence of other regions on SAMI region). All sensitivities consider changes in a single pollutant at a time. We do not know how results might differ if multiple pollutants were changed simultaneously.

Geographic Source Regions

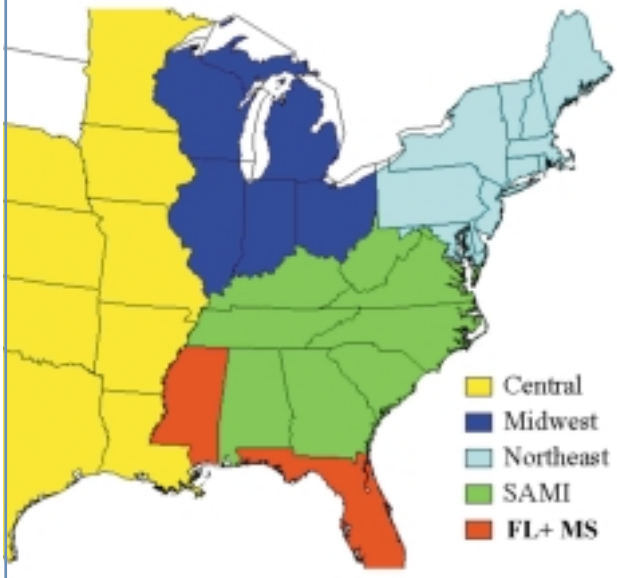


FIGURE 3.7: Geographic areas considered in SAMI geographic sensitivity analyses.

Responses Of Sulfate Fine Particles And Sulfate Wet Deposition To Changes In Sulfur Dioxide Emissions

On most modeled days, the greatest benefits of reducing sulfur dioxide emissions from the 2010 A2 strategy in the SAMI States are projected to occur in the SAMI States. On some days, sulfur dioxide emissions reductions in other regions also benefit the SAMI States. Changes in sulfate fine particles in response to 10% changes in sulfur dioxide emissions from the 2010 A2 strategy are illustrated fin Figure 3.8 or July 15, 1995, a day with high sulfate mass. Modeled sulfate fine particle levels for the 2010 A2 strategy are illustrated in the upper left map. On this day, the benefits of reducing sulfur dioxide emissions in the SAMI States occur primarily in the SAMI States (lower center map). Benefits of reducing sulfur dioxide emissions in the five Midwestern States occur primarily in those States, but also provide some benefits in the SAMI States (upper center map). On this day, reducing sulfur dioxide emissions from Northeastern or Central States and from Mississippi and Florida have small or no benefits in the SAMI States.

The greatest benefits from reducing sulfur dioxide emissions generally occur within the State where the reductions are made. Figure 3.9 illustrates changes in sulfate fine particles in response to 10% reductions in sulfur dioxide emissions in the 2010 A2 strategy from each of the SAMI States on July 15, 1995. On this day, sulfur dioxide reductions in each State reduce sulfate fine particles in that State. Each State also has some contribution to changes in sulfate fine particles in neighboring States.

Changes in annual average fine particle mass are useful to evaluate relative responses to emissions reductions averaged over a range of meteorological conditions. Changes in annual average sulfate fine particle mass at SAMI Class I areas in response to 10% reductions in sulfur dioxide emissions from SAMI States and non-SAMI States are illustrated in Figure 3.10. A 10% reduction in the 2010 A2 strategy sulfur dioxide emissions from the entire SAMI modeling domain is projected to result in 4 to 7% reductions in sulfate fine particle mass at the SAMI Class I areas. SAMI States collectively account for 40-80% of the total change in sulfate fine particles at each SAMI Class I area in response to sulfur dioxide emissions reductions.

Daily SO_4 Aerosol & its Change on July 15, 1995 for a 10% Reduction of 2010 Strategy A2 SO_2 Emissions

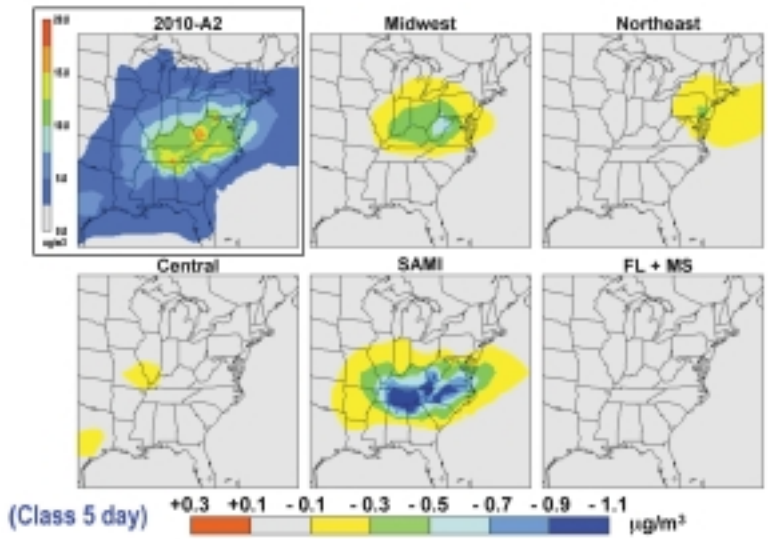


Figure 3.8: Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for the SAMI, Midwest, Northeast, and Central regions and from Mississippi and Florida.

Daily SO_4 Aerosol & its Change on July 15, 1995 for a 10% Reduction of 2010 Strategy A2 SO_2 Emissions

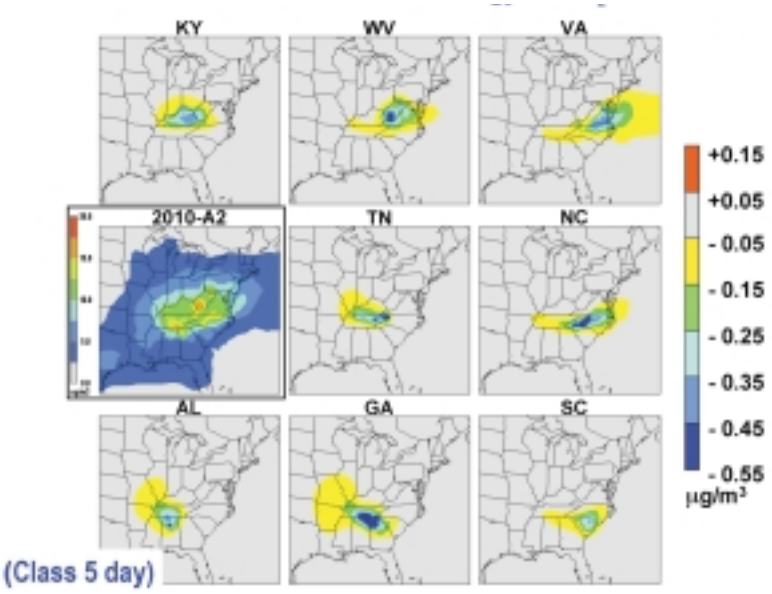


FIGURE 3.9: Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for each of the eight SAMI states.

Annual SO_4 Fine Particles Response to 10% Reduction in SO_2 Emissions from 2010 A2 Strategy

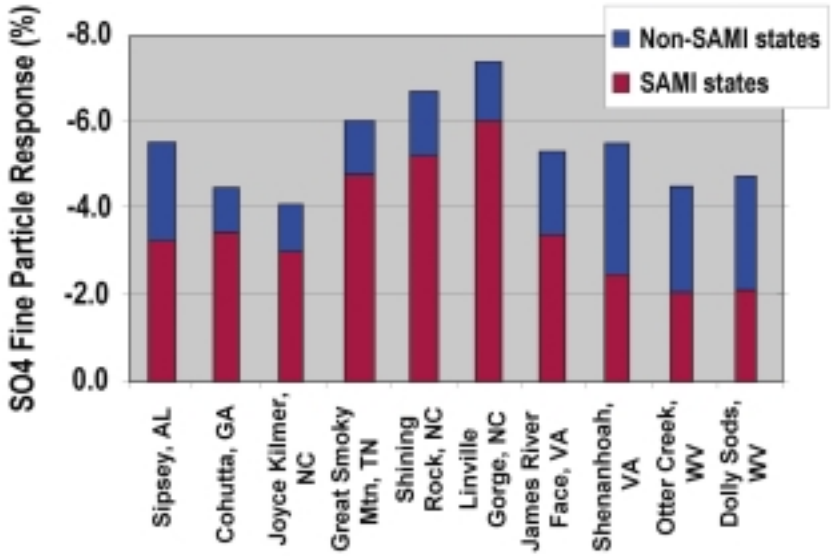


FIGURE 3.10: Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in SAMI states and non-SAMI states

The SAMI Class I areas can be grouped by common sensitivities to emissions changes. The greatest benefits from sulfur dioxide reductions are projected to occur at receptors in the same State or adjacent States. Figure 3.11 illustrates the same responses to changes in sulfur dioxide emissions as Figure 3.10, but separates responses to emission reductions from each SAMI State and surrounding regions. Annual average sulfate particle mass at Cohutta Wilderness Area in northern Georgia and Sipsey Wilderness Area in Northwestern Alabama are most influenced by sulfur dioxide emissions reductions in Georgia and Alabama, respectively. Tennessee, the Central Region, the Midwest Region, and Mississippi also influence sulfate fine particle mass at these sites.

Annual average sulfate particle mass at the Great Smoky Mountains National Park on the Tennessee-North Carolina border and at Joyce Kilmer, Slickrock, Shining Rock, and Linville Gorge Wilderness Areas in western North Carolina are most influenced by sulfur dioxide reductions in Tennessee. Sulfur dioxide emissions in Georgia, Alabama, North Carolina, and the Central and Midwest regions also influence sulfate fine particle mass at these sites. Annual average fine particle mass at Shenandoah National Park and James River Face Wilderness Area in Virginia and at Dolly Sods and Otter Creek Wilderness Areas in West Virginia are most influenced by sulfur dioxide reductions in Virginia, West Virginia, and the Midwest region. Annual average sulfate particle mass at Shenandoah and Dolly Sods is also influenced by the Northeast region.

Annual average sulfate wet deposition is reduced 4-9% at the SAMI Class I areas in response to a 10% reduction in sulfur dioxide emissions throughout the modeling domain (Figure 3.12). Changes in annual average sulfate wet deposition in response to sulfur dioxide emission reductions are somewhat different than those for changes in annual average sulfate particle mass. Class I areas in Georgia, Tennessee, and western North Carolina are most sensitive to changes in sulfur dioxide emissions from Georgia and Alabama. This is because precipitation events generally proceed from the Gulf of Mexico, across Alabama and Georgia, to eastern Tennessee and western North Carolina. Annual average sulfate wet deposition in Class I areas in Virginia and West Virginia are more influenced by sulfur dioxide emissions from those two States than is the case for annual average sulfate fine particle mass. These results may be influenced by the specific episodes selected and weightings used to calculate annual average wet deposition.

In addition to reducing sulfate fine particle mass and sulfate wet deposition, reducing sulfur dioxide emissions also reduced total fine particle mass and ammonium and increased nitrate fine particles. The increase in nitrate fine particle mass is due to the increase in available ammonia gas when sulfate particle mass is reduced.

Sensitivity Of Nitrate Fine Particles And Nitrate Wet Deposition To Reducing Nitrogen Oxide Emissions

The relative sensitivity of nitrate fine particle mass and nitrate wet deposition at the SAMI Class I areas to changes in nitrogen oxide emissions from SAMI States and other regions are similar to those illustrated here for sulfate fine particle mass and sulfate wet deposition. Reducing nitrogen oxide emissions by 10% from the 2010 A2 strategy reduced nitrate fine particles by 3.5 to 7% across the SAMI Class I areas. The response of nitrate wet deposition to nitrogen oxide emissions reductions was much smaller (1.5 – 3.5 % in response to 10% emissions reduction) and are less certain than for sulfate wet deposition responses to sulfur dioxide emissions reductions.

Annual SO_4 Aerosol Response to 10% Reduction in SO_2 Emissions from 2010 A2 Strategy

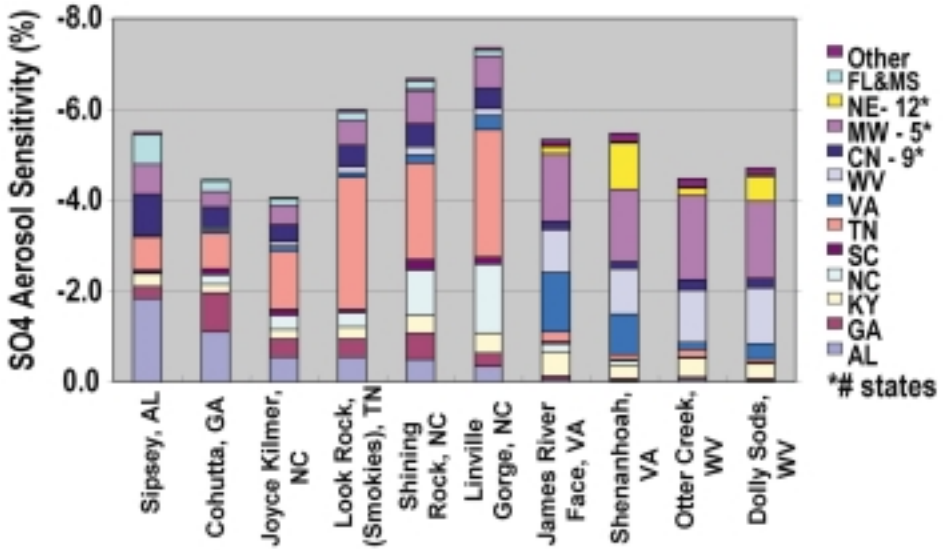


FIGURE 3.11: Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions.

Annual SO_4 Wet Deposition Sensitivity to 10% Reduction in SO_2 Emissions from 2010 A2 Strategy

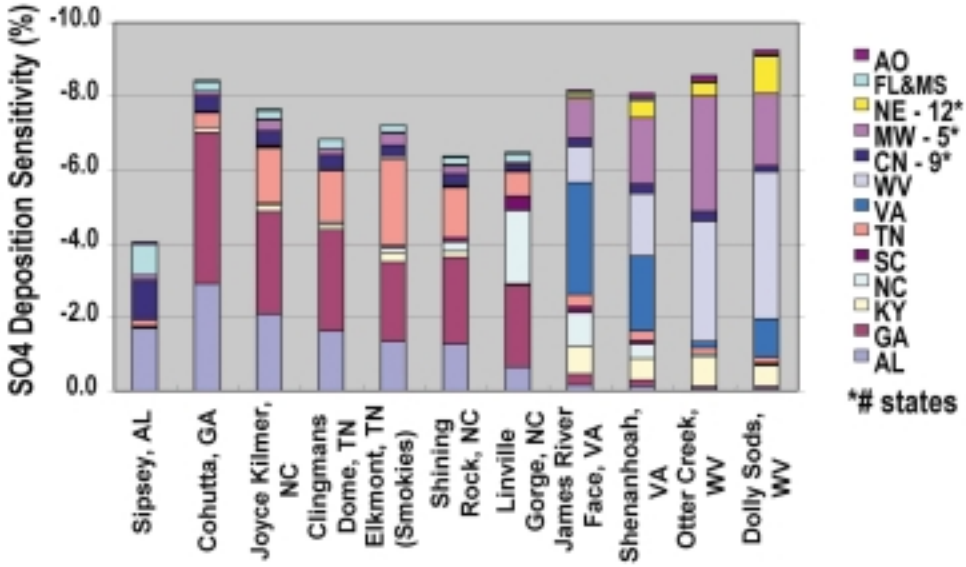


FIGURE 3.12: Annual Sulfate Wet Deposition Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions.

Sensitivities to changes in nitrogen oxide sources emitted at ground-level (highway vehicles, nonroad engines, and area sources) were considered separately from sensitivities to changes in elevated sources (utility and industrial) of nitrogen oxide. Nitrogen oxide emissions from utilities and large industries under the NOx SIP call are included in the 2010 A2 strategy. In all SAMI States except West Virginia, nitrogen oxide emissions in the 2010 A2 strategy are higher from ground level sources than from elevated sources (Figure 3.13).

In general, responses to nitrogen oxide emissions reductions from ground level sources are larger than responses to reductions from elevated sources. This point is illustrated in Figure 3.14 for responses of growing season (April to October) ozone to nitrogen oxide reductions from elevated and ground-level sources. For all SAMI Class I areas, reductions in ground level nitrogen oxide emissions are projected to be more effective in decreasing growing season ozone than nitrogen oxide reductions from elevated point sources. Ground level sources of nitrogen oxide emissions in the SAMI States have larger influences on growing season ozone at SAMI Class I areas than ground level sources in non-SAMI States. Reducing both ground-level and elevated sources of nitrogen oxides by 10% from the 2010 A2 strategy reduced growing season ozone by nearly 10% at the SAMI Class I areas (Figure 3.14).

Local vs. Regional Transport

The following general conclusions can be drawn from SAMI's episode selection and geographic sensitivity analyses:

- Transport distances from emissions source areas are generally shorter for gases, fine particles, and dry deposition, than for wet deposition. These results suggest that local sources have greater contributions to ozone and fine particles than to acid deposition. These conclusions may be influenced by the specific episodes selected for these analyses.
- Elevated sources of nitrogen oxides generally contribute more to changes in ozone levels, at more distant receptors, than do ground level sources of nitrogen oxides.
- Once the NOx SIP call is implemented, reducing ground-level nitrogen oxide emissions will have greater benefits in reducing growing season ozone than reducing elevated sources of nitrogen oxides.

UNCERTAINTIES

Uncertainties associated with the components of the atmospheric modeling system affect the confidence in model results. The major sources of uncertainty include:

- Emissions inventory of ammonia gas, primary organic carbon particles, elemental carbon, and soils.
- Representing precipitation and clouds spatially and temporally, and the scarcity of meteorological measurements within the Southern Appalachian Mountains and in the upper atmosphere.
- Episode selection techniques, especially reliance on episode weightings for two parks to define weighting for other locations in SAMI region and using fine particle mass as a surrogate for visibility
- Representing initial and boundary conditions for the air quality model (especially in the upper atmosphere) and influence of grid size on model outcome.
- Monitoring data for ammonium, total organic carbon and its components, and nitrate particle mass; the scarcity of fine particle, wet and dry deposition monitoring data and measurements in the upper atmosphere.
- Simplifying assumptions of the geographic sensitivity analyses; especially the influences from areas covered by coarse modeling grids.

Daily NO_X Emissions on July 12, 2010 Strategy A2

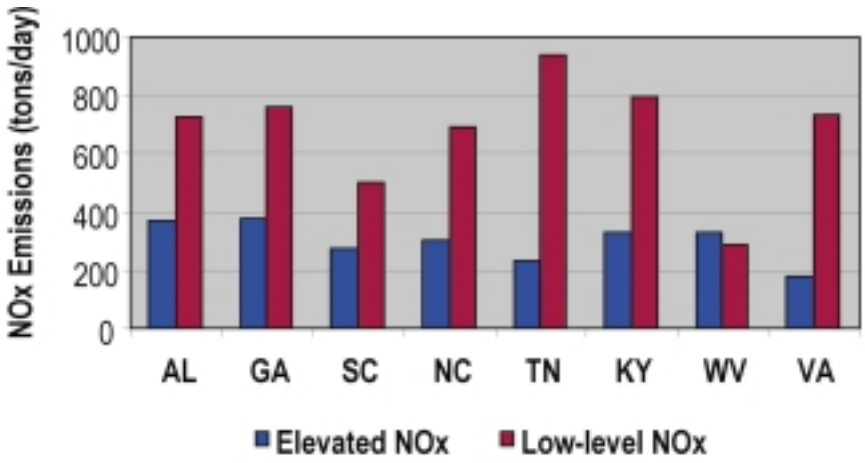


FIGURE 3.13: Nitrogen oxide emissions in the 2010 A2 strategy modeled for July 12, 1995 for elevated (utility and industrial point sources) and ground-level (highway vehicle, nonroad engines, and area) sources

Growing Season Ozone Sensitivity to 10% NO_X Reduction

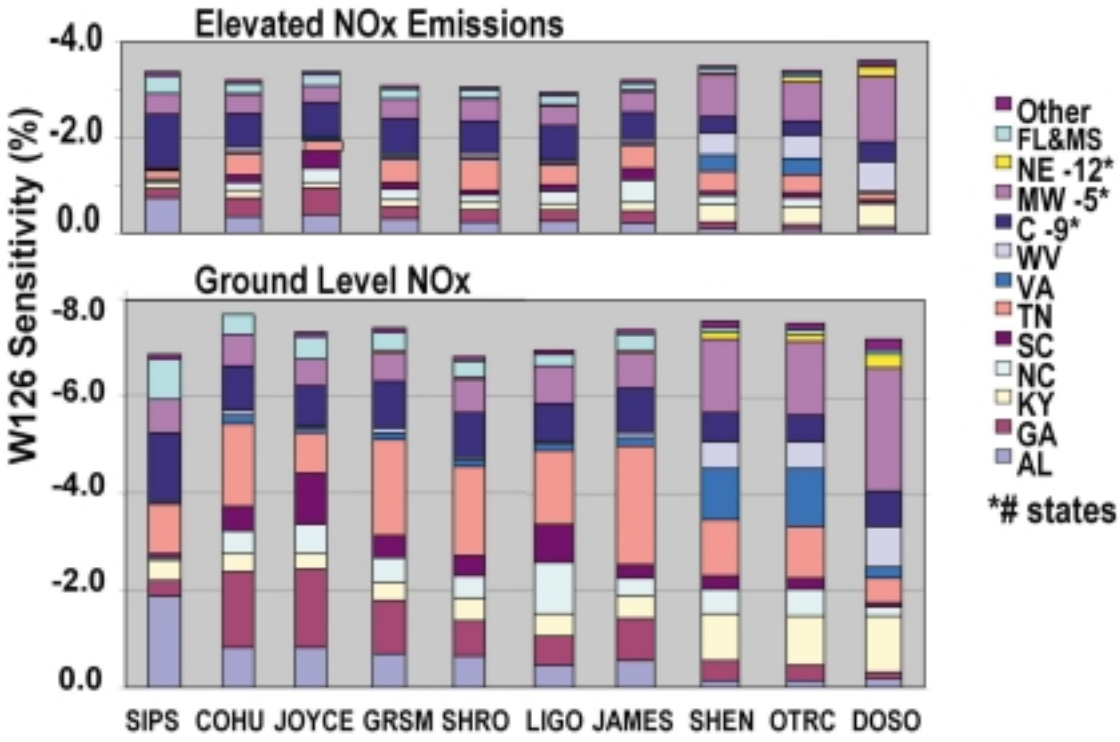


FIGURE 3.14: Growing season ozone responses at SAMI Class I areas to 10% reductions in nitrogen oxide emissions in the 2010 A2 strategy for each SAMI state and surrounding regions

LESSONS LEARNED

- SAMI demonstrated application integrated one-atmosphere photochemical model to simulate changes in fine particles, ozone, and acid deposition in response to emissions control strategies. SAMI demonstrated meteorological and photochemical model performance for 2 winter-time episodes.
  - Assumptions for initial and boundary conditions influence model results.
- Need more and better monitoring data for model performance evaluation. Since 1991-1995 period of record used by SAMI, the spatial coverage of monitors for PM2.5 mass and components of PM2.5 has increased considerably. We still need better temporal resolution (hourly, daily) of key components of PM2.5 to understand model performance.
  - Need improved techniques to represent precipitation and cloud formation. If deposition volume is in error then fine particle and deposition chemistry will likely also be in error.
- SAMI demonstrated use of episode selection techniques to minimize error in representing seasonal and annual air quality measures at multiple locations and the use of discrete episodes to represent a variety of meteorological conditions.
  - Measures used for episode selection constrain the analyses that can be done later in the project. In hindsight, total wet plus dry deposition instead of wet deposition alone might have been used for episode selection. Selecting episodes based on fine particle mass instead of visibility allowed a direct link to emissions changes but results were not directly comparable to the regional haze guidance (USEPA, 2001).
  - Using episode weighting at few locations to represent annual and seasonal air quality metrics at other locations contributed to uncertainty in model results.
- SAMI demonstrated sensitivity analysis tool to evaluate air quality changes at selected receptors in response to emissions changes from specific geographic areas
  - A finer grid scale in distant source areas is needed to have confidence in contributions from these areas.
- SAMI demonstrated methods to link atmospheric and effects models
  - It is challenging to address the spatial and temporal variability in emissions and air quality at receptors across as large a modeling domain as the SAMI region.
- Changes in emissions do not result in linear (one for one) changes in air quality. Sulfate fine particles and sulfate wet deposition responded in more nearly linear manner than did nitrate fine particles and nitrate wet deposition. Additional study is needed to evaluate whether the nitrate results were dependent on the specific model assumptions (e.g. initial and boundary conditions) or complex chemical interactions, or both.

KEY FINDINGS

1. In general, the largest air quality changes in response to SAMI emissions strategies occurred on the days with the poorest air quality and in the areas with the poorest air quality.
2. The atmospheric model projects that reductions in peak hourly ozone values were similar between the 2010 A2 and B1 strategies and greater for the 2010 B3 strategy.
3. Most of the reductions in daily average fine particle mass were due to reductions in sulfate fine particles. Changes in other components of fine particle mass were comparatively small in response to SAMI strategies.
4. Sulfate deposition was reduced by SAMI strategies while nitrogen deposition was little changed in response to SAMI strategies.
5. On most modeled days, the greatest benefits of reducing sulfur dioxide emissions from the 2010 A2 strategy in the SAMI States are projected to occur in the SAMI States.
6. The greatest benefits from reducing sulfur dioxide emissions generally occur within the State where the reductions are made.
7. For modeled days, local sources have greater contributions to ozone and fine particle mass than to acid deposition.
8. Once the NOx SIP call is implemented, reducing ground-level nitrogen oxide emissions will have greater benefits in reducing growing season ozone than reducing elevated sources of nitrogen oxides.

Photograph courtesy of Hugh Irwin

VISIBILITY

INTRODUCTION

The SAMI visibility assessment evaluated how visibility would change in response to emission reduction strategies. This was accomplished by projecting light extinction, deciviews, and visual range in response to changes in aerosol mass, size, and composition. SAMI also assessed trends in fine particle mass and visibility in the SAMI Class I areas.

SAMI Visibility Assessment Objectives

- Summarize visibility and fine particle trends for SAMI Class I areas based on data from the Interagency Monitoring of Protected Visual Environment (IMPROVE) network
- Assess methods used to calculate light scattering from measured or modeled fine particle mass
- Use SAMI air quality model results to project future fine particle levels and visibility in response to SAMI strategies
- Provide visibility estimates to support SAMI socioeconomic analyses
- Provide electronic software tools to archive and display SAMI visibility results
- Relate SAMI Assessment to EPA guidance for the regional haze rule

What Is Visibility?

Visibility is a term that refers to human perception of a scenic landscape or vista. The term addresses our ability to distinguish the color, contrast, and outline of objects viewed in a landscape. Fine particles and gases in the atmosphere scatter or absorb light and reduce the clarity of the view and the distance that can be discerned by the human eye. As visibility is reduced, colors appear washed out and less vivid, and landscape features become less clear, or may disappear altogether.

Light energy is transmitted through the atmosphere as electromagnetic waves called photons (Malm, 1999). The passage of light in the atmosphere can be altered in three ways:

- Light is scattered out of the sight path between the viewer and the image. Particles in the size range closest to the wavelengths of visible light (particles between 0.3 and 0.7 microns in diameter) are the most efficient in scattering light.
- Light is scattered into the sight path from sunlight or from light reflected off the ground or other objects in a landscape.
- Light is absorbed out of the sight path by nitrogen oxide gas and elemental carbon particles.

The color and clarity of a vista are also affected by the position of the sun in relation to the viewer. When the sun is overhead, light encounters few particles in the vertical sight path to our eye and little light is scattered. We perceive the sun as white. When the sun is nearer the horizon, more of the sight path to our eye is likely to be distorted by particles and gases in the atmosphere. At sunrise or sunset, blue light is scattered out of the sight path and we perceive the sun and sky as red. A viewer's perception of a vista is clearer when the sun is behind the viewer than when the sun is between the viewer and the scene.

What Causes Haze?

Particles and gases in the atmosphere scatter or absorb light and impair visibility. Fine particles are those less than 2.5 microns in diameter (PM2.5), while coarse particles are those particles between 2.5 and 10 microns. The fine particles that are most efficient in scattering light are secondary pollutant byproducts that are formed in the atmosphere from primary emissions of gases (sulfur dioxide (SO2), nitrogen oxides (NOx), ammonia (NH3), and organic compounds (OC)).

Fine particles include sulfate (SO4), nitrate (NO3), organic carbon (OC), elemental carbon (EC), and soil particles. Organic particles in rural areas are primarily attributed to natural emissions from vegetation. Organic compounds are also emitted from human activities, particularly highway vehicles. Organic particles reflect blue light and cause a bluish haze. The Great Smoky Mountains and Blue Ridge Mountains were named for the natural bluish haze and misty clouds common to these areas.

Sulfate particles are formed from sulfur dioxide emissions, primarily from coal combustion. As illustrated in Figure 4.1, sulfate particles occur in the atmosphere as sulfuric acid (H2SO4, one sulfate ion associated with two hydrogen ions), ammonium bisulfate (NH4HSO4, one sulfate ion associated with one hydrogen ion and

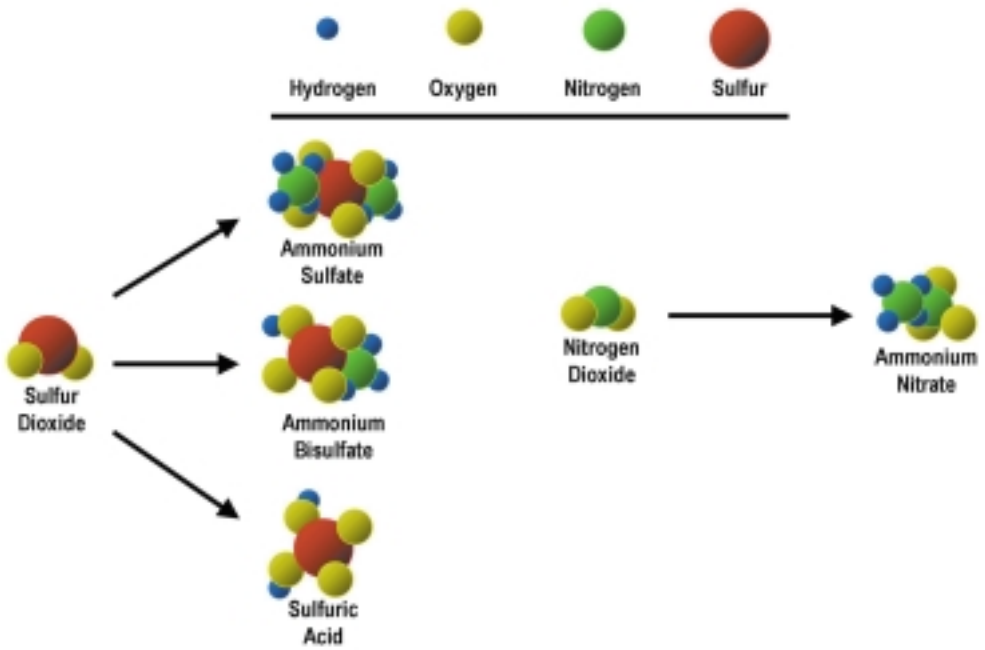


FIGURE 4.1: Illustration of sulfate and nitrate fine particle molecules (Malm, 1999)

one ammonium ion), or ammonium sulfate ((NH4)2SO4, one sulfate ion associated with two ammonium ions). Ammonia gas is emitted primarily from livestock and fertilizer applications. Ammonium sulfate particles scatter light of all colors and cause a whitish or gray haze.

Nitrate particles are formed from nitric acid gas and ammonia gas. Nitric acid gas is formed from nitrogen oxide emissions from combustion of fossil fuels (coal, natural gas, gasoline, and diesel). Ammonia gas reacts with nitric acid gas to form ammonium nitrate (NH4NO3) particles. Because ammonia gas preferentially binds with sulfate, few ammonium nitrate particles will be formed until all sulfate particles are fully neutralized (ratio of ammonium to sulfate ions of 2.0). For most of the year in the rural southeastern United States, sulfate particles are not fully neutralized by ammonium, and nitrate particles concentrations are low (Air Resource Specialists, 2002).

Fine soil particles are emitted primarily from construction, agricultural, and road sources. Fine soil particles scatter less light than sulfate, nitrate, and organic particles. Coarse particles (2.5-10 microns) originate primarily from soils, plants, and geological materials. Elemental carbon is emitted from forest fires and other combustion sources. Elemental carbon absorbs and removes light from the sight path. Nitrogen dioxide gas (NO2) absorbs blue light and thus we perceive a reddish brown haze. This is particularly notable above urban areas with high densities of nitrogen oxide emissions.

How Is Visibility Measured?

Visibility is measured through visual observations, optical instruments, or calculated from fine particle mass.

Light extinction is the basic term used to express visibility. Light extinction is a measure of both the absorption and scattering of light in a sight path and is reported in inverse megameters (Figure 4.2). The higher the extinction value, the poorer the visibility. Light extinction measures atmospheric conditions but does not address how people perceive visibility. Light extinction is measured directly using optical instruments (called transmissometers or nephelometers) or calculated from the measured mass of fine particle components.

Visual range is a common measure of visibility that describes the distance that a dark object can be viewed against the sky and is reported in miles or kilometers (Figure 4.2). Visual range is not a good measure of the clarity of an image. Visual range can be measured using observations of objects at fixed distances from an observation point. Visual range can also be calculated from light extinction.

Deciview is a measure of visibility best expressed as an index that is based on the same concept as decibels, which measure hearing. Deciviews are often used when discussing changes in visibility, because a one deciview change is an equivalent incremental change in visibility whether the atmosphere is clear or hazy. Most people can discern a 1 deciview change in visibility (Pitchford and Malm, 1994).

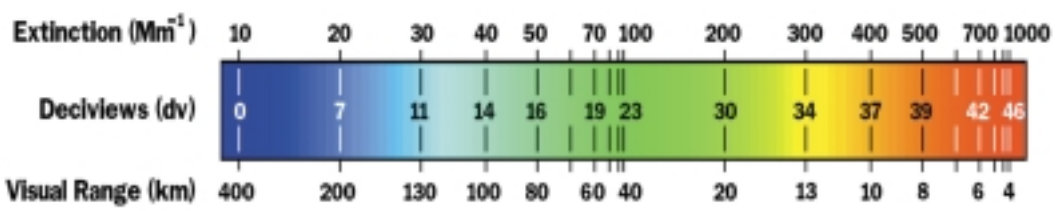


FIGURE 4.2: Comparison of extinction (Mm-1), deciview (dv), and visual range (km). From Introduction to Visibility, Maim, 1999.

Deciview is calculated from light extinction using a logarithmic scale (Figure 4.2). The higher the deciview value the poorer the visibility.

Photographic images are commonly used to illustrate visibility conditions. In recording a view, cameras function similarly to the human eye. The aperture of a camera controls the amount of light entering the camera in much the same manner that the iris of the eye controls the light reaching the retina. The retina of the eye detects the relative differences in brightness and contrast between objects and the background. Photographs capture the clarity, contrast, and colors of objects in an image. Because photographs cannot record as much detail as the human eye, they are imperfect images of how we perceive a vista.

Photographs of clear vistas in the SAMI Class I areas have been recorded as computer images using a computer program called WINHAZE (Molenar, 1994). These images represent visibility due to natural light scattering in clean air. The computer images can be adjusted to visualize how a view changes in response to changes in light extinction. SAMI used WINHAZE to illustrate how visibility at SAMI Class I areas would respond to emissions control strategies.

CALCULATING LIGHT EXTINCTION

Light extinction can be calculated using measured or modeled values for fine particle mass and relative humidity and assumptions about the extinction efficiency of each particle component. For simplicity this equation ignores the effects of different particle sizes and shapes on light extinction and assumes that particles behave the same way in mixtures as they do when all particles are the same chemical component.

A factor to account for the efficiency of light scattering or light absorption is assigned to each fine particle species. The dry extinction efficiency of each fine particle component is multiplied by the mass of that component. For particles that absorb water vapor (sulfate and nitrate) the dry extinction efficiency is increased by a factor that accounts for the effects of relative humidity.

With added water vapor, sulfate particles grow to larger particle sizes (0.6 microns in diameter) that are more efficient at scattering light. Acidic sulfate particles absorb more water vapor and scatter more light than ammoniated sulfate particles. At higher relative humidity sulfate and nitrate particles can scatter 2 to 30 times as much light as at lower relative humidity (Air Resources Specialists, 2002). Some organic carbon compounds can absorb water. Soils and elemental carbon do not absorb water.

What Is Natural Visibility?

In the absence of human emissions, natural background visibility is affected by light scattering from air molecules, water vapor, and naturally occurring particles such as organic compounds from vegetation. Variation in relative humidity, temperature, and the natural production of particles affect natural background visibility. On an annual average, natural background visibility in the Eastern United States is estimated as 93 miles plus or minus 30 miles (Trijonis, et al., 1990). Using EPA guidance for calculating natural background under the regional haze rules (USEPA, 2001), annual average visibility in the SAMI Class I areas is estimated as 112-114 miles. Natural visibility is lower in the summer than in the winter in the Southeastern U.S., because both relative humidity and natural production of gases and secondary particles are higher in the summer than in the winter.

VISIBILITY AND FINE PARTICLE TRENDS IN SAMI CLASS I AREAS

SAMI relied on data from the Interagency Monitoring of Protected Visual Environments (IMPROVE, 2002) network to assess trends in fine particle mass and visibility in the SAMI Class I areas. IMPROVE began measuring fine and coarse particles at national parks and wilderness areas in the late 1980s. By 2002, the network includes 110 sites nationally, and 8 sites in the SAMI region. Six Class I areas in the SAMI region have IMPROVE data for at least a portion of the days in 1991-1995 that were modeled in SAMI's Assessment. (Figure 4.3). Great Smoky Mountains and Shenandoah National Parks have the longest IMPROVE data records in the SAMI region.

Methods

The IMPROVE network collects particles on teflon, nylon, or quartz filters (Malm, et al., 1996; IMPROVE, 2002) over a 24-hour period, for two days per week (prior to 2000, every Wednesday and Saturday; since 2000, every 3rd day). Average daily particle mass is measured directly for sulfate, nitrate, soil, organic carbon, and elemental carbon. Ammonium mass is not routinely measured by IMPROVE. Sulfate mass is reported as the mass of ammonium sulfate assuming that sulfate is fully neutralized (ratio of ammonium to sulfate ions is 2.0). Nitrate is reported as the mass of ammonium nitrate.

To account for the unmeasured, non-carbon material associated with organic carbon, IMPROVE multiplies the measured organic carbon mass by a factor of 1.4 to report total organic carbon mass.

Total measured PM2.5 mass is often larger than the sum of the measured individual species: sulfate, nitrate, organic carbon, soils, and elemental carbon. The composition of the unmeasured mass is attributed to water associated with the fine particles, but may also include unmeasured organic carbon compounds (Saxena, et al., 1998; CIRA, 2000).

Light extinction is currently measured directly using nephelometers at Great Smoky Mountains, TN, Shenandoah, VA, and James River Face, VA. Light scattering is measured directly using a transmissometer at Shenandoah, VA. Relative humidity is also measured directly at these sites. Measured light extinction corresponds favorably to light extinction calculated from the measured components of fine particle mass (Watson, 2002).

SAMI Geographic Domain

and 10 Class I areas

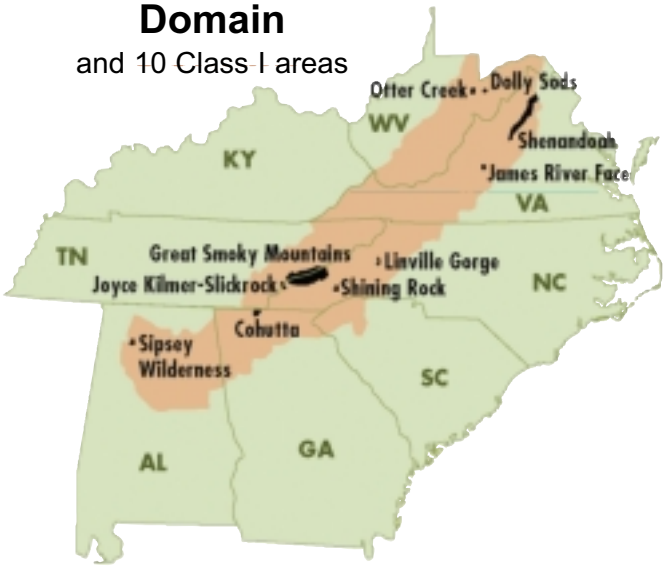


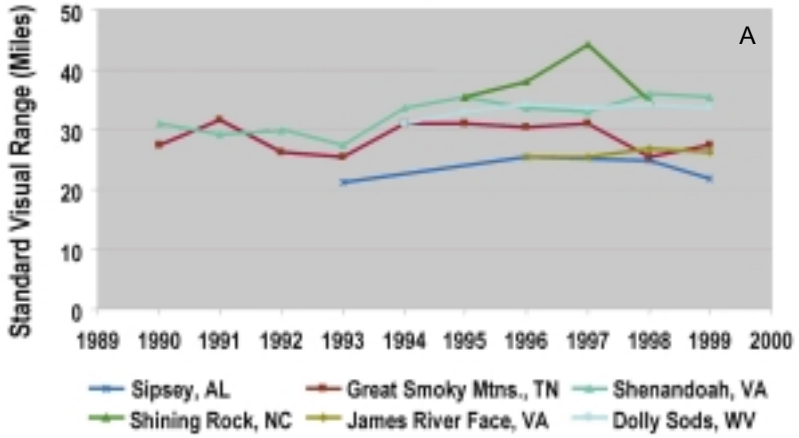
FIGURE 4.3: Map of SAMI region and locations of IMPROVE monitors in SAMI Class I areas.

Annual Trends

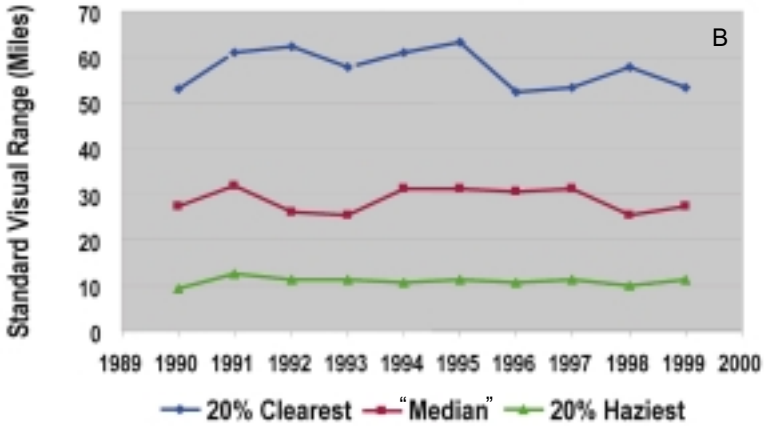
Based on the IMPROVE monitoring data and assumptions for calculating light extinction, there have been no clear changes in the annual "median" (more accurately the mean of the central 20 percent of all data) visual range (Figure 4.4a) over the past decade at SAMI Class I areas (IMPROVE, 2002). There are greater differences in annual "median" visibility between Class I areas than between years at any one site. Summer days tend to be hazier than the annual average. Current (1999) annual "median" visibility at Shenandoah National Park is 35 miles and at Great Smoky Mountains is 27 miles. Visibility on the 20% clearest and the 20% haziest days also has not changed appreciably over the decade (Figures 4.4b and 4.4c).

Standard Visual Range - Annual Median

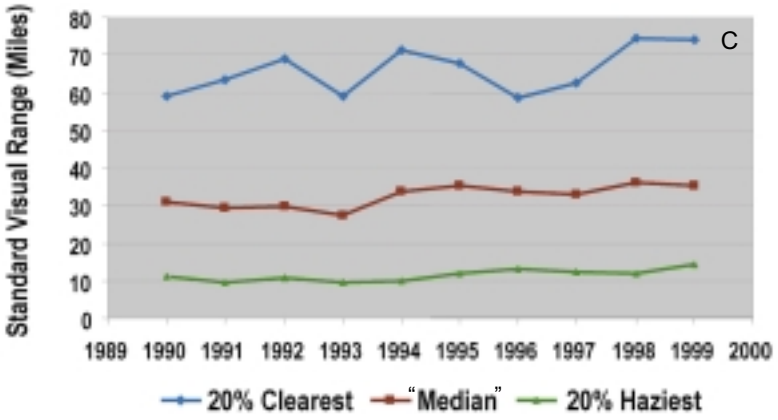
SAMI Region



Great Smoky Mountains, TN



Shenandoah, VA



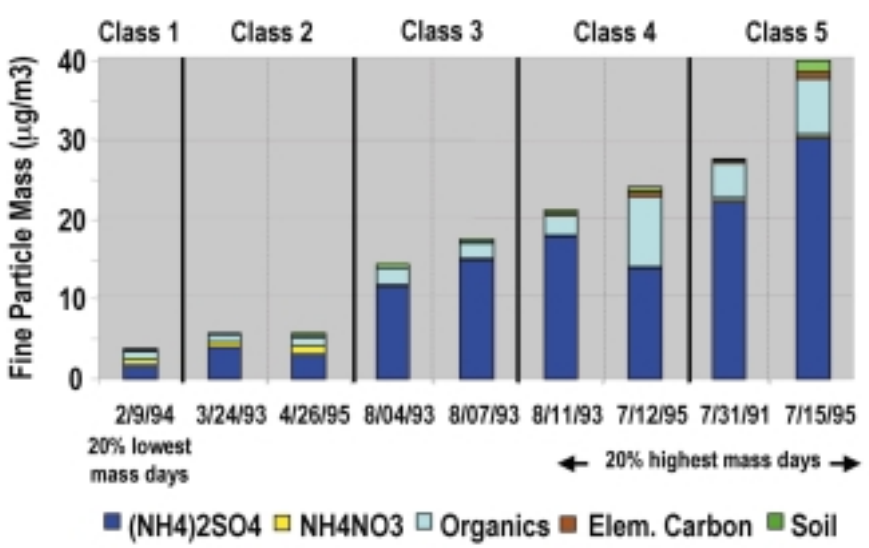
Based on IMPROVE fine particle data and assumptions

FIGURE 4.4: Visual Range at SAMI Class I area based on IMPROVE MONITORING data and assumptions for calculating light extinction (a) Annual "median" (more accurately the mean of the central 20% of all data), (b) Annual "median", 20% haziest and 20% clearest days at Great Smoky Mountains National Park, (c) Annual "median", 20% haziest and 20% clearest days at Shenandoah National Park.

For annual average conditions and on most individual days at SAMI Class I areas, ammoniated sulfate particles are the largest contributors to fine particle mass and visibility impairment (Figures 4.5). Organic particles are the second largest contributors to fine particle mass. On an annual average, nitrate particles contribute 5-10% of fine particle mass. On some winter days at some sites such as Shenandoah, nitrate contributes 10-20% of total fine particle mass and visibility impairment (IMPROVE, 2002). On most days elemental carbon and soils are minor contributors to fine particle mass and visibility impairment. On the 20% haziest days, sulfate particles contribute greater than 70% of total light extinction. On the 20% clearest days, sulfate contributes roughly 50% of light extinction. Organic carbon, nitrate, soils, and elemental carbon have larger percentage contributions to light extinction than on hazier days (IMPROVE, 2002).

Linking SAMI Air Quality Model And Visibility Effects Assessment

IMPROVE fine particle and relative humidity data from 1991 to 1995 at Look Rock, TN, in Great Smoky Mountains National Park and at Big Meadows, VA, in Shenandoah National Park were used to select episode days for air quality modeling (see Atmospheric Modeling Chapter 2; Deuel and Douglas, 1998; Timin, 2002). All IMPROVE days were assigned to one of five classes based on the combined fine particle mass of sulfate, nitrate, organics, and soil (Table 4.1). Fine particle mass was used to classify days instead of visibility to avoid confounding influences from relative humidity on the episode classification technique. Class 1 days are those days with the lowest 20% fine particle mass. Class 4 plus Class 5 days together represent the 20% highest mass days in the 1991-1995 record.

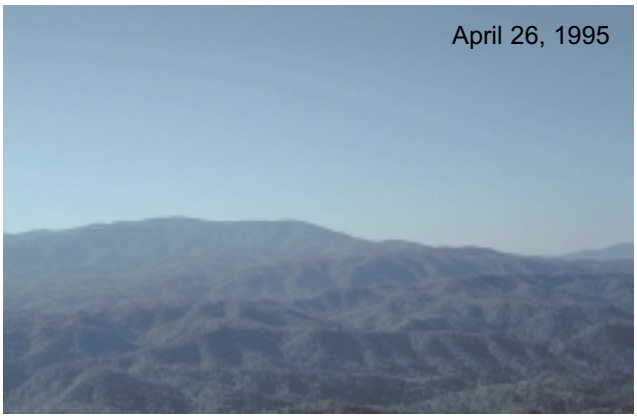


Based on IMPROVE fine particle data and assumptions

FIGURE 4.5: Fine particle mass at Shenandoah National Park for modeled days in each of five visibility classes based on improve monitoring data.

Class 5 alone addresses the days with the 3% highest mass. Examples of visibility at Look Rock in Great Smoky Mountains National Park on modeled days in Classes 2, 4, and 5 are illustrated at right.

Of the 69 days selected for modeling, IMPROVE monitoring data are available for 22 days for model performance evaluation (see Chapter 3). Weights were assigned to each of these 22 days to account for the frequency of occurrence of days with similar meteorology in 1991-1995 and were used to reconstruct fine particle mass and visibility for annual average, summer average, and class average conditions at Great Smoky Mountains and Shenandoah National Parks (Timin, 2002). The same weights assigned to modeled days for the Great Smoky Mountains National Park were also used for Sipsey, Cohutta, Joyce Kilmer-Slickrock, Shining Rock, and Linville Gorge Wilderness areas. The same weights used for modeled days at Shenandoah were used for James River Face, Dolly Sods, and Otter Creek Wilderness areas (Table 4.2).



Visibility at 9 am on three modeled days at Look Rock in Great Smoky Mountains National Park. April 26, July 12, and July 15, 1995 represent Class 2, 4, and 5 days, respectively (see also Table 4.1 and Figure 4.5).

Table 4.1: Classification of Days based on combined fine particle mass at Great Smoky Mountains and Shenandoah National Parks during 1991-1995 (Deuel and Douglas, 1998)

Visibility Class	Combined Fine Particle Mass (SO4, NO3, organics, and soils, mg/m3)	Frequency of Days
1	0 - 5.0	0 - 20%
2	5.1 - 9.1	21 - 50%
3	9.1 - 15.8	51 - 80%
4	15.8 - 24.9	81 - 97%
5	24.9 - 41.5	98 - 100%

IMPROVE monitoring data were used as the basis for projecting future changes in visibility in response to SAMI strategies. The modeled percentage changes of fine particle mass from the 1991-1995 reference year to 2010 or 2040 were used to adjust the measured components of fine particle mass (Odman, et al., 2002). The modeled percentage change is called the relative reduction factor. If modeled mass of a chemical component varied from measured mass on a modeled day by more than a factor of two, then the relative reduction factor was not used. Instead the relative reduction factor was selected from the maximum or minimum relative reduction factor from days with good model performance (modeled mass within a factor of two of measured mass).

Where IMPROVE particle monitoring data were not available, particle data was borrowed from nearest IMPROVE site (see Table 4.2; Air Resource Specialists, 2002; Air Resources, 2002). Borrowed data were scaled based on periods of overlap in data collections between sites. If relative humidity was not measured at the sites for the modeled days, then modeled hourly relative humidity data were used for visibility calculations.

Table 4.2: Data sources for calculating visibility at SAMI Class I areas for 1991 to 1995

Class I area	Source of particle data	Source of relative humidity data	Weights assigned to modeled days
Sipsey Wilderness Area, AL	Borrow July 1991 episode from GRSM	Use modeled hourly RH	Use GRSM
Cohutta Wilderness Area, GA	Use 1991-1995 episodes from GRSM	Use modeled hourly RH	Use GRSM
Great Smoky Mountains National Park, TN (GRSM)	Use GRSM data	Use measured hourly RH	GRSM
Joyce Kilmer- Slickrock Wilderness Area, NC	Use GRSM data	Use measured RH at Great Smoky Mtns.	Use GRSM
Shining Rock Wilderness Area, NC	Borrow data for 5 episodes 1991-1993 from GRSM, use on-site data for 4 episodes 1994-1995.	Use on-site measured hourly RH when available; use modeled hourly RH when measured RH not available	Use GRSM
Linville Gorge Wilderness Area, NC	Borrow data for 1991-93 episodes from GRSM and 1994-1995 episodes from Shining Rock	Use modeled RH	Use GRSM
James River Face Wilderness Area, VA	Borrow data for 1991-1993 episodes from SHEN; use on-site data for 5 episodes	Use modeled hourly RH	Use SHEN
Shenandoah National Park, VA (SHEN)	Use SHEN data	Use measured hourly RH	SHEN
Dolly Sods Wilderness Area, WV	Borrow July 1991 episode from SHEN; use on site data for 8 episodes	Use modeled hourly RH for July 1991 episode, measured hourly RH for 8 episodes	Use SHEN
Otter Creek Wilderness Area, WV	Use Dolly Sods data	Use same RH data as Dolly Sods	Use SHEN

Evaluating Assumptions For Calculating Light Extinction

SAMI investigated the sensitivity of light extinction calculations to some of the assumptions used in the extinction equation. SAMI tested the effects of the following assumptions on calculated light extinction:

- There may be greater amounts of organic carbon particle mass than is accounted for by current IMPROVE assumptions. To test whether the factor used to calculate total organic carbon from measured organic carbon would affect calculated light extinction, this factor was increased from 1.4 (value assumed by IMPROVE) to 1.7 or 2.0.
- Some organic carbon components may absorb water. To test whether this assumption would affect calculated light extinction, 15% of total organic carbon mass was assumed to absorb water vapor (IMPROVE assumes organics do not absorb water).
- The two assumptions above were combined to test the cumulative effect of increasing the organic carbon factor and assuming that 15% of organic carbon mass absorbs water.
- As the acidity of sulfate fine particles increases, so does the amount of water adsorbed and the amount of light scattered by sulfate particles. SAMI tested the effect of varying the ratio of ammonium to sulfate ions in fine particles from 0.5 to 2.0 (the value assumed by IMPROVE) on calculated light extinction.
- The scattering efficiency of coarse mass may be higher than assumed by IMPROVE. SAMI varied the scattering efficiency of coarse mass from 0.6 (value assumed by IMPROVE) to 1.5.
- Relative humidity has a large effect on calculated light extinction. SAMI tested the effects of using measured hourly, modeled hourly, or monthly average relative humidity data.

In all cases, the standard IMPROVE assumptions produced lower light extinction values than the alternatives tested. The acidity of sulfate particles and the source of relative humidity data were the two assumptions that had the greatest affect on calculated light extinction. All other assumptions that SAMI tested showed negligible or small changes in extinction and were not considered in SAMI's strategy analyses. These results might not apply in urban areas where organic carbon compounds contribute a larger percentage of the total particle mass and extinction.

Ammonium To Sulfate Ratio

IMPROVE does not routinely measure ammonium but assumes that measured sulfate particles are fully neutralized (ratio of ammonium to sulfate ions of 2.0). Since 1997, ammonium has been measured from the filters at three IMPROVE sites in the SAMI region: Great Smoky Mountains National Park in eastern Tennessee, Shenandoah National Park in Virginia, and Dolly Sods Wilderness Area in West Virginia (IMPROVE, 2002). These ammonium measurements and those from other studies (Saxena, 1998; SEARCH, 2002) indicate that on many days sulfate particles are not fully neutralized. On a daily basis, that ratio may be below 1.0, especially in the summertime. At ammonium to sulfate ratios below 1.0, sulfate is more efficient at scattering light than when the ratio is in the range 1.5 – 2.0. These ammonium measurements suggest that, at least in the rural Southeastern U.S., light extinction by sulfate may be underestimated on some days.

SAMI chose to use the monthly average measured ratio of ammonium to sulfate based on 1997-1999 data (Figure 4.6) to calculate light extinction in 1991-1995, and in 2010, and 2040 in response to SAMI strategies.

Relative Humidity

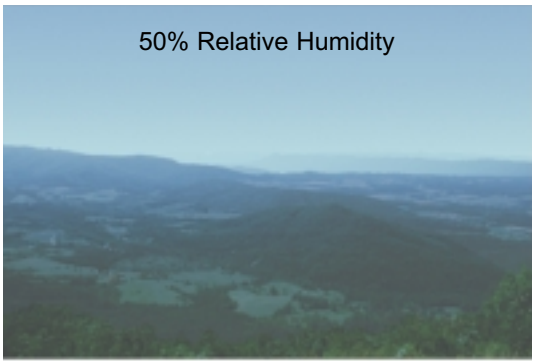
The data sources for relative humidity had the greatest affect on calculated light extinction. Because relative humidity affects how much light is scattered by fine sulfate and nitrate particles, days with the lowest particle mass are not necessarily the days with the clearest visibility. As illustrated below for Shenandoah National Park on July 12, 1995, relative humidity can significantly affect visibility. Fine particle mass is the same in both images, at 90% relative humidity (image on right) visibility is poorer than at 50% relative humidity (image on left). Across the seasons, relative humidity is generally higher in the summer than in the winter. The highest relative humidity generally occurs in the hours before and after dawn and the lowest relative humidity at mid-day.

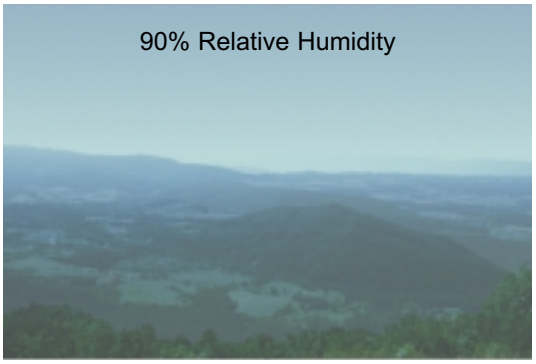
The Environmental Protection Agency recommends using monthly average relative humidity data for the purpose of evaluating visibility trends over time (USEPA, 2001). This approach minimizes the effects of variation in weather on future trends. When assessing the effectiveness of emissions strategies, using measured relative humidity from the same site as air quality data is appropriate. Monthly average relative humidity can differ significantly from measured daily relative humidity. SAMI used relative humidity measured at the same site as fine particle mass as the most accurate representation of visibility on the modeled days. If measured hourly relative humidity data were not available, modeled hourly relative humidity data were used (Table 4.2).

IMPROVE assumes that the multiplier mass to calculate total organic carbon mass from measured organic mass is 1.4. More recent measurements (Turpin and Lim, 2001) suggest that in the Southeastern United States, a multiplier for measured organic carbon mass of 1.6 to 2.2 might be more appropriate. Increasing the organic mass multiplier from 1.4 to 2.0 changed visibility by less than 1 deciview on 94% of the days in the 1991-1995 monitoring records for Great Smoky Mountains and Shenandoah National Parks (Air Resources Specialists, 2002). The response to changes in the assumed multiplier for organic mass might be larger at sites where organic compounds have a larger percentage contribution to visibility than is the case at the SAMI Class I areas.

VISIBILITY RESPONSES TO SAMI STRATEGIES

The SAMI Strategies are projected to reduce annual average SO2 and NOx emissions in 2010 and 2040. Ammonia gas emissions are projected to increase in the A2 and B1 strategies, and decrease in the B3 strategy. Changes in emissions of volatile organic compounds, elemental carbon, and soils are projected to be small (Figure 4.7, Chapter 2 - Emissions Inventory).





The effect of relative humidity on visibility on July 12, 1995, at Shenandoah National Park. Photo on left assumes relative humidity of 50%. Photo on right assumes same fine particle mass as image on left, but relative humidity of 90%.

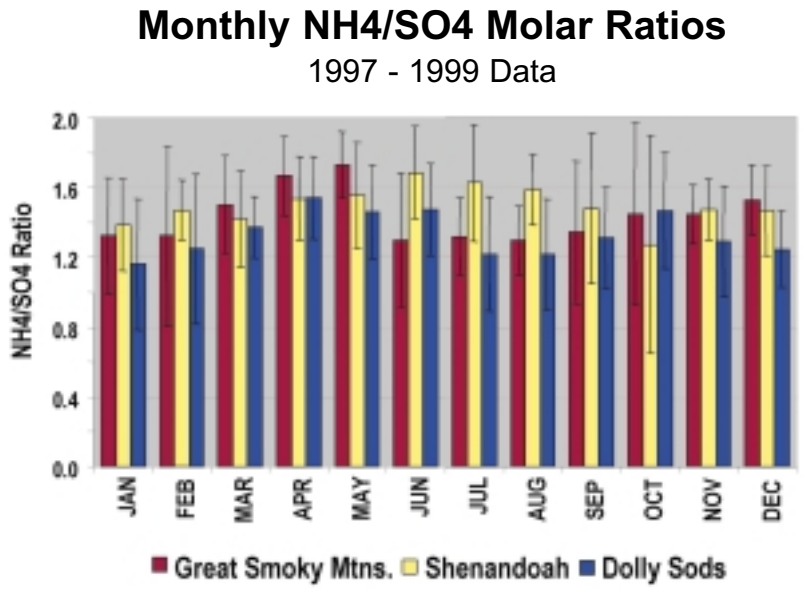
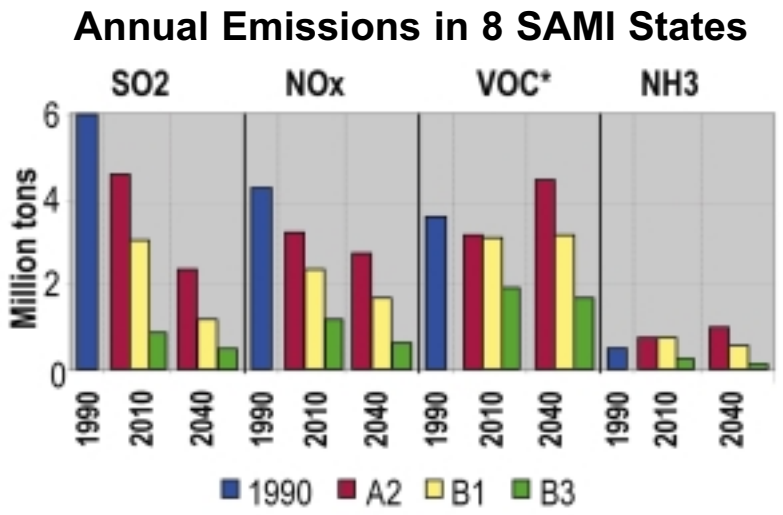


FIGURE 4.6: Monthly average ratio of ammonium to sulfate ions measured at IMPROVE monitoring sites at Great Smoky Mountains, Shenandoah, and Dolly Sods from 1997 to 1999.



*Anthropogenic VOC only, not included natural sources of VOC

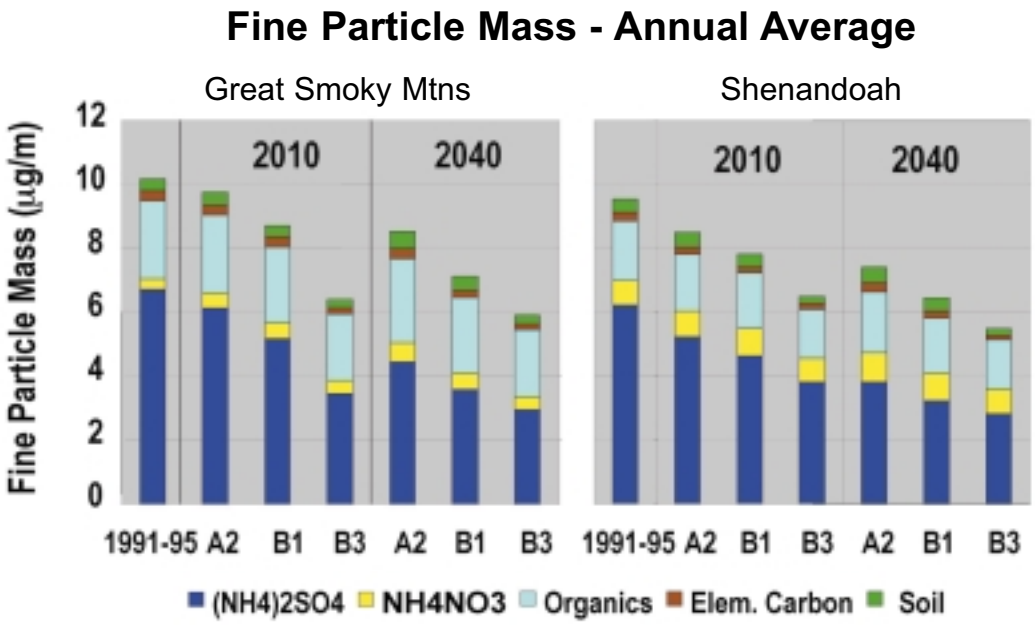
FIGURE 4.7: Annual emissions of sulfur dioxide, nitrogen oxides, volatile organic compounds, and ammonia in eight SAMI states.

Sulfate particles account for the greatest portion of the annual average reconstructed fine mass and light extinction. Fine particle responses to SAMI strategies are illustrated in Figures 4.8 and 4.9 for Great Smoky Mountains and Shenandoah National Parks. These trends are representative of those at the other SAMI Class I areas. In 1991-1995 at Great Smoky Mountains and Shenandoah National Parks, sulfate particles accounted for 65-66% of annual average reconstructed fine particle mass and 70-71 % of annual average light extinction.

Sulfate contributions to fine particle mass and light extinction are projected to decrease under all SAMI strategies, and the largest improvements in visibility are projected to occur in response to sulfur dioxide reductions. At Great Smoky Mountains National Park in 2010, annual average sulfate fine particles are projected to decrease by 9, 23, and 49% under SAMI's A2, B1, and B3 strategies, respectively, compared to 1991-1995. Annual average visibility at Great Smoky Mountains National Park is projected to increase from 23 miles in 1991-1995 to 24, 28, and 38 miles in 2010 under the SAMI A2, B1, and B3 strategies. At Shenandoah National Park in 2010, annual average sulfate fine particles are projected to decrease by 16, 25, and 39% under SAMI's A2, B1, and B3 strategies. Annual average visibility at Shenandoah is projected to increase from 21 miles in 1991-1995 to 23, 25, and 29 miles in 2010 under SAMI's A2, B1, and B3 strategies.

On some days, nitrate particles are projected to increase in response to SAMI strategies. On these days, sulfate particle mass is reduced. When all sulfate particles are fully neutralized, ammonia gas is available to react with nitric acid vapor and nitrate particles are formed. The increases in nitrate particles are much smaller than the decreases in sulfate particles projected on these days, so visibility is still projected to improve, but less than would be expected based solely on sulfate reductions.

Changes in visibility at the SAMI Class I areas due to changes in organic carbon particles were small. SAMI's atmospheric model projects that natural emissions sources are larger contributors to organic carbon particles at SAMI Class I areas than are human emissions sources. Therefore changes in organic carbon emissions under the SAMI strategies were small compared to natural emissions and changes in organic carbon mass at SAMI Class I areas were small.



*based on IMPROVE data and URM modeled change for strategies

FIGURE 4.8: Annual Average Fine Particle Mass at Great Smoky Mountains and Shenandoah National Parks in 1991-1995 and in 2010 and 2040 in response to SAMI strategies

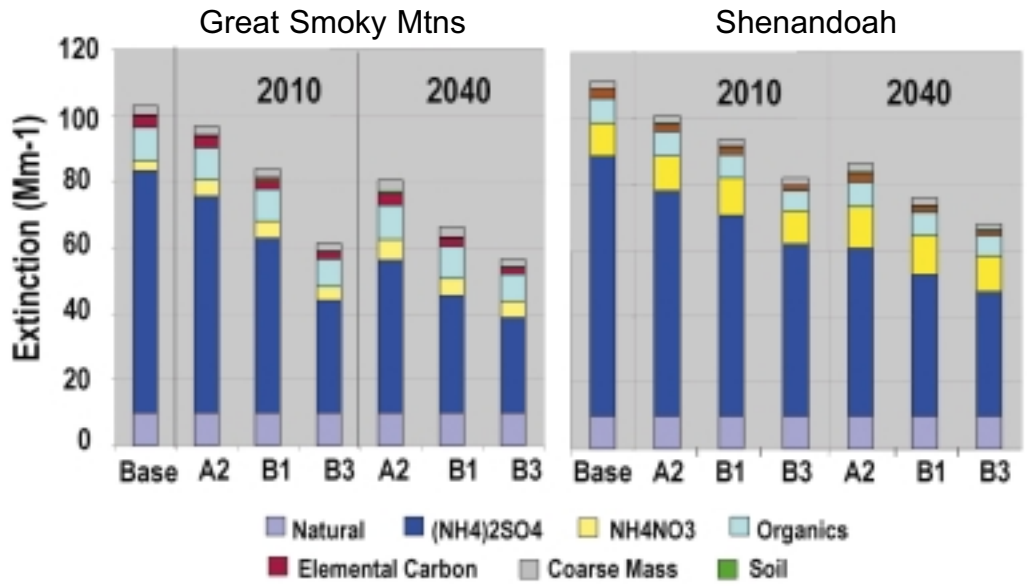
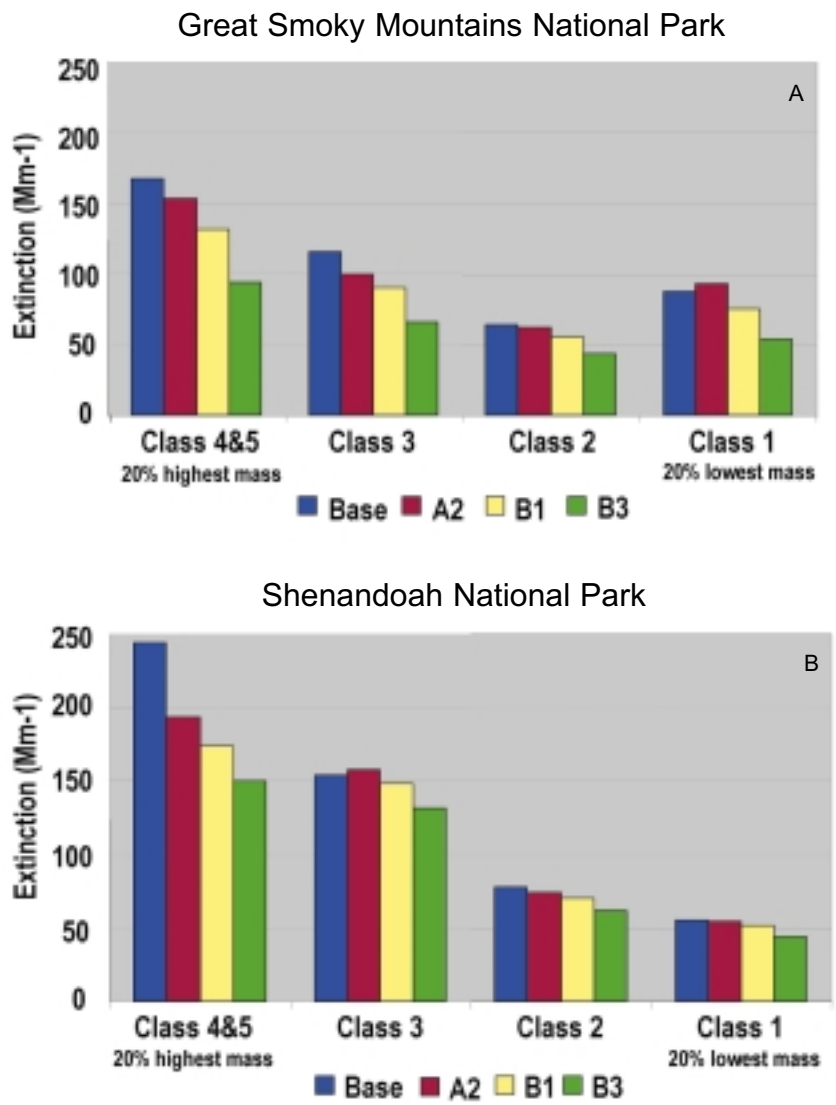


FIGURE 4.9: Annual Average Light Extinction at Great Smoky Mountains and Shenandoah National Parks in 1991-1995 and in 2010 and 2040 in response to SAMI strategies

The largest improvements in visibility in response to SAMI emissions strategies are projected to occur on days with the highest fine particle mass (Figure 4.10 a and b).

Annual average visibility range in 1991-1995 varied from 10-25 miles across the 10 SAMI Class I areas (Figure 4.11). The poorest annual average visibility occurred at Dolly Sods in West Virginia and Sipsey in northern Alabama. The best annual average visibility occurred at Great Smoky Mountains in eastern Tennessee. Across the 10 SAMI Class I areas, the annual average visibility range in 2010 is projected to increase by less than 2 miles under the A2 strategy, by 1-6 miles under the B1 strategy, and by 4-15 miles under the B3 strategies.



FIGURES 4.10 A AND B: Changes in Visibility in 2010 in response to SAMI strategies for modeled days in five classes based on fine particle mass at (a) Great Smoky Mountains and (b) Shenandoah national Parks

The greatest improvements in annual average visibility are projected for those Class I areas that are mostly influenced by emissions from the SAMI states: Cohutta, GA; Great Smoky Mountains, TN; Joyce Kilmer, NC; Shining Rock, NC; and Linville Gorge, NC (see Chapter 3, also Odman, et al., 2002). Fine particle mass at Sipsey Wilderness Area in North Alabama, and the Class I areas in West Virginia and Virginia receive greater contributions from states outside the SAMI region than the other SAMI Class I areas. Because emissions for sources in the non-SAMI states were held at the same levels in the B1 and B3 strategies as the A2 strategy, annual average visibility at these Class I areas did not improve as much as for the Class I areas in Georgia, Tennessee, and North Carolina.

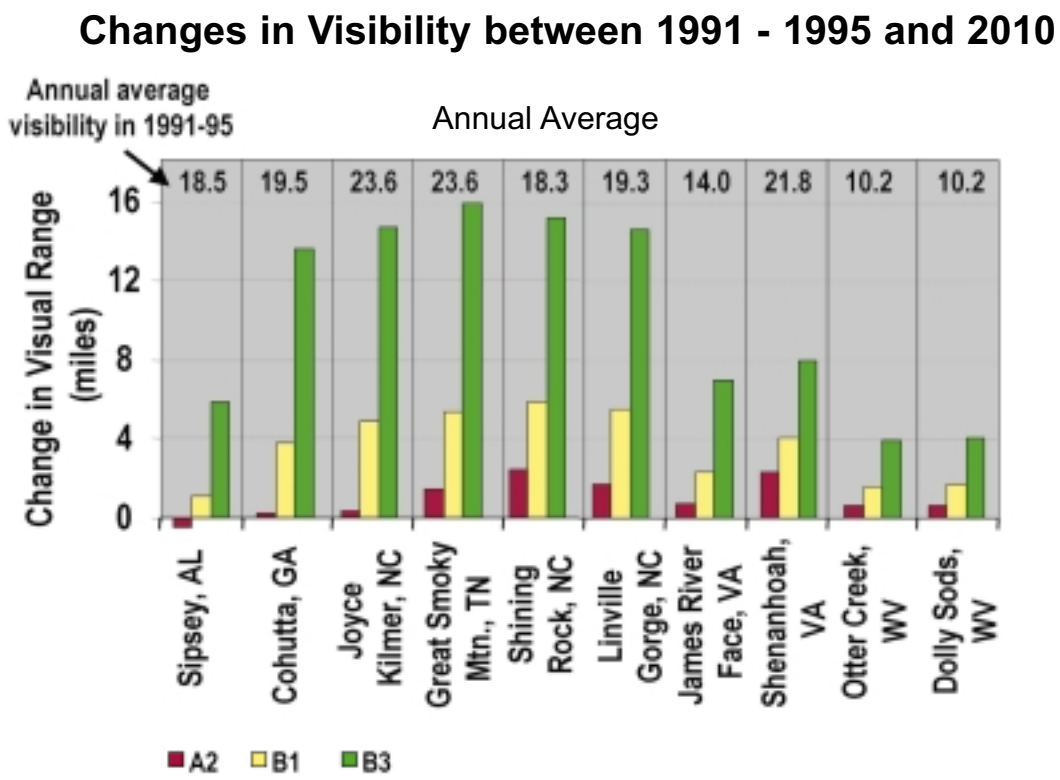


FIGURE 4.11: Changes in Annual Average Visibility between 1991-1995 and 2010 at 10 Class I areas in response to SAMI Strategies

At most SAMI Class I areas, visibility on the 20% highest mass days is projected to improve more than annual average visibility. For the 20% highest mass days in the SAMI analyses, visibility across the SAMI Class I areas is projected to improve from 1 to 2 deciviews (1 to 3 miles) for the A2 strategy between 1991-1995 and 2010 (Figure 4.12). Visibility at the SAMI Class I areas is projected to improve by 2 to 3 deciviews (2 to 5 miles) under the B1 strategy and by 3 to 7 deciviews (3 to 15 miles) for the B3 strategy, compared to 1991-1995. Between 1991-1995 and 2040, visibility at the SAMI Class I areas is projected to improve 2 to 5 deciviews for the A2 strategy, 4 to 7 deciviews for the B1 strategy, and 6 to 8 deciviews for the B3 strategy.

SAMI considered summer average visibility for Great Smoky Muntains National Park and the associated Class I areas. Summer average visibility improved more than the annual average visiblility in response to SAMI strategies (Figure 4.13 and Table 4.3). Summer average visibility was not calculated for Shenandoah National Park and associated Class I areas because the modeled days did not include clear summer days at Shenandoah.

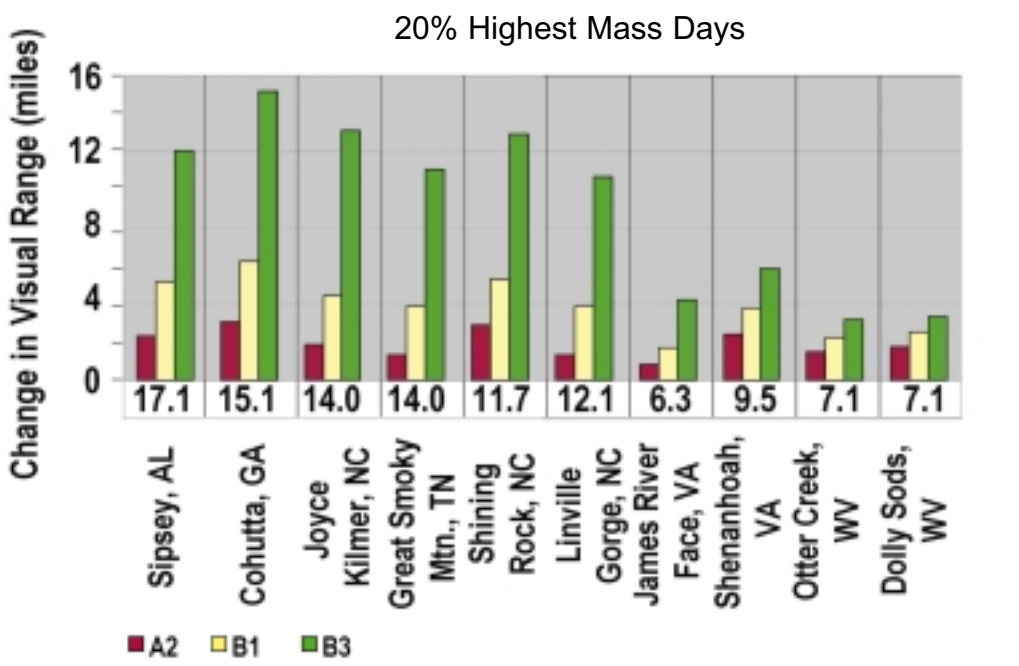


FIGURE 4.12: Changes in visual range between 1991-1995 and 2010 for the 20% highest mass days at 10 Class I areas in response to SAMI Strategies

Changes in Visibility between 1991 - 1995 and 2010

Summer Average

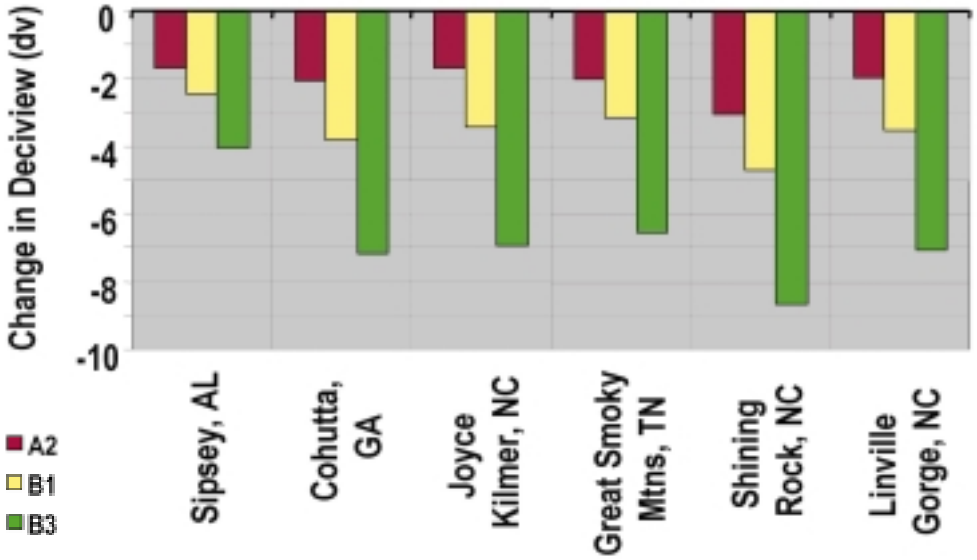


FIGURE 4.13: Changes in Summer Average Visibility between 1991-1995 and 2010 at six Class I areas in response to SAMI Strategies

Table 4.3: Annual average and summer average visibility at SAMI Class I areas for 1991-1995 and in response to SAMI strategies.

Standard Visual Range in Miles - Annual Average							
Class I Area:	1991-1995 Base Year	2010 A2	2010 B1	2010 B3	2040 A2	2040 B1	2040 B3
Sipsey	18.5	18.0	19.6	24.4	21.2	24.9	27.5
Cohutta	19.5	19.8	23.4	33.1	24.5	31.2	37.7
Joyce Kilmer	23.6	24.1	28.4	38.2	28.5	34.9	41.3
Great Smokies National Park	23.6	25.1	28.9	39.5	30.2	36.6	42.9
Shining Rock Wilderness	18.3	20.8	24.2	33.5	26.1	31.8	36.6
Linville Gorge Wilderness	19.3	21.1	24.8	33.9	26.0	32.2	38.0
James River Face	14.0	14.8	16.3	21.0	17.2	21.4	25.5
Shenandoah	21.8	24.1	25.9	29.7	28.1	31.9	35.7
Otter Creek	10.2	10.8	11.8	14.2	14.1	16.0	19.0
Dolly Sods	10.2	10.9	11.9	14.2	14.4	16.1	19.0

Standard Visual Range in Miles - Summer Average							
Class I Area:	1991-1995 Base Year	2010 A2	2010 B1	2010 B3	2040 A2	2040 B1	2040 B3
Sipsey	16.4	19.1	20.6	24.3	21.7	24.6	26.6
Cohutta	15.7	19.0	22.3	31.3	24.3	29.9	35.8
Joyce Kilmer	13.8	16.1	19.1	27.1	20.3	25.1	30.0
Great Smokies National Park	13.8	16.8	18.8	26.3	21.1	24.9	28.8
Shining Rock Wilderness	10.9	14.5	16.8	24.7	19.5	23.8	27.4
Linville Gorge Wilderness	16.2	19.3	22.3	31.8	25.0	30.6	36.3

"*Not available for Shenandoah, James River Face (JEFF), Dolly Sods, or Otter Creek "

The WINHAZE program was customized to calculate light extinction at the SAMI Class I areas in response to SAMI strategies. Changes in visibility for July 15, 1995 assuming emissions in 2010 under A2, B1, and B3 strategies are illustrated in Figure 4.14. July 15, 1995 is a high mass day with large responses to SAMI strategies compared to other modeled days.

LINK TO SOCIOECONOMIC ANALYSES

Annual average visibility in the SAMI Class I areas in 1991-1995 and the changes in annual average visibility in response to SAMI strategies in 2010 and 2040 were provided to support socioeconomic analyses of recreational benefits. Light extinction was calculated using SAMI's assumptions for the molar ratio of ammonium to sulfate ions and relative humidity. Annual average visibility for 1991-1995 and for SAMI strategies was also provided for every grid cell in the 12-km and 24-km grids to support socioeconomic analyses of residential benefits. To calculate annual average visibility, the same weights as assigned to modeled days at Great Smoky Mountains National Park were assigned to all grid cells in the 12 and 24 km grids in Tennessee, North Carolina, Alabama, Georgia, and South Carolina. The same weights as assigned to modeled days at Shenandoah National Park were assigned to all grid cells in the 12 and 24 km grids in Kentucky, Virginia, and West Virginia. Light extinction was calculated using IMPROVE assumptions and modeled relative humidity for each grid cell. There is significantly greater uncertainty associated with the assumptions used to calculate annual average visibility for all grid cells in the 12-km and 24-km grids than for the SAMI Class I areas.

Great Smoky Mountains National Park – July 15, 1995

FIGURE 4.14: Visibility on July 15, 1995, illustrated using the software program WINHAZE, assuming emissions on July 15, 1995 and assuming emissions in 2010 under the A2, B1, and B3 strategies.

UNCERTAINTIES

The greatest source of uncertainties comes from the cumulative uncertainties in the emissions inventory and the atmospheric model assumptions and performance. The greatest confidence is in sulfate and organic particles, intermediate for elemental carbon and soil, and least for nitrate and ammonium.

Other, smaller sources of uncertainty include:

- Using relative reduction factor from the air quality model to project changes in future fine particle mass in response to SAMI strategies
- Using modeled days to represent all other days.
- Assumptions used to calculate visibility
- Borrowing IMPROVE data for sites without monitoring data
- Uncertainties in IMPROVE measurement techniques

LESSONS LEARNED

SAMI's visibility assessment demonstrated several unique accomplishments:

- Of the many assumptions used to calculate light extinction from the mass of fine particle components, the most important are relative humidity and the assumed ratio of ammonium to sulfate ions. SAMI's sensitivity tool can be used to test the effects of alternative assumptions in future analyses.
- A relative reduction factor can be used with measured fine particle mass and modeled changes in fine particle mass to project changes in visibility in response to emissions reductions. Model performance needs to be considered to assure credible reduction factors are used.
- Based on ambient monitoring and air quality modeling results, nitrate particle formation in the rural southeastern US is likely limited by levels of ammonia, not nitric acid vapor, in the atmosphere.

KEY FINDINGS

1. Sulfate particles account for the greatest portion of the annual average reconstructed fine mass and light extinction.
2. The largest improvements in visibility in SAMI Class I areas are projected to occur in response to reductions in sulfur dioxide emissions under SAMI strategies.
3. The largest improvements in visibility are projected to occur on days with the poorest visibility and in areas with the poorest visibility.
4. Across the 10 SAMI Class I areas, annual average visual range in 2010 is projected to increase by less than 2 miles under the A2 strategy, by 1-6 miles under the B1 strategy, and by 4-15 miles under the B3 strategies.
5. The greatest improvements in annual average visibility are projected for those Class I areas that are mostly influenced by emissions from the SAMI states.
6. Formation of nitrate particles is currently limited in the rural southeastern United States by availability of ammonia. As sulfate particles are reduced, more ammonia will be available to react with nitric acid vapor and form nitrate particles.

OZONE EFFECTS TO FORESTS

INTRODUCTION

The Ozone assessment evaluated the response of forests to changing levels of ozone that would result from emission reduction strategies. The forest response models used ozone data from the atmospheric model to project how different tree species within a forest respond to changes in ozone levels over several decades.

SAMI Ozone Assessment Objectives

- Describe current forest distribution in SAMI region
- Characterize sensitivity to ozone of different tree species
- Use ambient ozone monitoring data and SAMI air quality model results to project future ozone exposures in response to SAMI strategies
- Project future changes in forests in the SAMI region and Class I areas in response to SAMI strategies

What Is Ozone?

Ozone occurs naturally in the atmosphere at the earth's surface and in the upper atmosphere. The air we breathe contains oxygen that has two atoms (O2), whereas ozone has three oxygen atoms (O3). Ozone is formed by the reaction of nitrogen oxides (formed primarily by the combustion of fossil fuels) and volatile organic compounds from fossil fuel and vegetation in the presence of sunlight. Ozone exposures are highest on warm sunny days. Daily summer nitrogen oxide estimates from 1990 indicate utility power plants were the largest source followed by highway vehicles (Figure 5.1). By the year 2010, highway vehicles are estimated to be the largest source of nitrogen oxides.

Daily Exposure Patterns

Daily patterns of ozone exposures are different at low and high elevations. Typically, lower elevation monitoring sites (below 915 meters or approximately 3000 feet) show ozone exposures increasing during the daytime, peaking in late afternoon, and then decreasing during the night and early morning (Figure 5.2a). Nitrogen oxide emissions react with ozone to form nitric acid. At night ozone removed by reaction with nitrogen oxides is not replaced and ozone levels in the atmosphere decrease. This decrease is more apparent in urban areas with local sources of nitrogen oxides. High elevation and exposed ridge-top sites typically lack a strong diurnal pattern since there are few local sources of nitrogen oxides to scavenge ozone from the atmosphere at night (Figure 5.2b and 5.2c). Also, the total ozone exposure is greater for most high elevation and exposed ridge-top sites when compared to low elevation sites. Some high elevation and exposed ridge-top sites exhibit maximum hourly average ozone concentrations between 10:00 pm and 2:00 am due to long-range transport of ozone and its precursors.

Summer Day NO_X Emissions - 8 SAMI States

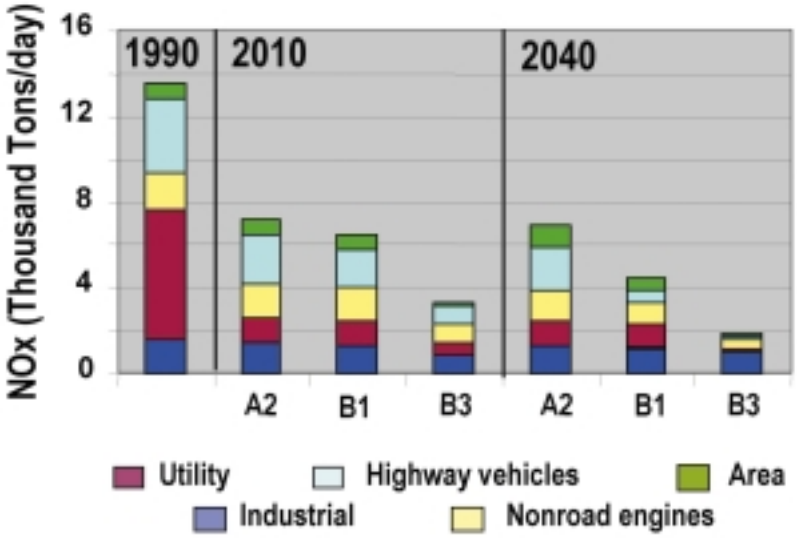


FIGURE 5.1: Comparison of daily summer nitrogen oxide emissions for three years (in 1990, 2010, and 2040) and five source types (area, highway vehicles, nonroad engines, utility, and industrial).

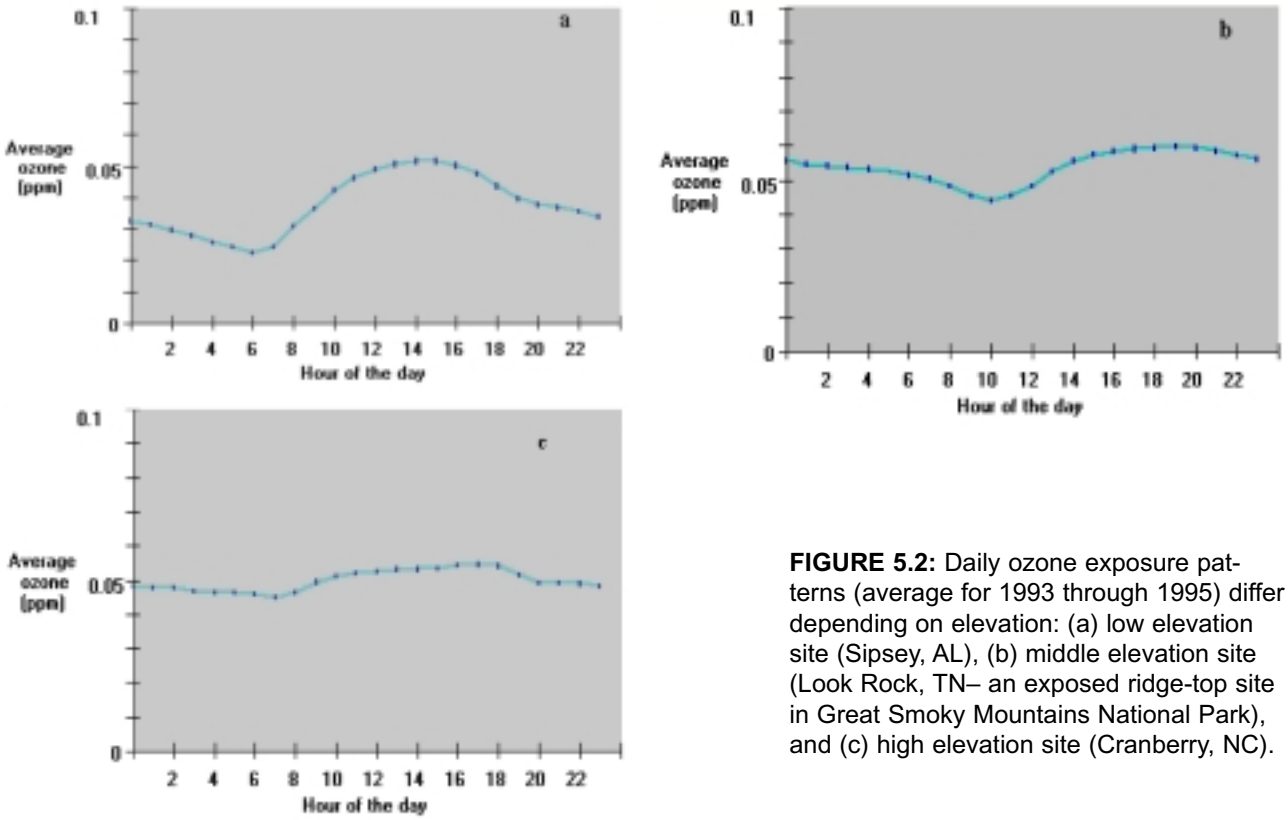


FIGURE 5.2: Daily ozone exposure patterns (average for 1993 through 1995) differ depending on elevation: (a) low elevation site (Sipsey, AL), (b) middle elevation site (Look Rock, TN– an exposed ridge-top site in Great Smoky Mountains National Park), and (c) high elevation site (Cranberry, NC).

Annual Trends and Regional Exposures

Cumulative ozone exposures over the growing season (April through October) are a relevant measure for evaluating ozone effects to vegetation. Growing season ozone exposures vary year to year depending on meteorology. In the past decade, ozone exposures were highest during the hot, dry summers of 1997-1999 (Figure 5.3). Usually, growing season ozone exposures are greatest at higher elevation and ridge-top sites (such as at Big Meadows, Virginia; Cranberry, North Carolina; and Look Rock, Tennessee) than low elevation and valley sites (such as Coweeta, North Carolina; and Parsons, West Virginia).

Growing season ozone exposures also vary across the SAMI region (Figure 5.4). Most of the available ozone monitors within and near the SAMI areas were used in a mathematical extrapolation technique (Lefohn, et al., 1997) to estimate the seasonal (April through October) ozone exposure for 1993 through 1995. Average (1993 – 1995) growing season ozone exposures (W126) across the Southern Appalachians is greatest in south-central West Virginia and north-central Virginia. The lowest ozone exposures were found in the southern portion of the SAMI region in Alabama.

How Does Ozone Impact Vegetation?

Ozone can affect trees, shrubs, herbaceous plants, and agricultural crops. Both high (greater than or equal to 0.100 ppm) and chronic (0.50 to 0.099 ppm) hourly average ozone concentrations can cause damage to sensitive agricultural and forest vegetation species. Ozone enters a plant through specialized cells in the leaf, called stomata, which allow gases to enter and exit the leaf. Inside the leaf, ozone can damage cell walls and chloroplasts. Plant photosynthesis, the process of converting carbon dioxide and inorganic salts to simple sugars, occurs in the chloroplasts. These sugars are food to the plant and, along with other nutrients, are used to produce new leaves, increase height, and expand the root system. When high or chronic ozone exposures result in the damage to chloroplasts, then photosynthesis is reduced and the amount of simple sugars produced and stored in the roots is reduced. Continued ozone exposure and uptake into the leaves can cause reduced growth of leaves, stems, or roots of individual plants.

Stomata open and close in response to changes in environmental conditions. Stomata are known to close when nutrients are lacking, or during periods of low soil moisture availability. Because stomata respond to light and humidity conditions, stomata of some plant species close at night, while in other species a portion of the stomata remain open at night. Because ozone enters a plant through the stomata, environmental factors favoring closure of stomata are associated with reduced damage from ozone. However, these same environmental factors such as low nutrient availability and drought can have a severe negative impact on the health of vegetation.

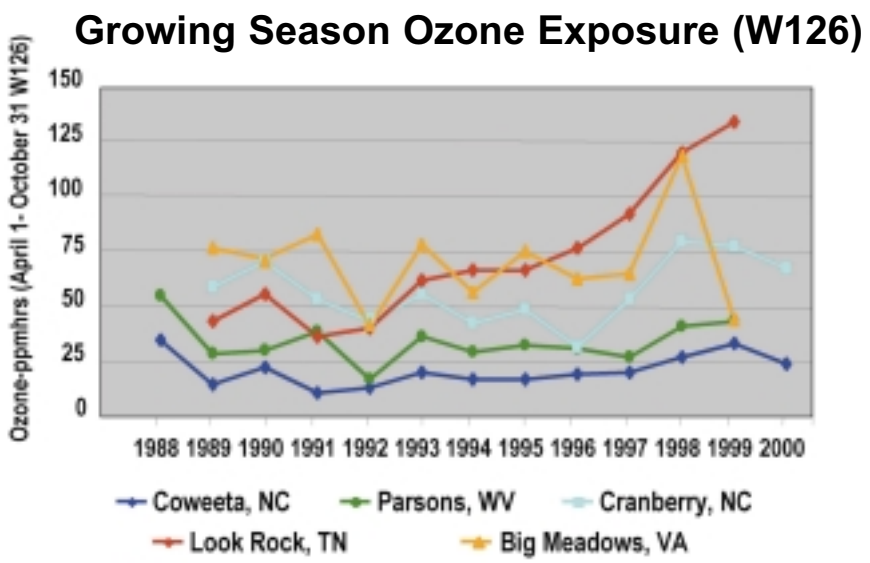


FIGURE 5.3: Growing season ozone exposures at several forested sites in the SAMI region.

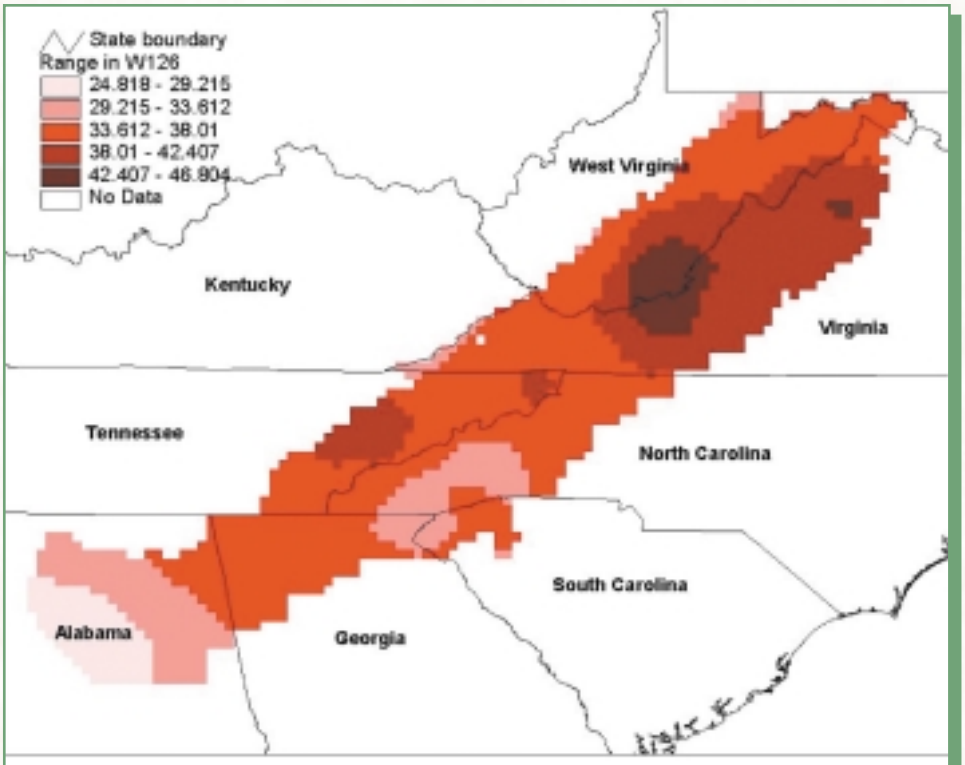


FIGURE 5.4: Average 1993-1995 growing season ozone exposures (W126) across the SAMI region.

Plant species vary in sensitivity and response to ozone. Fast-growing tree species such as black cherry and tulip-poplar are often more sensitive to growth reductions due to ozone than are slower growing species such as northern red oak, eastern hemlock, and red spruce (Figure 5.5). In some sensitive species ozone can kill cells within the leaf and this can be seen as spotting or stippling on the upper leaf surface (Figure 5.6). Foliar symptoms are commonly found throughout the SAMI region, but the amount of foliar symptoms cannot be predicted based upon the ozone exposure (Chappelka, et al., 1996, Lefohn, 1998). High exposures of ozone are known to have the following impacts to vegetation, including:

- Growth and yield reductions in one or more portions of the plant because energy is diverted to protect cells attacked by ozone, rather than into growth of the plant.
- Causes plants to be more susceptible to insect and disease attack, due to chronic stress.

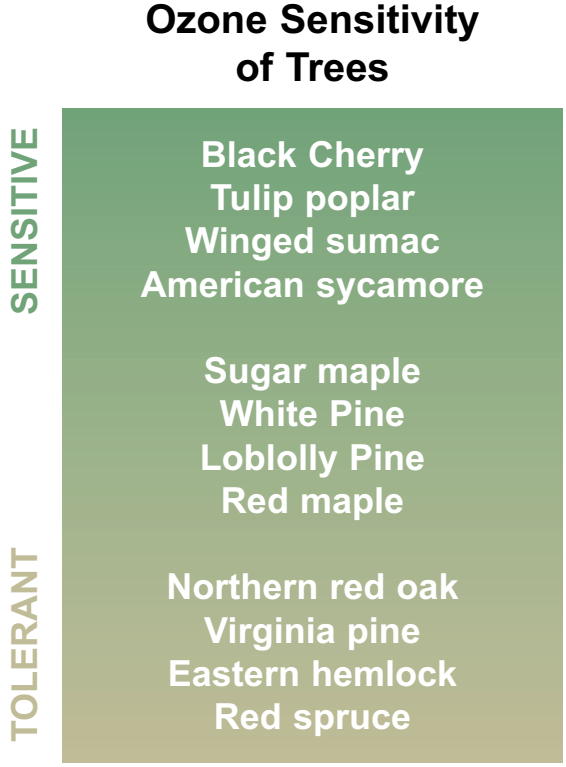


FIGURE 5.5: Ozone sensitivity of tree species based on growth response in controlled exposure studies (Chappelka et al., 1996 and Lefohn, 1998).

- Symptoms may be present on the foliage.
- In forest stands competition between individual trees for light and nutrients may be affected as a result of high levels of ozone exposures. If sensitive genotypes of a species were lost due to competition, then biological diversity would be reduced.

FIGURE 5.6: The dark stipple on the upper leaf surface of two of the yellow-poplar leaves is attributed to ozone exposures.

SAMI'S OZONE ASSESSMENT

Ozone impacts to forest resources have been a concern prior to the SAMI analysis (U.S. EPA 1996). A previous assessment of the Southern Appalachians identified areas of concern for growth losses based on ozone exposure and long-term soil moisture conditions (Lefohn et al., 1997). However, they could not provide regional estimates on ozone impacts to forest growth. The purpose of the ozone portion of SAMI's integrated assessment is to understand how ozone exposures in rural areas of the SAMI region would change under SAMI emission strategies, and how the changes in ozone exposure would affect growth of trees in forests, especially in the Class I areas.

Approach For Ozone Exposures

Hourly average ozone values from April through October (growing season) for each SAMI emission strategy were used in the regional and Class I analyses. It was cost prohibitive to conduct an atmospher-

ic modeling analysis to estimate a growing season of hourly average ozone values for each of SAMI's control strategies. Therefore, SAMI modeled a series of episodes selected to represent the range in ozone exposures that contribute to the cumulative growing season ozone exposure (see Atmospheric Modeling Chapter 2; Odman, et al., 2002a). The SAMI Effects Subcommittee choose the W126 metric (Lefohn and Runeckles, 1987) to examine how the SAMI control strategies would influence the distribution of hourly average ozone during the growing season (Lefohn, 1998). The W126 is a statistic that places a weight on each of the hourly average ozone concentration. The highest ozone concentrations are believed to result in greater ozone damage (U.S. EPA, 1996), therefore the W126 statistic places greater emphasis on the higher hourly ozone exposures. Hourly ozone values below 0.040 ppm are treated as 0, and above 0.040 ppm the weight used to multiply the ozone concentration increases as the ozone concentration increases. The maximum weight of 1.0 is applied to ozone concentrations of approximately 0.100 ppm and greater.

Ozone monitoring data from 13 rural sites (Figure 5.7) were selected to represent ozone exposures in forests across the Southern Appalachian Mountains and the Class I areas. Ozone monitors were selected to represent low (< 500 meters, <1640 feet), middle (500 to 800 meters, 1640 feet to 2625 feet), and high elevation (greater than 800 meters, >2625 feet) exposures (Weinstein, et al., 1992). Ambient hourly ozone data for 1993 to 1995 were used as the basis for forest modeling. Changes in hourly ozone in response to SAMI strategies were derived from the URM-1ATM atmospheric model (Odman, et al., 2002a) and were used to adjust hourly monitoring data (Imhoff and Jackson, 2001).

Approach For Forest Response

Studies conducted for SAMI provided a summary of the known biological responses that could be predicted based upon ozone exposures (Chappelka, et al., 1996 and Lefohn, 1998). For example, foliar symptoms are commonly found throughout the SAMI region, but the amount of foliar symptoms cannot be predicted based upon the ozone exposure. Another study (Weinstein, et

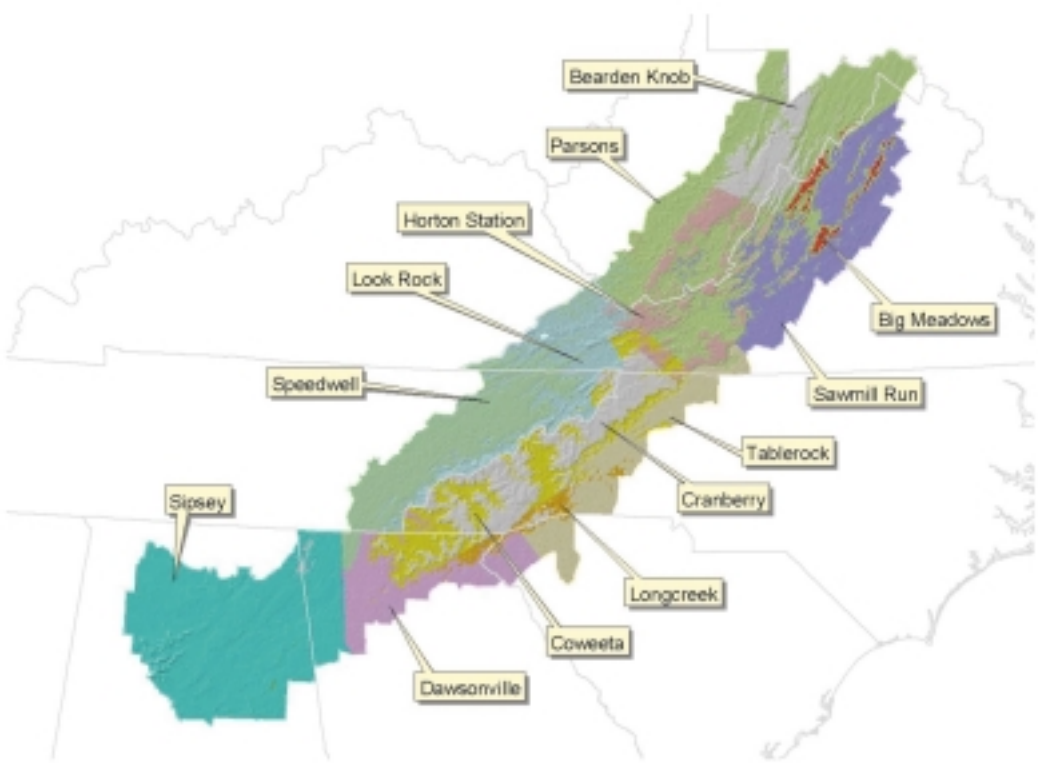


FIGURE 5.7: Location of SAMI ozone regions displayed on top of a digital elevation model.

al., 2000) described an approach used at Great Smoky Mountains National Park, where changes in response of individual trees to changes in ozone exposure were modeled (using the TREGRO model), and the results were used as inputs to a second model (ZELIG) that examined the dynamics of forest growth over time. The TREGRO model tracks plant physiology including water and gas exchange, photosynthesis and carbon use and predicts how an individual tree species' growth in total height, leaf area, and amount of fine roots would respond to changes in ozone (Weinstein, et al., 1991). The results from TREGRO are then used in a second model called ZELIG (Urban, et al., 1991) to examine how the predicted changes for an individual species would affect competition among different tree species in a stand.

The forest effects analysis for SAMI used the TREGRO and ZELIG simulation models. Due to the complexity and costs of the modeling, it was necessary to stratify the SAMI region into 13 different areas (Figure 5.7). Next, USDA Forest Service Forest Inventory and Analysis data (Hansen, et al., 1992) were used to identify the most abundant forest types in each of the 13 areas. Once the most abundant forest types were established, species were identified that had been calibrated for TREGRO and also occupied five percent or more of the basal area of each forest type. A TREGRO and ZELIG simulation was performed for 37-forest types in the SAMI region (Weinstein, et al., 2002).

The TREGRO model was calibrated for the following tree species: sugar maple (Acer saccharum Marsh.), red maple (A. rubrum L.), white ash (Fraxinus americana L.), yellow-poplar (Liriodendron tulipifera L.), loblolly pine (Pinus taeda L.), black cherry (Prunus serotina Ehrh.), and red oak (Quercus rubra L.). These tree species have varying responses to ozone and were selected because: 1) the trees species was known to occur in the SAMI region, and 2) the physiological parameters needed to initialize TREGRO were available. However, there are probably an additional 90 plus tree species in the SAMI region without sufficient information to initialize TREGRO. While some of these species may be sensitive to ozone, the models assumed that ozone had no effect on any of these species (Weinstein, et al., 2002). Furthermore, the SAMI analysis did not include any evaluation of how changing ozone exposures may affect the abundance or presence of forest herbs or shrubs.

Change in tree basal area was selected as the metric to measure potential forest impact from different ozone strategies. Basal area is the cross-sectional area of a single tree stem, including the bark, measured at breast height (1.37 m, or 4.5 feet, above the ground). Basal area (reported in m^2 per hectare) is a common measurement of forest tree density in a stand that is easily obtained from forest inventory data. Basal area is reported for individual tree species or summed for the entire forest stand. As trees grow, basal area increases, and forest stand models such as ZELIG can project annual incremental changes in basal area as an indicator of future growth.

The SAMI regional analysis examined which forest types showed a measurable change in basal area by the years 2010 and 2040. A threshold of three percent change was chosen because it is possible to measure this amount of change in basal area between forest inventories conducted numerous years apart. Changes less than three percent could be due to errors in measurement or the models. SAMI's regional analysis focused on the response (expressed in terms of basal area) of the modeled forest stands and not the responses of individual tree species in the stands. In contrast, the Class I analysis considered whether any of the seven modeled species exhibited measurable changes in the basal area they occupy. Congress has mandated that Class I areas be protected from anthropogenic influences that may alter natural processes in the ecosystems (Wilderness Act of 1964, Public Law 88-577; and Clean Air Act Amendments of 1977, Public Law 95-95). The fate of individual species can be important in determining whether or not natural processes have been affected.

SAMI STRATEGY RESULTS

Ozone Exposures

The highest growing season ozone values (using the W126 metric) at the 13 ozone-monitoring sites occurred at the higher elevation (above 800 meters) sites, and Look Rock (793 meters), an exposed ridge-top site (Table 5.1). Higher growing season ozone values are expected for the remote high elevation sites because nearby sources of nitrogen oxides are not emitted in sufficient amounts to remove ozone during the nighttime hours (see Figure 5.2). Look Rock in the Great Smoky Mountains and Big Meadows in Shenandoah National Parks had the highest average growing season ozone exposures. Look Rock also had the highest average number of hours greater than or equal to 0.100 ppm for 1993 through 1995 (Table 5.1). The Look Rock monitor represents ozone exposures found in western portions of Great Smoky Mountains National Park (at elevations 500m or greater), and Joyce Kilmer/Slickrock Wilderness. The Coweeta monitoring site had the lowest growing season ozone of the monitoring sites. The Coweeta monitoring site is located in a protected valley in a remote section of western North Carolina. The average number of hours greater than 0.100 ppm in 1993-1995 across the SAMI sites varied from 18.3 at Look Rock to 0 at Coweeta (Table 5.1).

TABLE 5.1: Elevation for each of the 13 ozone monitoring sites used in the SAMI analysis, and the 1993 through 1995 average (Base) for growing season ozone (W126) and numbers of hours greater than 0.100 ppm ozone (N100).

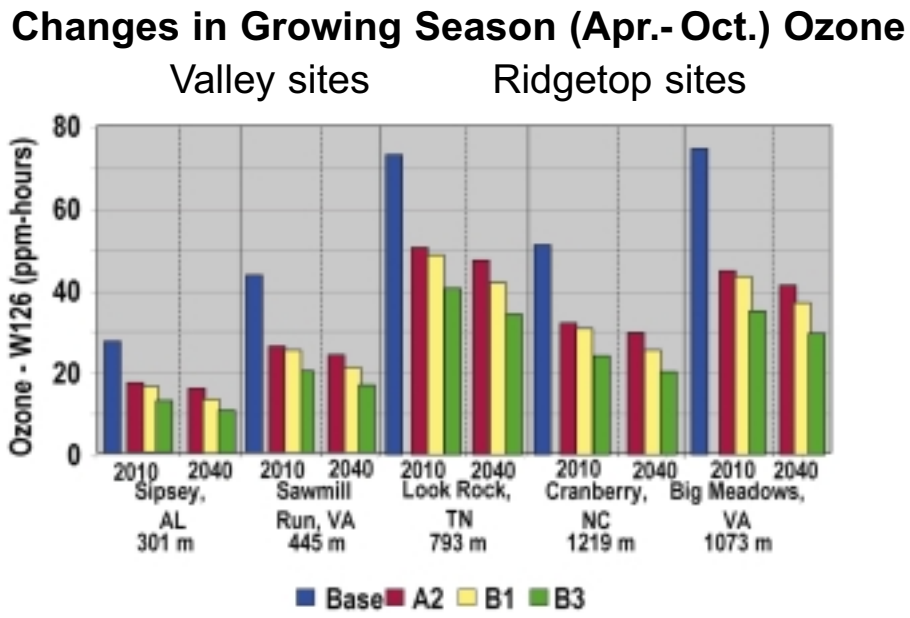
Site	Elevation (meters)	Elevation Category	Base W126 (ppm – hours)	Base N100 (# of hours)
Sipsey, AL	301	Low	27.4	1.7
Dawsonville, GA	372	Low	27.8	4.0
Table Rock, NC[1]	415	Low	30.9	0.7
Speedwell, TN	400	Low	34.3	7.3
Sawmill Run, VA[1]	445	Low	43.4	12.7
Coweeta, NC	686	Middle	18.3	0.0
Longcreek, SC	658	Middle	32.3	1.3
Parsons, WV	505	Middle	33.3	3.3
Look Rock, TN	793	Middle	73.0	18.3
Cranberry, NC	1219	High	50.7	1.3
Bearden Knob, WV	1175	High	63.4	1.3
Horton Station, VA	972	High	67.8	0.0
Big Meadows, VA	1073	High	74.9	1.7

[1] No ozone monitoring was conducted in 1995 at Table Rock, NC and Sawmill Run, VA. 1995 data from Coweeta, NC, and Parsons, WV, respectively were substituted for the missing data (Imhoff and Jackson, 2001; Weinstein, et al., 2002).

Ozone Response To SAMI Strategies

The SAMI emissions strategies showed large percentage reductions in summer-time nitrogen oxide emissions from the 1990 emission estimates (see Figure 5.1). A reduction in nitrogen oxide emissions throughout the SAMI region resulted in reductions of ozone exposures in forested areas (Figure 5.8). The growing season ozone exposure decreased for the A2 strategy in 2010 between 29 and 48 percent from the 1993-1995 levels, and in 2040 between 34 to 52 percent (Figure 5.9). The A2 strategy included summer-time nitrogen oxide reductions in the Eastern United States. The B1 strategy includes small additional reductions in NO_X from highway vehicles within the eight SAMI States only (Figure 5.1). As would be anticipated, the percentage reduction in ozone from 1993-1995 for the B1 strategies was not much larger than seen for the A2 strategy. The B1 strategy in 2010 resulted in a 32 to 51 percent reduction in growing season ozone exposures, and in 2040 the range in reduction was 41 to 55 percent (Figure 5.9). The B3 strategy represented the most aggressive control strategies with larger summer-time nitrogen oxide reductions by 2040 from all source categories (Figure 5.1). Compared to 1990 emissions levels, reductions in the growing season ozone for the B3 strategy in 2010 ranged from between 43 and 57 percent, and for 2040 ranged from 51 to 67 percent (Figure 5.9). The number of hours greater than or equal to 0.100 ppm was reduced at all sites in response to SAMI strategies.

The TREGRO model uses hourly meteorological, soil moisture, and nutrient status information to determine if the ozone is likely to penetrate into the stomata (Weinstein, et al., 2002). The SAMI strategies reduce the number of hours with ozone concentrations greater than or equal to 0.060 ppm, 0.080,



Growing season ozone higher at ridgetop sites than valley sites.

FIGURE 5.8: Cumulative growing season (April-October) ozone exposures (W126) in 1993-1995 and in response to SAMI strategies at example forested sites in the SAMI's region.

Changes in Growing Season Response to SAMI Strategies

1993 - 1995 to 2010 and 2040

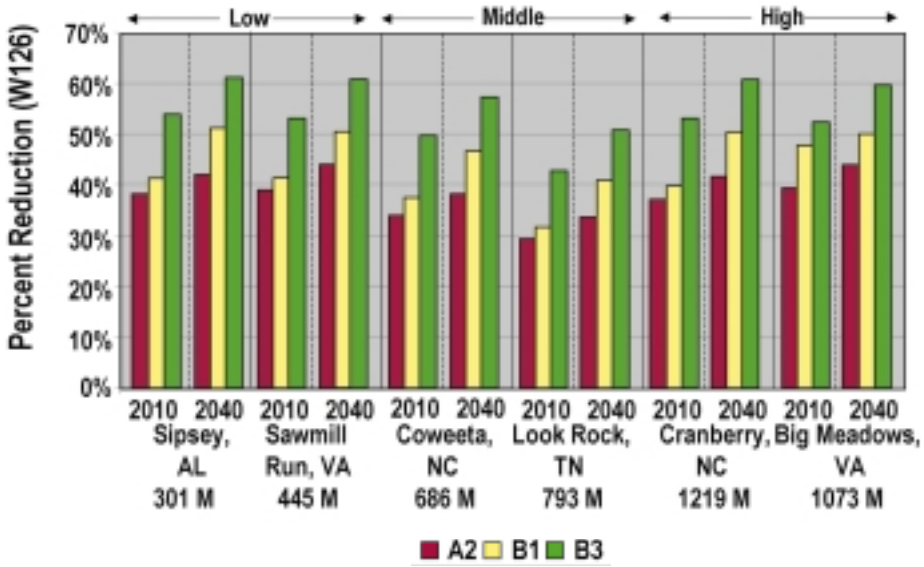


FIGURE 5.9: Percent reduction in the growing season ozone exposures (W126) from the 1993 through 1995 average (Base) in response to SAMI strategies at example low, middle, and high elevation monitoring sites.

TABLE 5.2: Three year totals or averages shown by SAMI strategies in 2040 for Cranberry, North Carolina, and Sipsey, Alabama, ozone-monitoring sites. Data presented includes: number of hours greater than or equal to (>=) 0.060 ppm, 0.080 ppm, 0.100 ppm, average W126, and maximum average hourly ozone values in the 1993-1995 record.

Monitoring Site	Strategy	Number of hours > = 0.060 ppm	Number of hours > = 0.080 ppm	Number of hours > = 0.100 ppm	Average W126 (ppm-hour)	Maximum 1-hour average (ppm)
Cranberry, NC	1993-1995	2846	153	4	51.3	0.106
	2040 A2	1136	27	0	29.6	0.094
	2040 B1	790	17	0	25.2	0.090
	2040 B3	470	12	0	19.9	0.08
Sipsey, AL	1993-1995	1490	153	5	27.4	0.112
	2020 A2	640	17	0	15.9	0.098
	2040 B1	469	6	0	13.3	0.092
	2040 B3	251	2	0	10.6	0.085

and 0.100 ppm (Table 5.2). As illustrated in Figures 5.10 for a high elevation site (Cranberry, North Carolina) and Figure 5.11 for a low elevation site (Sipsey, Alabama) the number of hours with ozone concentrations equal to and above 0.050 ppm are reduced and the number of hours with ozone concentrations between 0.030 and 0.049 ppm are increased as larger nitrogen oxide reductions are implemented. Reductions in the higher ozone concentrations are likely to reduce the risk of damage to forest trees if ozone penetrates into the leaf. However, there is a point at which further reductions in nitrogen oxides will not significantly reduce the ozone exposures (Lefohn, et al., 1998). Most likely this resistance to a further reduction in ozone exposures is a result of natural background levels impeding further decreases in ozone exposures with increasing control strategies.

REGIONAL FOREST ANALYSIS

The purpose of the regional analysis was to examine whether changes in ozone exposures could measurably affect total stand basal area. The SAMI region covers approximately 45,499,017 acres and 46 percent of the total forested area (32,360,457 acres) was represented in the modeling analysis (Table 5.3). The only forest types included in the analysis were those where one or more of the seven TREGRO modeled species were considered to occupy a "significant" portion of the stand basal area.

TABLE 5.3: A summary of the area within the SAMI region modeled in the ozone analysis.

Ozone Region	Total Area (acres)	% of Total SAMI Area	% of Total Area Occupied By Forests	# OF FOREST Types Analyzed	% of Forested Area Modeled
Bearden Knob	1,587,865	3	88	3	51
Big Meadows	276,752	1	98	3	59
Coweeta	2,671,151	6	85	3	50
Cranberry	3,388,729	7	90	2	47
Dawsonville	2,588,867	6	81	3	58
Horton Station	1,983,225	4	82	3	42
Longcreek	515,451	1	85	2	21
Look Rock	3,122,356	7	80	3	68
Parsons	8,619,342	19	68	3	61
Sawmill Run	4,412,218	10	43	3	64
Sipsey	8,952,186	20	75	2	28
Speedwell	4,629,913	10	46	1	13
Table Rock	2,750,964	6	76	2	35

Hourly Ozone Distributions

Cranberry, NC

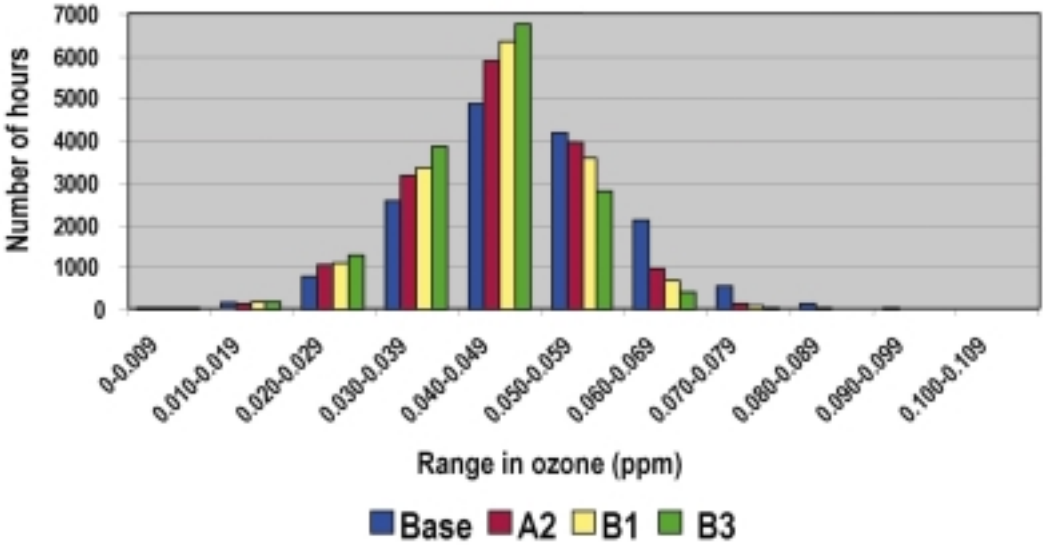


FIGURE 5.10: Frequency distributions at the Cranberry, North Carolina, monitoring site comparing hourly ozone data for April-October, 1993 through 1995, with hourly data projected for the SAMI strategies in 2040.

Sipsey, AL

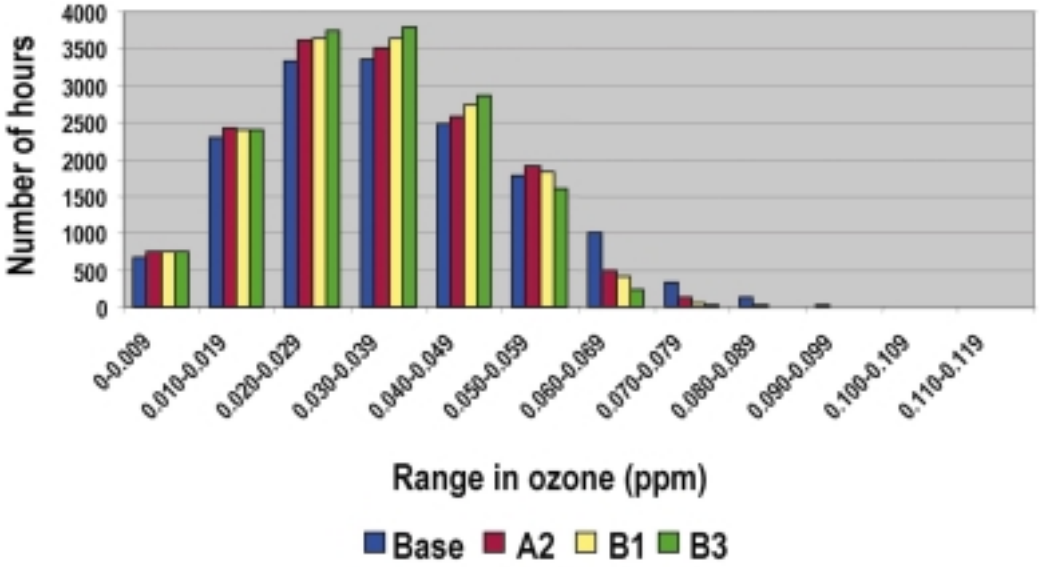


FIGURE 5.11: Frequency distributions at the Sipsey, Alabama, monitoring site comparing hourly ozone data for April-October, 1993 through 1995, with hourly data projected for the SAMI strategies in 2040.

Regional Forest Response To SAMI Strategies

The changes in basal area for individual species between the Base (1993 – 1995) and the 2040 SAMI strategies are small (Figure 5.12), except for loblolly pine in the Sipsey region. The results for 11 of the 13 regions predicted changes of less than 3 percent in total stand basal area for each of the forest types in response to SAMI strategies. For these forests, modeled responses were below the level that could be measured under field conditions. For forest types showing significant results (greater than three percent change from Base), there was little difference between the A2 and B1 strategies (Table 5.4). This was expected since the percent reductions in the growing season ozone values were similar (Figure 5.8) for these two strategies. By 2010, there could be a measurable change in basal area in the loblolly pine-hardwood forest type in the Sipsey region if ozone exposures were reduced to levels under the A2 or B1 strategies, and further increases in stand basal area under the B3 strategy. By 2040, implementation of the A2 or B1 strategies would increase basal area in two forest types in the Sipsey region, and one forest type in the Cranberry region. Implementation of the B3 strategy would produce even greater measurable changes in two forest types in the Sipsey region, and two forest types in the Cranberry region (Table 5.4).

Class I Response To SAMI Strategies

Seven of the 10 Class I areas had sufficient information on forest types to use results from the regional simulations to analyze how basal area will change for individual species as a result of the three SAMI strategies. Positive and negative responses of three percent or greater in basal area were found for several species/forest type combinations at all seven of the Class I areas (Table 5.5). Changes in species basal area of three percent or more are considered significant since results of this level could be measured in forest stands by 2010 or 2040. Congress has mandated that Class I areas be protected from anthropogenic influences that may alter natural processes in the ecosystems (Wilderness Act of 1964, Public Law 88-577; and Clean Air Act Amendments of 1977, Public Law 95-95). The projected changes of three percent or more in the species basal area indicate that ozone exposures may be having an adverse impact to the natural processes in these Class I areas. In general, as ozone levels are reduced by the SAMI strategies, fewer species are likely to experience reductions in basal area due to ozone (Table 5.5).

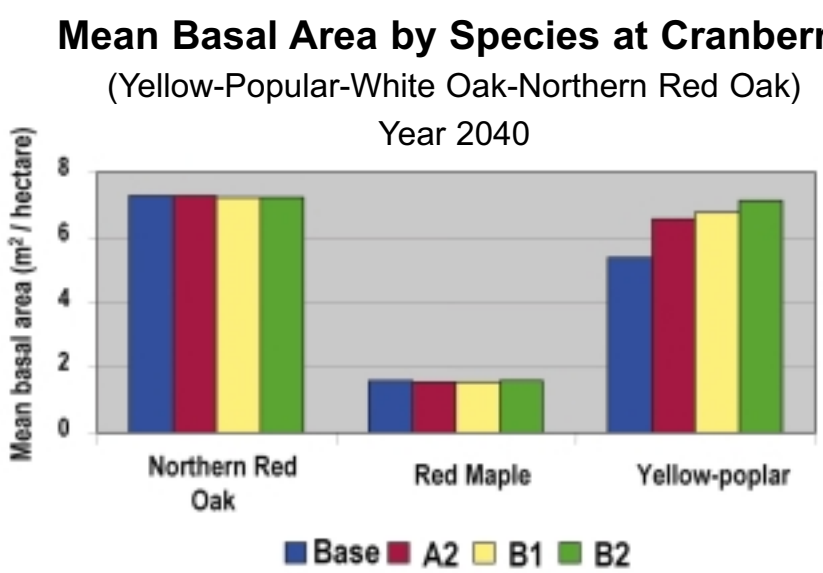


FIGURE 5.12: In response to SAMI strategies, changes in basal area of species with known sensitivity to ozone are projected to be small.

TABLE 5.4: Forest types with modeled measurable (positive and/or negative) percentage changes (greater than 3%) in basal area (BA) between the Base (1993 – 1995) and A2, B1, and B3 SAMI strategies (Weinstein, et al., 2002)

Year	Ozone Region	Forest Type	Acres	Net % Change in BA from Base to A2	Net % Change in BA from Base to B1	Net % Change in BA from Base to B3
2010	Sipsey, AL	Loblolly pine-hardwood	715,440	9.3	9.5	12.4
2040	Sipsey, AL	Loblolly pine-hardwood	715,440	16.5	16.4	22.7
2040	Sipsey, AL	Loblolly pine	1,171,358	3.8	3.8	5.2
2040	Cranberry, NC	Yellow poplar-white oak-northern red oak	423,759	4.6	5.7	8.2
2040	Cranberry, NC	Mixed Central Hardwood	1,004,915	2.3	2.5	3.1

TABLE 5.5: Summary of the number of modeled species predicted to show measurable increasing and decreasing changes in percent1 of basal area by the year 2040, comparing SAMI strategies Base (1993 – 1995) to A2, B1, and B3 in the seven SAMI region Class I areas.

CLASS I AREA	% of Class 1 Area	Ozone Region	# Of Forest Types Repre-sented	# of Species Modeled	# of Species Changing Between Base and A2		# of Species Changing Between Base and B1		# of Species Changing Between Base and B3	
					# increasing and range	# decreasing and range	# increasing and range	# decreasing and range	# increasing and range	# decreasing and range
Great Smoky Mountains National Park (520,977 acres)										
North Carolina	48	Cranberry	2	5	3 10.2 – 16.2	0	3 7.4 – 17.8	2 -3.1 & -3.5	4 6.9 – 20.1	0
Tennessee	48	Look Rock	2	5	3 3.9 – 8.9	3 -6 to -13.7	1 12.2	1 -5.7	2 4.4 & 8.5	2 - -4.3 & 4.6
Shinning Rock Wilderness (18,500 acres)	71	Cranberry	3	3	2 10.2 & 21.8	0	3 7.4 – 25.5	2 -3.5 & -5.0	3 7.8 – 32.6	0
Joyce Kilmer/ Slickrock Wilderness (17,013 acres)	76	Cranberry	3	3	2 10.2 & 21.8	0	3 7.4 & 25.5	2 -3.5 – -5.0	3 7.8 – 32.6	0
Linville Gorge Wilderness (10,975 acres)	10	Cranberry	2	3	2 10.2 & 21.8	0	3 7.4 – 25.5	2 -3.5 & –5.0	3 7.8 – 32.6	0
Shenandoah National Park (197,060 acres)	55	Big Meadows	3	5	2 10.2 & 14.3	3 -5.4 to -20.2	3 3.3 – 9.8	3 -3.4 to –10.7	4 4.3 – 22.6	2 -8.3 & -13.6
James River Face Wilderness (8,886 acres)	77	Sawmill Run	1	3	1 3.9	0	0	0	0	0
Sipsey Wilderness (25,906 acres)	70	Sipsey	2	3	2 5.5 & 53.8	1 -87	2 5.6 & 53.2	1 -95.7	2 7.8 & 73.8	1 -100

[1] The numbers in the last six columns represents and effect on a species in one or more forest types.

UNCERTAINTIES

An asterisk system was used to describe the confidence about how a factor influences SAMI's ozone assessment (Weinstein et al., 2002). The findings are listed below. The more asterisks that are shown the greater confidence in the factor:

	1. Assemble ozone and meteorology scenarios
* * * *	Selection of ozone data from 1993 to 195 for base case.
* * * * *	Use of auxiliary data and regressions to fill gaps in ozone and met data.
* * *	Extrapolation from event-based regional scenarios to hourly inputs for TREGRO.
	2. Extrapolate from experimental data to mature tree response
	TREGRO parameterization:
* * * *	Size of internal pool of available carbon.
* * * *	Root turnover rate.
* * *	Carbon budget for some species at some sites.
* * * *	Assumption of linear response to cumulative ozone dose.
* * *	Characterization of ozone response based on single or few studies.
* * * *	Non-linearity in TREGRO predicted response to ozone.
	3. Extrapolate from individual trees to forest stands
* * * *	Ability of gap models to capture important forest dynamics.
* * * * *	Details of linkage between TREGRO and ZELIG.
	ZELIG parameterization:
* * *	Initial stand structure.
* * * * *	Variation in dynamics among simulated plots.
	4. Extrapolate simulated effects on stand growth to a large region.
* * *	Regional coverage of data on soil texture and nitrogen availability.
* * *	Regional coverage of data on spatial patterns of ozone exposure.
* * *	Use of a single stand to represent responses across a large region.
	5. Factor not included in Analysis.
* * * *	Genetic variability in response to ozone.
* * * * *	Representation of sites that may be especially vulnerable to ozone.
* * * * *	Effects of forest management.
* * * *	Interaction of drought and ozone stress (included in analysis to a limited extent.
* * *	Adequacy of data on the ozone response of common tree species.

KEY FINDINGS

1. The SAMI A2 and B1 strategies reduced growing season ozone by similar amounts while the B3 strategy had greater percent reductions in ozone exposures.

2. Each of the SAMI emission strategies reduced the frequency of hours greater than or equal to 0.100 ppm and 0.050 ppm of ozone, and increased the number of hours in the 0.030 to 0.049 ppm range. These lower concentrations are unlikely to cause significant impact to forest trees.

3. Shifts in competition between species within forest stands appears to be the major ozone effect.

4. The greatest changes in basal area in SAMI forest areas were between the Base and the A2 strategies. The B1 and B3 strategies do not result in measurable improvements in basal area over the A2 strategy or the Base for most SAMI areas. However, there were measurable improvements in basal area for the loblolly pine-hardwood forest type with a maximum of 22.7 percent for the B3 strategy in comparison to the Base in 2040. Improvements were also predicted to occur in the Cranberry region.

5. The changes in tree species basal area indicates that ozone exposures may be having an adverse impact to the natural processes in Class I areas. For the species used in the TREGRO analysis at the Class I areas there were fewer species with negative basal area response and a wider range in the positive response with the Base to B3 results in comparison to the Base to A2 or B1.

6. Forests are dynamic and forest composition changes over time. In response to ozone changes under SAMI strategies, changes in total basal area of forests in the SAMI region are likely to be small. Forest types are unlikely to shift in abundance. Tree mortality in direct response to ozone is not expected.

ACID DEPOSITION AND THE EFFECTS ON STREAMS AND FORESTS

INTRODUCTION

SAMI's acid deposition assessment characterized the current status of streams and forests in the southern Appalachian Mountains, and projected stream and forest response to changes in future acid deposition resulting from emissions reduction strategies. The forest assessment evaluated 14 forest stands and the effects of deposition to three forest types within those stands: spruce-fir, northern hardwood, and mixed hardwood. The stream assessment evaluated effects of acid deposition levels on 155 streams, which represented a range of stream, soil, geology, forest cover, and topographic conditions.

SAMI Acid Deposition Assessment Objectives

- Characterize current acid sensitivity of streams and forests in SAMI region.
- Use Urban to Regional Multiscale-One Atmosphere (URM) model to project future changes in deposition in response to SAMI strategies.
- Use two well-accepted watershed models to project stream and forest responses to future deposition under SAMI strategies (Model of Acidification of Groundwater in Catchments, MAGIC, and Nutrient Cycling Model, NuCM)
- Estimate changes in the percentage of streams suitable for supporting brook trout to support socioeconomic analyses of fishing impacts.

What Is Acid Deposition?

Acid deposition, sometimes also called acid rain, refers to the delivery of strong acid ions (sulfate and nitrate) and acid-forming ions (ammonia) from the atmosphere to the surface of the earth. Deposition occurs via several pathways. Precipitation, in the form of rain, snow, or hail, contributes to what is collectively called wet deposition. Dry deposition of fine particles and gases from the atmosphere also occurs on the earth's surface. At most low elevation sites in the Eastern United States, wet and dry deposition have similar contributions to total annual deposition (Baumgardner et al., 2002). Cloud water interception occurs when water droplets from clouds deposit on forest canopies and other surfaces and is an additional source of acid deposition in many mountainous forests. In the SAMI region, cloud water interception increases with increasing elevation, beginning around 3500 ft in elevation. Above 5000 feet elevation in the Great Smoky Mountains, forests may be immersed in clouds for 30-50% of the year (Johnson and Lindberg, 1992). At elevations below

3500 feet, fog may be an additional but minor (usually <10% of the total) source of deposition. These elevational limits for cloud interception are lower for mountains farther north in Virginia and West Virginia.

The predominant chemical components of wet and cloud water deposition are sulfate (SO_4), nitrate (NO_3), hydrogen (H), ammonium (NH_4), and base cations, such as calcium (Ca) and magnesium (Mg). In dry deposition, both sulfate (SO_4) particles and sulfur dioxide (SO_2) gas are important sources of sulfur. Nitric acid gas (HNO_3), ammonia gas (NH_3), and ammonium (NH_4) in fine particles are the predominant nitrogen species in dry deposition. Base cations occur as both fine and coarse soil particles in the atmosphere.

Deposition Trends

Sulfate deposition has been reduced across much of the Eastern United States since 1990 in response to sulfur dioxide emissions controls under the acid rain rules of the 1990 Clean Air Act Amendments (Lynch, et al., 2000a; Lynch, et al., 2000b; Driscoll, et al., 2001). Sulfate wet deposition at Parsons, WV and Big Meadows, VA has decreased since 1990 (Figure 6.1A), but has not changed significantly at other monitoring sites in the SAMI region (National Atmospheric Deposition Program, 2002).

These observed deposition trends are consistent with emissions trends. Sulfur dioxide emission reductions were required by January 1, 1995 from 110 coal-fired electric utility plants under Phase I of Title IV of the 1990 Clean Air Act Amendments. These Phase I facilities are concentrated in the States surrounding the Ohio River and include utility units in Alabama, Georgia, Kentucky, Tennessee, and West Virginia. Twenty-one utility units in these five SAMI States installed scrubbers after 1990 (E. H. Pechan & Associates, 2002). Other utility units in the SAMI States were required to meet sulfur dioxide emissions limits beginning January 1, 2000. Utilities expect to switch to lower sulfur fuels or to purchase sulfur dioxide emissions credits from the national sulfur dioxide trading system to meet sulfur dioxide limits. Sulfur dioxide emissions have grown since 1990 in some SAMI States (VA, NC).

Nitrogen dioxide emissions from utilities and large industries have decreased since 1990 in response to the 1990 Clean Air Act Amendments (E. H. Pechan & Associates, 2002). Emissions from highway vehicles

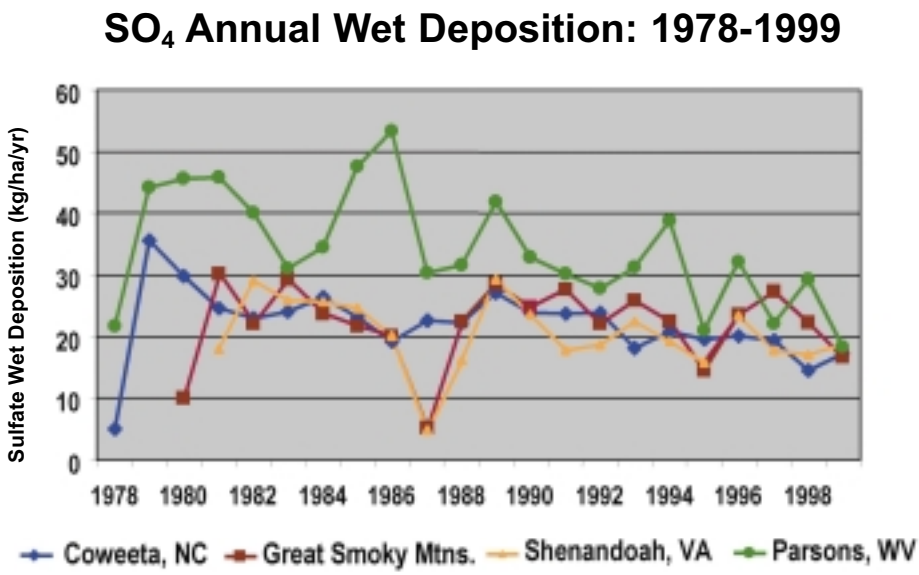


FIGURE 6.1A: Annual average sulfate at monitoring sites in the SAMI region operated by the National Atmospheric Deposition Program

have increased over this same period due to increased vehicle use. Nitrate deposition has decreased at Parsons, WV, but has not changed since 1990 at other sites in the SAMI region (Figure 6.1B). Ammonia emissions and ammonium deposition have increased at most sites in the Eastern U.S. since 1990; trends are not as clear at monitoring sites in the SAMI region (Figure 6.1C). Base cation deposition has decreased significantly since the 1980s. Similar trends are observed for dry deposition of sulfur, nitrogen, and base cation components (Baumgardner et al., 2002).

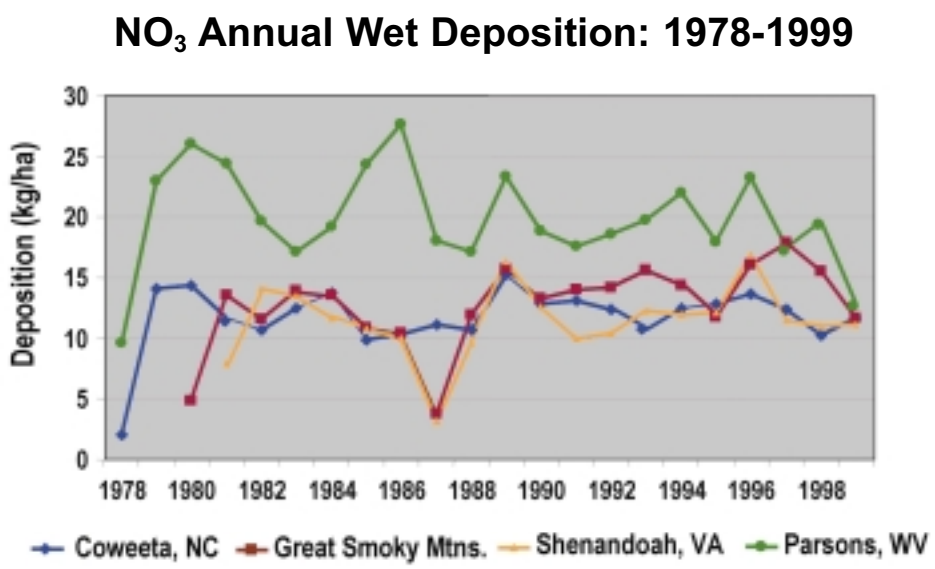


FIGURE 6.1B: Annual average of nitrate at monitoring sites in the SAMI region operated by the National Atmospheric Deposition Program

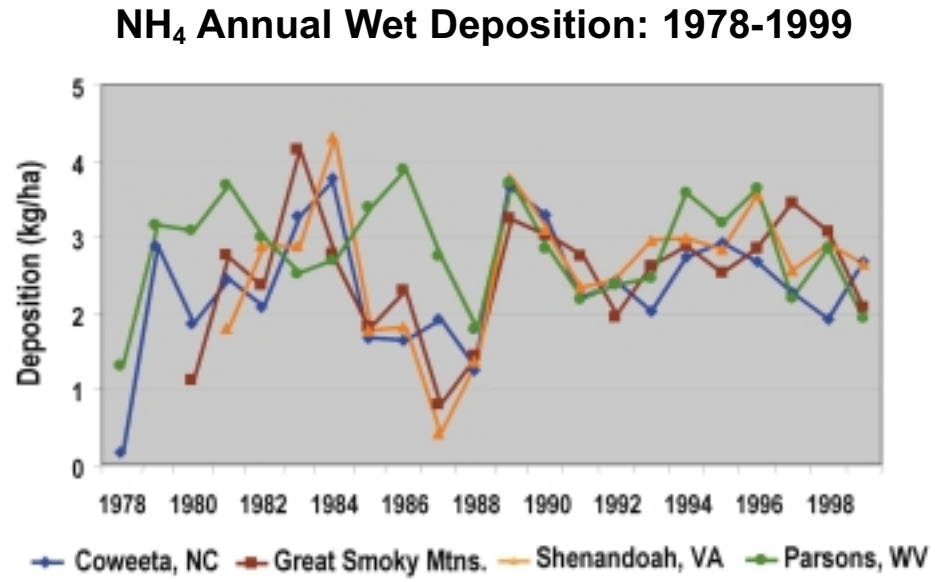


FIGURE 6.1C: Annual average of ammonium wet deposition at monitoring sites in the SAMI region operated by the National Atmospheric Deposition Program

Overall, the highest wet deposition of sulfur and nitrogen in the SAMI region occurs in West Virginia and Virginia and in high elevation areas in eastern Tennessee and western North Carolina.

Current Sensitivity Of Streams And Forests To Acid Deposition

Acid deposition has reduced the buffering capacity (ability to neutralize acids) and increased the acidity of soils and streams in some forested watersheds in the southern Appalachian Mountains (Baker, et al., 1990; Herlihy, 1996; Eagar et al., 1996). The affected streams generally occur in upland and mountainous areas in the Appalachian Plateau region of West Virginia, the ridge and valley region of Virginia, and higher elevations in eastern Tennessee and western North Carolina (Sullivan, et al., 2002a). Soils and streams in many of these watersheds are naturally acidic. By lowering stream pH, acid neutralizing capacity, and in some cases base cation concentrations, acid deposition has reduced the ability of certain aquatic life, including native brook trout and other fish, to survive or maintain stable populations in affected streams.

Stream Acid Neutralizing Capacity (ANC) is one indicator of the suitability of a stream to support fish and is measured in microequivalents per liter (μeq/l). Stream acid neutralizing capacity reflects the combined impact of the concentrations of sulfate and nitrate anions, organic acids, base cations, aluminum, and hydrogen ions in streamwater. Streams can be naturally acidic due to organic acids and poorly buffered soils. Streams for which the annual average acid neutralizing capacity is less than 0 μeq/l throughout the year are considered **chronically acidic.** Streams that have an annual average acid neutralizing capacity below 20 μeq/l are likely to drop below 0 μeq/l during storm events. These streams are considered to be **episodically acidic.** Streams with annual average acid neutralizing capacity between 20 and 50 μeq/l can experience episodic events with acid neutralizing capacity less than 20 μeq/l.

Stream acid neutralizing capacity levels can be used to define streams that are suitable to support brook trout (Table 6.1) and can also be used to predict the numbers of fish species that might be present in streams. Brook trout are more tolerant of acid stream conditions than other fish species. Factors other than stream acid neutralizing capacity (for example, stream flow rates, stream bottom substrate) also influence fish habitat and not all streams with suitable acid neutralizing capacity will be suitable for brook trout. At stream acid neutralizing capacity less than 20 μeq/l, the ability of native brook trout to survive or maintain stable populations is compromised. The relationship between stream acid neutralizing capacity and fish survival has been best documented for brook trout. Research at Shenandoah National Park suggests that one fish species is lost for approximately every 21 μeq/l decrease in acid neutralizing capacity (Sullivan, et al., 2002a).

TABLE 6.1: Stream Acid Neutralizing Capacity (ANC) as an indicator of stream suitability to support brook trout (Sullivan, et al., 2002a)

Stream ANC Class	Biological Response
ANC < 0 μeq/l	Acidic, unsuitable for brook trout
ANC > 0 to < 20 μeq/l	Highly sensitive to chronic and episodic acidification; marginal benefit for brook trout
ANC >20 to < 50 μeq/l	Potentially sensitive to chronic and episodic acidification; brook trout status indeterminate, site specific factors influence suitability for brook trout
ANC >50 to < 150 μeq/l	May be sensitive to episodic acidification in future; suitable for brook trout but may be poor habitat for some other aquatic life

Several factors influence the responsiveness of forests and streams to acidic deposition.

- **Bedrock geology** determines the ability of a watershed to neutralize acids. Base cations in rocks and minerals are slowly released to the soils. Limestone is a rich source of base cations and watersheds underlain by limestone have low risk of acidic soils and streams. In contrast, most sandstones (and related rock types) have a low supply of base cations. Many of the watersheds on the Appalachian Plateau of West Virginia are underlain by sandstone and related rock types, and this region has more acidic streams than other parts of the SAMI region.
- **Soil base** cation supply and soil retention of sulfate anions are two important factors that control soil acidity. In acidic soils, aluminum can be released into soil solutions and transported to streams at levels that are toxic to plants and fish. Many of the soils on the Appalachian Plateau in West Virginia are acidic and have low base cation supply and low ability to retain sulfate. In contrast, soils on the Blue Ridge Province in western North Carolina and northern Georgia have greater capacity to retain sulfate and higher base cation supplies. Therefore, fewer soils and streams in the Blue Ridge Province are acidic.
- At **elevations** above about 900 meters (3000 feet), watersheds are smaller and steeper, deposition is higher and streams are more likely to be chronically or episodically acidic.
- **Forest type** can be an indicator of the acidity of soils and streams. Streams draining spruce-fir forests are more likely to be acidic than those draining northern hardwood and mixed hardwood forests.

Area in SAMI region most likely to have streams with low Acid Neutralizing Capacity (ANC)

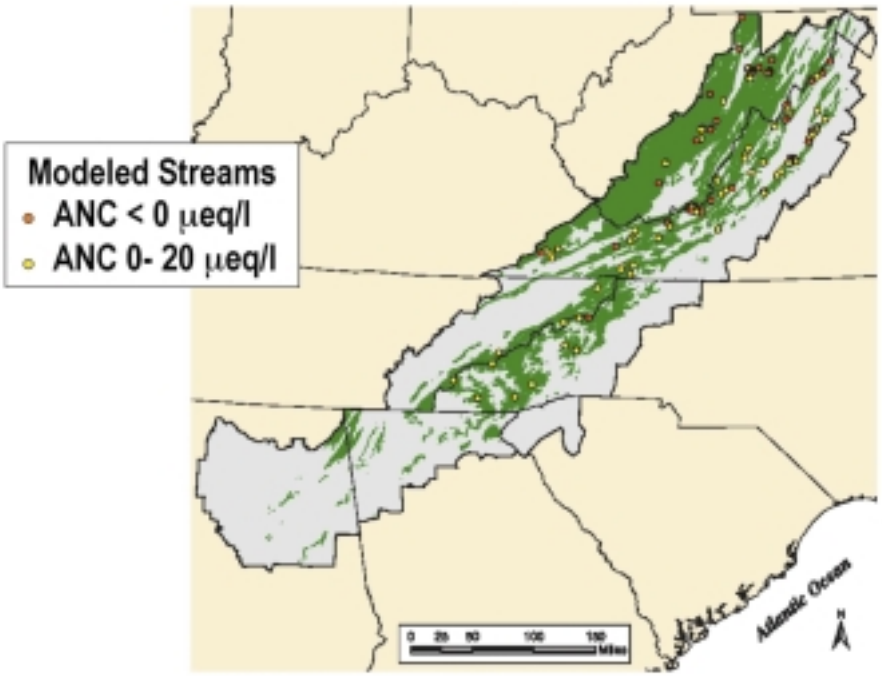


FIGURE 6.2: Areas in the SAMI region most likely to have streams with acid neutralizing capacity (ANC) LESS THAN 20 microequivalents per liter (µeq/l).

- **Previous land use or disturbance** (e.g. forest harvesting, fire, or insect or disease outbreak) can also contribute to acidity of soils.

SAMI's landscape analyses (Sullivan, et al., 2002a) established that underlying bedrock geology dominated by sandstone or related rock types or elevations greater than 1000 meters (3250 feet) could be used to identify areas of the SAMI region most likely to have acidic streams. Ninety five percent (95%) of the known streams with acid neutralizing capacity less than 0 μeq/l and 88% of the streams with acid neutralizing capacity less than 20 μeq/l occur in the areas highlighted in green in Figure 6.2. Not all streams in this areas have acid neutralizing capacity less than 20 μeq/l. Streams with acid neutralizing capacity greater than 20 μeq/l occur throughout the SAMI region.

Based on the 1985-86 National Stream Survey (Kaufmann, et al., 1988), 3% of the total stream length in the SAMI region has stream acid neutralizing capacity less than 20 μeq/l and 7% has stream acid neutralizing capacity less than 50 μeq/l (Figure 6.3). In the SAMI region, streams with acid neutralizing capacity less than 20 μeq/l are most likely to occur in headwater systems draining higher elevation watersheds or watersheds overlying base-poor geology (Sullivan et al., 2002a). These headwater systems are habitat for cold-water fish such as brook trout, that are at risk from stream acidification. If stream conditions are otherwise suitable for brook trout habitat, increasing acid neutralizing capacity in streams with acid neutralizing capacity less than about 50 μeq/l would likely improve survival and/or stability of brook trout populations.

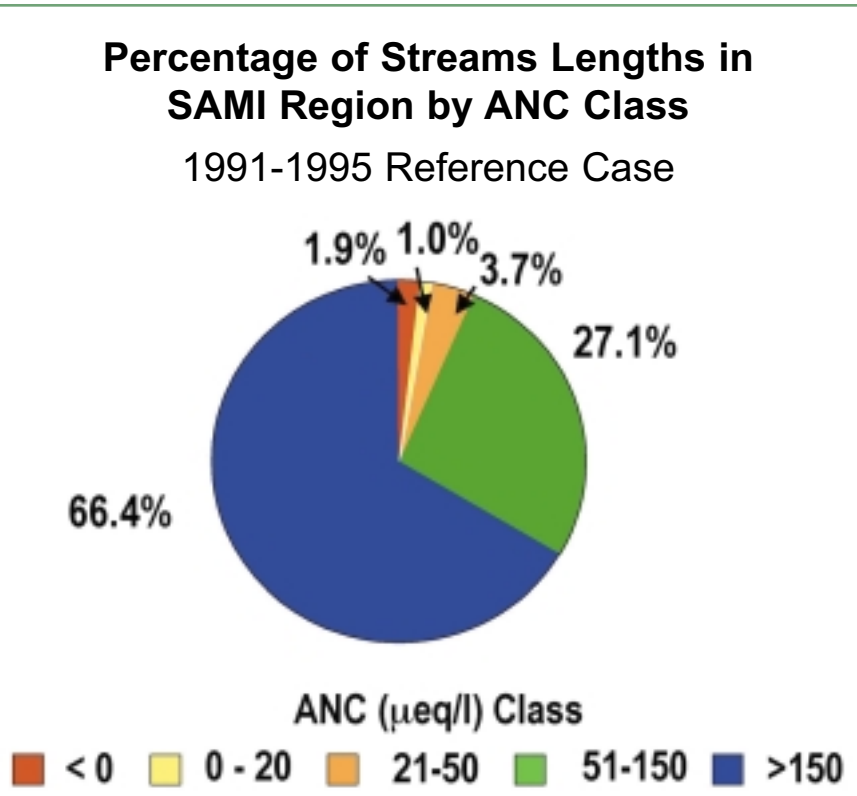


FIGURE 6.3: Percentage of stream lengths in SAMI region in each of five classes of Acid Neutralizing Capacity (ANC), based on 1985-1986 National Stream Survey (Turner, et al., 1990).

The red spruce-Fraser fir forest ecosystem is the forest type in the southern Appalachian Mountains most likely to be affected by acidic deposition (Eagar, et al, 1996). These forests have a limited geographic distribution (Figure 6.4), occurring at elevations greater than 1370 meters or 4400 feet (Eagar, et al., 1996) and covering approximately 109,915 acres (Dull et al. 1988; DiGiovanni. 1990) to 157,869 acres (Jackson, personal communication) in disjunct areas in eastern Tennessee, western North Carolina, Southwestern Virginia, and northern West Virginia. The spruce-fir ecosystem provides unique habitat to several native and rare plant species. These forests have experienced serious disturbances in the last century. Commercial logging and associated fires in the early 1900 reduced spruce-fir forests to a fraction of their former expanse. Acidic deposition levels are high in this forest type within the southern Appalachians because of high amounts of cloud deposition. Currently these forests are also being severely impacted by the balsam woolly adelgid, an invasive insect from Europe that was first detected in the southern Appalachian Mountains on Mount Mitchell in the 1950s and has since spread throughout the region. Most mature Fraser fir trees are killed by the adelgid within 2 to 7 years after infestation. Fir mortality has opened the forest canopy and exposed co-occurring red spruce trees to increased wind damage and drying of soils. Declines in red spruce growth were reported in the 1980s, but it is not clear whether these trends are greater than normal variation over the past 200 years and whether factors other than acidic deposition have also contributed to these trends (Eagar, et al., 1996). Surveys in the 1990s indicate that fir seedlings are growing vigorously in some stands and are being crowded out by competition from other species in other stands.

Southern Appalachian spruce-fir forests are more susceptible to acidic deposition than other forest types for two main reasons: 1) soils are acidic (due to high organic acid content and low base cation supply) and 2) sulfur and nitrogen deposition levels are high, due to the high volume of wet, dry, and cloud water precipitation (Eagar, et al., 1996). Depending on the ability of soils to adsorb sulfate, sulfur deposition to spruce fir forests may be retained in soils or leached to streams. Sulfate absorption varies geographically, with generally higher capacity in soils characteristic of the Southern Blue Ridge Province and generally

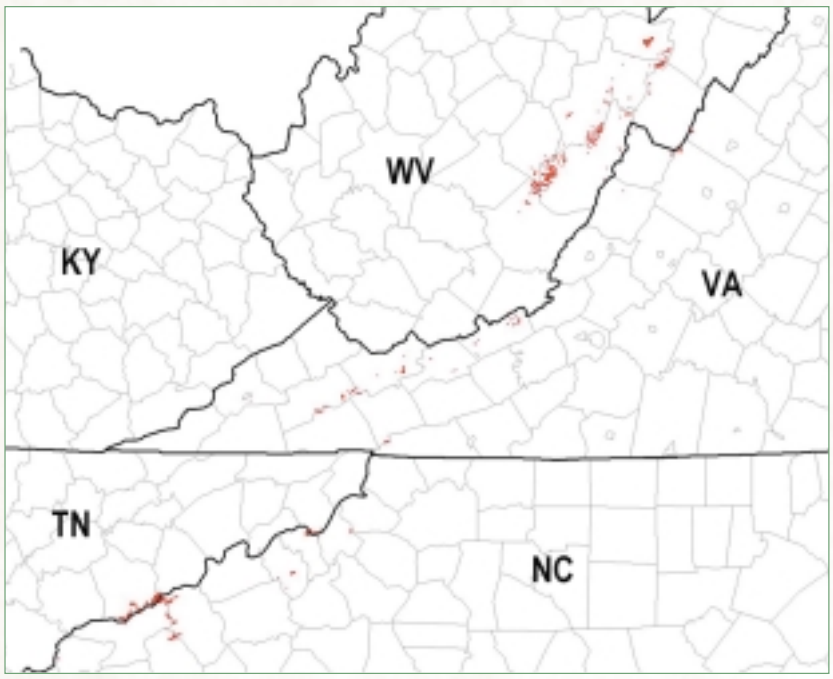


FIGURE 6.4: Locations of spruce-fir forest ecosystem in SAMI region

lower capacity in soils characteristic of the northern Appalachian Plateau (Sullivan et al, 2002a; Sullivan et al, 2002b). Nitrogen deposition to these slow growing forests is likely to exceed nitrogen uptake by vegetation and micro-organisms in the soil (Fenn, et al., 1998). Nitrate and sulfate in soil solutions can remove base cations from soil surfaces and reduce the availability of these essential nutrients for uptake by plant roots. In soils with low levels of base cations, aluminum that is released into soil solutions by deposited sulfate and nitrate can further inhibit nutrient uptake by plant roots.

FUTURE CHANGES IN ACID DEPOSITION DUE TO SAMI STRATEGIES

Linking SAMI's Atmospheric And Acid Deposition Effects Models

SAMI's Assessment is unique in that it used air quality model results to project the acid deposition changes that were used in the stream and forest effects models. Previous effects modeling efforts have relied on projected changes in emissions to estimate future regional changes in deposition and effects. SAMI's analyses used deposition monitoring data to establish the deposition inputs to the effects models and used percentage changes in deposition, projected by the atmospheric model for each stream and forest site, to modify the base year deposition in response to SAMI strategies.

Wet deposition monitoring data from the National Atmospheric Deposition Program (NADP) for the period 1991-1995 were the basis for calculating annual average total deposition for the Base year and future years. Wet deposition data from 16 sites were spatially extrapolated to 170 stream and forest sites in the SAMI region using elevation and distance techniques of Grimm and Lynch (1997). Because dry deposition measurements are infrequent and influenced by local conditions, ASTRAP, a general atmospheric transport model, was used with 1990 emissions data to project wet, dry, and fog/cloud deposition across the SAMI region (Shannon, 1998). The ratios of wet to dry deposition and wet to cloud deposition at 33 sites from the ASTRAP model were used with calculated wet deposition to estimate dry, cloud, and total deposition at each of the 170 stream and forest sites. The only exception was for high-elevation sites in Great Smoky Mountains National Park where site-specific monitoring data for wet, dry, and cloudwater deposition (Johnson and Lindberg, 1992) were used in place of ASTRAP model results to calculate total deposition. In SAMI's analyses, the total annual average deposition for 1991-1995 is referred to as the Base year.

To project future deposition under SAMI strategies, the percentage changes in wet and dry deposition components were calculated from the URM atmospheric model results (Odman et al., 2002 a; Odman, et al., 2002b). Percentage changes in cloud deposition were assumed to be the same as changes in dry deposition. The percentage changes were used to adjust the wet, dry, and cloud deposition components in the Base year for each stream and forest site in order to estimate future deposition (Sullivan et al., 2002a).

Deposition Response To SAMI strategies

Future changes in sulfur and nitrogen deposition in response to SAMI strategies are consistent with projected changes in emissions under these strategies, as illustrated in Figure 6.5 (E. H. Pechan & Associates, 2002).

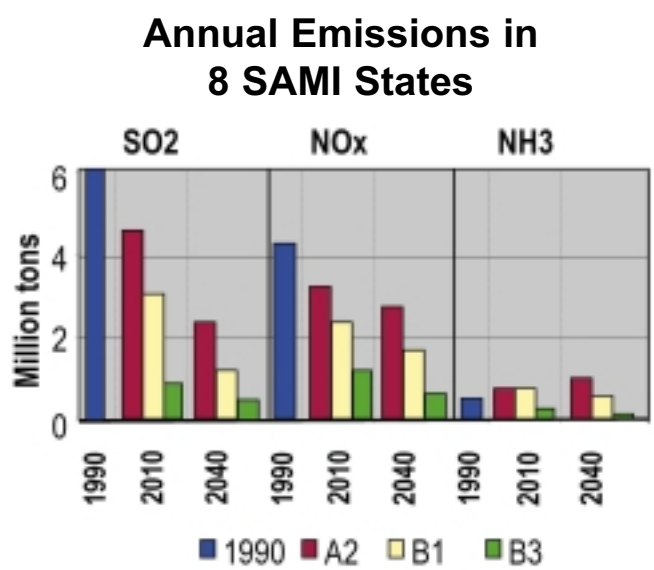


FIGURE 6.5: Emissions of sulfur dioxide, nitrogen oxides, and ammonia in eight SAMI states in 1990 and in 2010 and 2040 in response to SAMI strategies

In the SAMI region, sulfur and nitrogen deposition in the 1991-1995 Base year are highest in West Virginia and at higher elevations in eastern Tennessee and western North Carolina. These same areas see the largest reductions in sulfur and nitrogen deposition in response to SAMI strategies.

SULFUR DEPOSITION

Under all SAMI strategies, sulfur deposition is projected to decrease at all modeled sites in 2010 and in 2040. The changes in total annual average sulfur deposition in 2010 at five modeled sites in SAMI Class I areas are illustrated in Figure 6.6. These sites are examples that represent the geographic range from Sipsey Wilderness in Northwestern Alabama to Dolly Sods in Northern West Virginia and a range from low elevation (Sipsey) to high elevation (Noland Divide in Great Smoky Mountains National Park) sites. Across all modeled sites, total sulfur deposition in 2010 is projected to decrease from 15 to 70% (average 28%) for the A2 reference strategy compared to the 1991-1995 Base year. Total sulfur deposition in 2010 under the B1 and B3 strategies is projected to decrease by an average of 44 and 61%, respectively, compared to the 1991-1995 Base year.

The largest reductions in total sulfur deposition in 2010 are projected for sites in West Virginia and Virginia. The largest reductions in sulfur dioxide emissions in the A2 strategy were projected to occur in the Midwestern States where many of the electric utility units were required to reduce sulfur dioxide emissions under Phase I of Title IV of the 1990 Clean Act Amendments. SAMI's geographic sensitivity analyses indicate that the West Virginia and Virginia sites are heavily influenced by emissions in the Midwestern States, West Virginia, and Virginia (Odman, et al. 2002a). Sulfur deposition at sites in eastern Tennessee, Northern Georgia, and western North Carolina showed less response to the A2 strategy, and greater response to the B1 and B3 strategies, than sulfur deposition at sites in West Virginia and Virginia. The southern sites are most influenced by emissions in the SAMI States (Odman, et al 2002a), and deposition responses were consistent with emissions trends in these States.

NITROGEN DEPOSITION

In contrast to sulfur deposition, SAMI's atmospheric model results project that changes in total nitrogen deposition in 2010 and 2040 in response to SAMI strategies will be small (Figure 6.7). Deposition of oxidized nitrogen species (including nitrogen oxides, nitric acid vapor, and nitrate particles) is projected to decrease in 2010 and 2040 under all strategies. Across the 170 modeled sites, total deposition of oxidized nitrogen species in 2010 is projected to decrease by an average of 24, 25, and 30% under the SAMI A2, B1, and B3 strategies, compared to the Base year. Dry deposition is projected to decrease more than wet deposition (Odman, et al., 2002a). Deposition of reduced nitrogen species (ammonia and ammonium), however, is projected to increase in the A2 and B1 strategies and decrease in the B3 strategy. Across the modeled sites, total deposition of reduced nitrogen in 2010 is projected to increase by an average of 39 % for the A2 strategy or 15% for the B1 strategy, and to decrease by an average of 2% for the B3 strategy. For high elevation spruce-fir forest sites in the Great Smoky Mountains, total nitrogen deposition in 2010 is projected to decrease by 3-4% under the A2 and B1 strategies and by 11% under the B3 strategy. Averaged across the SAMI region, total annual average nitrogen deposition is projected to decrease by 10% under the A2 and B1 strategies and by 19% under the B3 strategy.

These deposition trends are consistent with projected emissions under the SAMI strategies (Figure 6.5). Nitrogen oxide emissions from utilities, industries, highway vehicles and nonroad engines are projected to decrease in all strategies. Ammonia emissions from livestock and fertilizer are projected to increase in the A2 and B1 strategies and decrease in the B3 strategy. Uncertainties in the emissions inventory projections and atmospheric modeling are greater for nitrogen species than sulfur species (Odman, et al., 2002a), so our confidence in the nitrogen deposition trends is less than in the sulfur deposition trends.

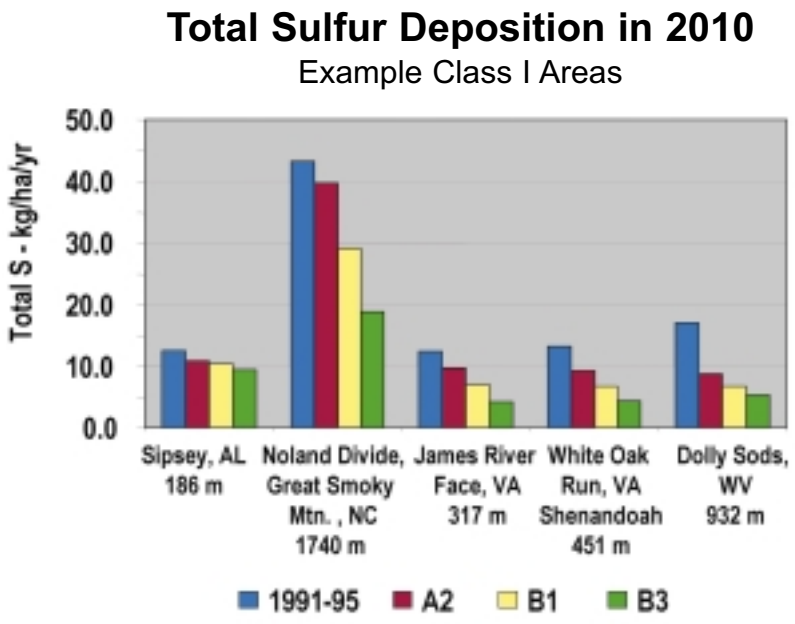


FIGURE 6.6: Total annual average Sulfur Deposition in 1991-1995 and in 2010 under SAMI strategies for 5 example sites in SAMI Class I areas.

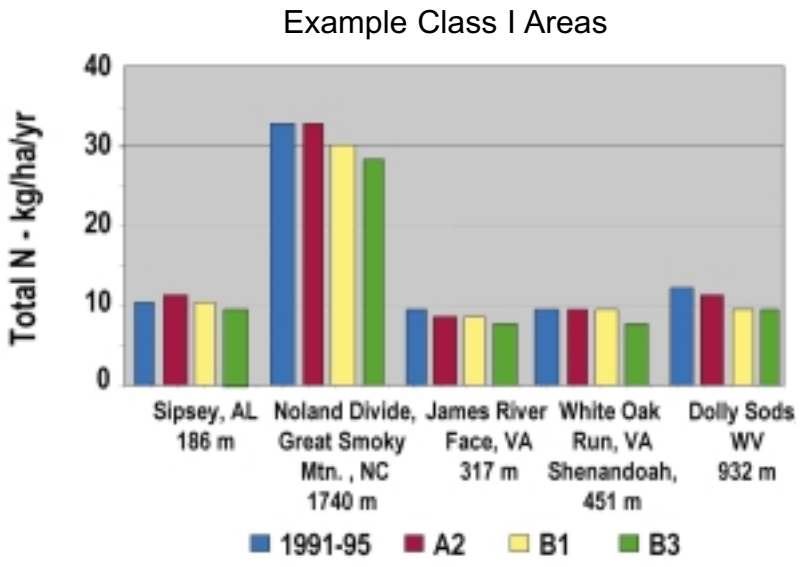


FIGURE 6.7: Total annual average Nitrogen Deposition in 1991-1995 and in 2010 under SAMI strategies for 5 example sites in Class I areas

BASE CATION DEPOSITION

Base cation deposition is projected to show small changes in future years in response to SAMI strategies (Sullivan, et al., 2002a). Base cations are primarily emitted as fine and coarse particles from area sources such as construction and agriculture. Activity for these source categories and resulting base cation emissions from these sources are projected to increase in future years. Because base cations are predominantly associated with coarse particles, which are deposited near the emission sources, changes in regional deposition of base cations are expected to be small.

SAMI STREAM ASSESSMENT

Approach

The Model of Acidification of Groundwater in Catchments (MAGIC) was used to project current and future streamwater chemistry in response to the SAMI strategies (Sullivan, et al., 2002a, Cosby and Sullivan, 1999). MAGIC is a watershed model that integrates the combined impacts of physiographic features, geology, soils, and forest cover to project streamwater quality. Stream acid neutralizing capacity was used as the primary indicator of stream habitat suitability for fish, especially native brook trout.

SAMI used the 1985-86 National Stream Survey database (Kaufmann, et al, 1988) as the statistical basis to define the regional distribution of stream acid neutralizing capacity in the SAMI region. This database is the most complete survey of streams in the southern Appalachian Mountains. Based on this survey, 7 percent of the total stream length in the SAMI region has stream acid neutralizing capacity less than 50 µeq/l (Figure 7.3). A larger percentage of streams with acid neutralizing capacity less than 50 µeq/l was modeled than occurs in the regional population because these are the streams that are at greatest risk of acidifying and affecting brook trout populations.

SAMI Acid Deposition Regional Stream Modeling Sites

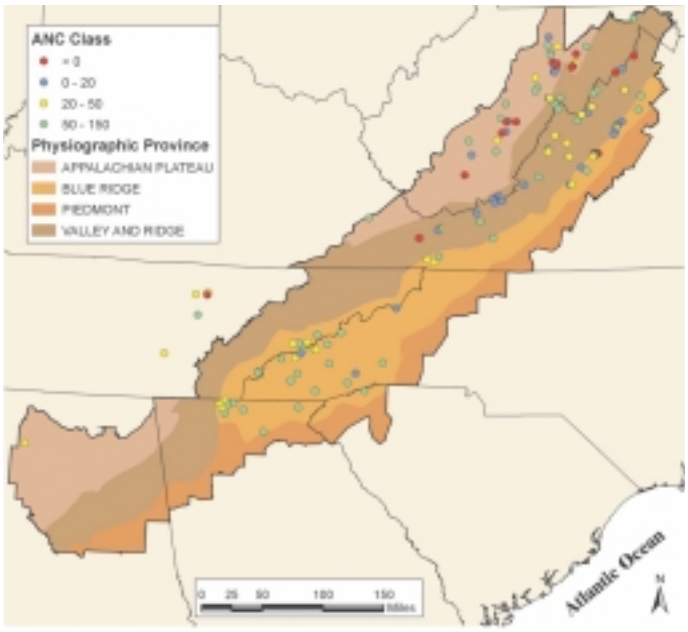


FIGURE 6.8. Physiogeographic provinces in SAMI region and locations of streams modeled in SAMI analyses

Streams in the national database were classified in one of twelve categories based on four acid neutralizing capacity classes and three physiographic provinces (Figure 6.8). Additional stream data were used where necessary to represent specific geographic areas. Streams that are obviously impacted by other factors (e.g. acid mine drainage, insect defoliation) were excluded from the analyses. Within each category streams were selected to represent the range of geographic coverage and stream chemistry. Results for 130 modeled streams were extrapolated to statistically represent all other streams in the SAMI region (Table 6.2). Average responses of modeled streams within a class were used to represent responses of all streams in the same acid neutralizing capacity class and geographic province.

In addition to this regional analysis, 27 additional streams in Class I areas were modeled to provide a qualitative, site-specific, analysis for each of the Class I areas (Table 6.2). Results are specific to the modeled streams and can not be interpreted as representative of the entire Class I area. Acidic streams (acid neutralizing capacity less than 0 μeq/l) were most prevalent in the Dolly Sods and Otter Creek Wilderness areas on the Appalachian Plateau in West Virginia. Many streams in the Shenandoah and Great Smoky Mountains National Parks and James River Face Wilderness area have stream acid neutralizing capacity less than 20 μeq/l. Streams in Class I areas in the southern portion of the SAMI region generally have higher acid neutralizing capacity.

Stream Responses to SAMI Strategies

Streamwater acid neutralizing capacity is determined primarily by the combined effects of sulfate, nitrate, and base cation concentrations. Under SAMI's A2 strategy, stream acid neutralizing capacity is projected to decrease at most modeled streams in the SAMI region compared to conditions in the 1991-1995 Base year. By 2040, the numbers of modeled streams in the acid neutralizing capacity classes less than 0 μeq/l and 0-20 μeq/l are projected to increase under the A2 strategy (Table 6.3). For most sites, increases or decreases in stream acid neutralizing capacity under the A2 strategy were less than 20 μeq/l between the Base year and 2040 and

TABLE 6.2: Numbers of streams modeled in each acid neutralizing class in each of three physiogeographic provinces (used for the regional assessment) and additional special interest streams in Class I areas

Stream Acid Neutralizing Capacity(ANC)	Numbers of Modeled Streams			
	Appalachian Plateau	Ridge and Valley	Blue Ridge	Class I area special interest streams
< 0 μeq/l	25	6	3	10
0 – 20 μeq/l	8	14	12	3
21 – 50 μeq/l	9	12	17	5
50 – 150 μeq/l	11	11	36	9

TABLE 6.3: Stream Acid Neutralizing Capacity (ANC) in response to SAMI strategies for 130 modeled streams

Stream Acid Neutralizing Capacity Class (μeq/l)	1991-95	2040 CC (deposition continues at 1991-95 levels)	2040 A2	2040 B1	2040 B3
	# of modeled streams				
< 0	19	54	33	26	19
0 - 20	30	21	33	29	31
21-50	32	23	27	35	35
51 - 150	49	32	37	40	45

few streams changed acid neutralizing capacity response class. These results suggest that risk to brook trout populations would be little changed by the A2 strategy. The exception is acidic streams in West Virginia where increases in acid neutralizing capacity under the A2 strategy are projected to be sufficient to improve fish habitat for several streams with acid neutralizing capacity below 20 μeq/l.

If deposition continues at 1991-1995 levels through 2040 (constant conditions or CC), more modeled streams are projected to acidify than under the A2 strategy. These results suggest that without sulfur dioxide reductions under the 1990 Clean Air Act Amendments, as represented by SAMI's A2 strategy, additional streams in the SAMI region would become acidic. By 2040, fewer modeled streams are projected to have acid neutralizing capacity less than 20 μeq/l under the B1 and B3 strategies than under the A2 strategy. By 2040 only the B3 strategy is projected to have fewer modeled streams with acid neutralizing capacity less than 50 μeq/l than in the Base year. These results suggest that sulfate deposition reductions beyond those represented by the SAMI A2 strategy will be required to prevent an increase in numbers of acidic streams.

These results reflect the cumulative impacts of many decades of acidic deposition on soil base cation supply and soil sulfate retention. Recovery of the watershed processes that control streamwater acidification will likely require many decades of reduced deposition levels. Changes in stream acid neutralizing capacity in response to SAMI strategies are projected to continue beyond 2040 (Figure 6.9) even if deposition is constant at 2040 levels. Acid neutralizing capacity is projected to continue to increase after 2040 in streams that are projected to see increases by 2040. Acid neutralizing capacity is projected to continue to decrease beyond 2040 in many streams that are projected to see decreased acid neutralizing capacity by 2040.

In response to reduced sulfate deposition under SAMI's A2 strategy, streamwater sulfate levels are projected to decrease by 2040 for some streams (mostly in West Virginia and Virginia) and to increase at most streams region wide (Virginia, Tennessee, North Carolina, Georgia, and Alabama). The largest reductions in streamwater sulfate (> 20 μeq/l) by 2040 are projected for streams in West Virginia. In these watersheds, soils are currently retaining little of the deposited sulfate and reductions in sulfate

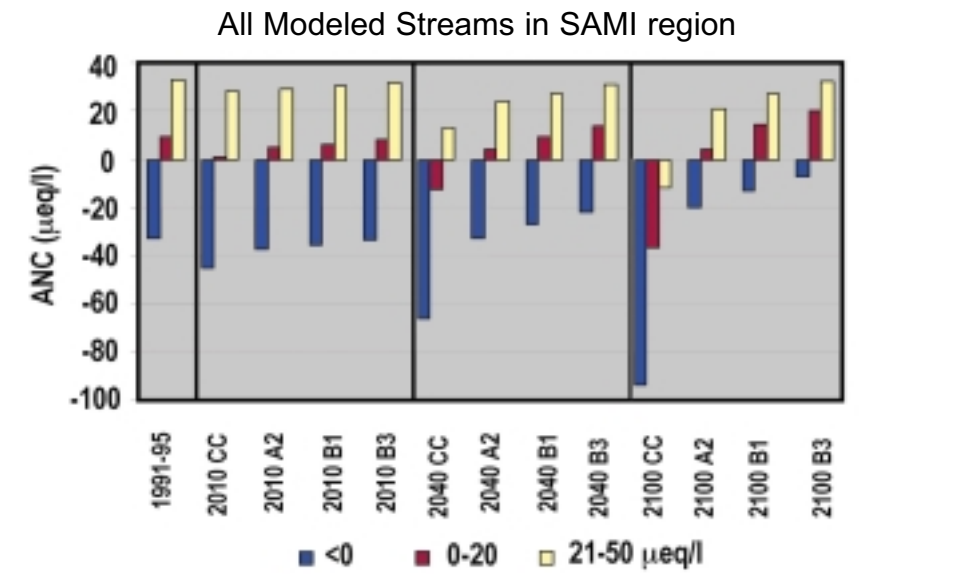


FIGURE 6.9: Average Stream Acid Neutralizing Capacity (ANC) for modeled streams in SAMI region in response to SAMI Strategies

deposition are projected to result in reduced streamwater sulfate. At most sites other than those in West Virginia, streamwater sulfate is projected to increase (< 10 μeq/l) under the A2 strategy, despite decreased sulfate deposition. Soils at these sites are currently retaining a high percentage of the deposited sulfur and are expected to exhibit gradual decreases in the ability to retain sulfur in future years. For these streams, even as sulfate deposition is projected to decrease, streamwater sulfate levels are projected to increase. In response to the B1 and B3 strategies, more streams are projected to show decreased sulfate streamwater concentrations than in the A2 strategy.

Streamwater nitrate concentrations are elevated in streams that drain watersheds where total nitrogen deposition exceeds nitrogen uptake. These streams are scattered throughout the SAMI region but occur primarily in West Virginia and higher elevations in eastern Tennessee and western North Carolina. Streamwater nitrate concentrations respond to changes in total nitrogen deposition, with both increases and decreases in response to the A2 strategy. The largest nitrate reductions are projected for those streams with the highest nitrate concentrations in the Base year. Streamwater nitrate levels are projected to decrease at most streams under the B1 strategy and at all streams under the B3 strategy.

At most modeled sites, base cation levels in streamwater are projected to decrease under SAMI strategies. This is in response to reduced sulfate levels in soil solutions and reduced leaching of base cations from soils to streamwater. By 2040, particularly in West Virginia streams, reduced base cations in streamwater offset the benefits of sulfate reductions in streamwater. As a result, changes in stream acid neutralizing capacity are smaller than might be expected given the magnitude of sulfate deposition reductions.

Extrapolating from modeled stream results to the population of streams in the SAMI region, by 2040, the percentages of streams in each acid neutralizing capacity class are little changed in response to SAMI strategies (Figure 6.10). Streams with acid neutralizing capacity less than 50 μeq/l constitute a small percentage of the total stream length in the SAMI region. By 2040, average acid neutralizing capacity within a class is projected to

Stream Acid Neutralizing Capacity (ANC) in SAMI Region

2040 SAMI Strategies Compared to 1991-1995

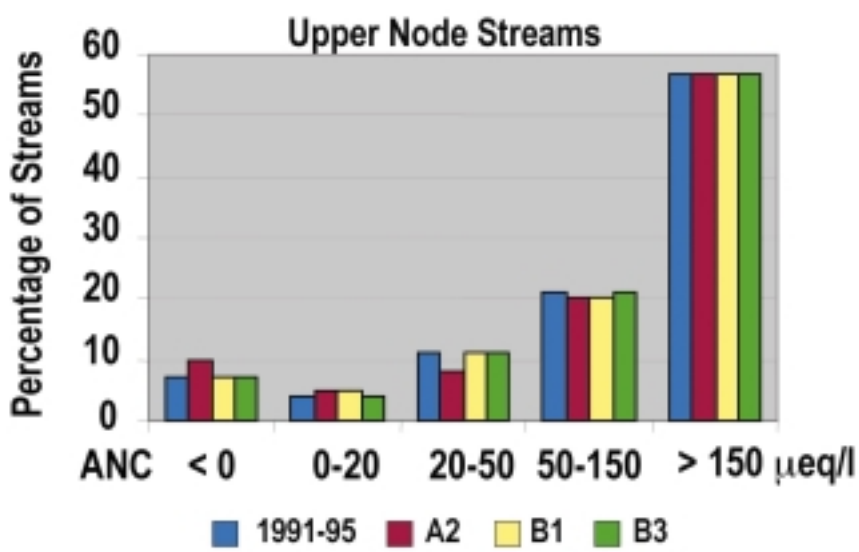


FIGURE 6.10: Stream Acid Neutralizing Capacity (ANC) for upper node stream in SAMI region in 2040 under SAMI strategies

decrease for all streams under the A2 strategy (Table 6.4). Under the B1 and B3 strategies by 2040, class average acid neutralizing capacity is projected to increase for acidic streams and to decrease for streams with acid neutralizing capacity greater than 20 μeq/l. These results for the SAMI region are consistent with those discussed for modeled streams.

Stream results in Class I areas followed the same trends as those for the region. Dolly Sods, Otter Creek, and James River Face wilderness areas and Great Smoky Mountains and Shenandoah National Parks have higher percentages of acidic streams than the region as a whole. Acid neutralizing capacity is generally projected to increase for acidic streams and decrease for most streams with acid neutralizing capacity greater than 20 μeq/l.

In summary, SAMI's stream assessment indicates that the emissions controls represented by the A2 strategy should reduce the acidification of streams with acid neutralizing capacity less than 20 μeq/l more than would occur under constant levels of deposition in1991-1995. Further reduction in acid deposition, as represented by the B1 and B3 strategies, should increase acid neutralizing capacity and improve brook trout habitat in some acidic streams but most changes would be expected to be small. Acid neutralizing capacity of most streams with acid neutralizing capacity greater than 50 μeq/l is projected to decrease, but not to the point of dropping below 50 μeq/l or increasing biological risk for brook trout populations.

Link To Socioeconomic Analyses

The changes in percentages of streams in each acid neutralizing capacity class by 2040 in response to SAMI strategies are small. Therefore the increases in numbers of streams suitable for brook trout are projected to be small. The exception is a contiguous eight county area in West Virginia where increases in stream acid neutralizing capacity were projected to result in more substantial changes in numbers of streams in classes with acid neutralizing capacity less than 50 μeq/l. If stream conditions provide habitats otherwise suitable for native brook trout, then increased acid neutralizing capacity in these streams should decrease the risk of aluminum toxicity and improve stream suitability for brook trout in some of those streams. The projected changes in stream acid neutralizing capacity in these counties were used in SAMI's socioeconomic analyses of fishing impacts in response to SAMI strategies (see Chapter 8 - Socioeconomics).

FOREST RESPONSE TO SAMI STRATEGIES

Approach

The Nutrient Cycling Model was used to project forest responses to changes in deposition due to SAMI strategies (Sullivan, et al., 2002b, Munson, 1999). The Nutrient Cycling Model represents the effects of acid deposition on the chemistry of foliage, soils, and soil solutions. The model is not able to project how forest growth or species composition will respond to

TABLE 6.4: Projected Changes in class average acid neutralizing capacity (ANC) between 1991-1995 and 2040 in response to SAMI strategies for upper stream reaches In the SAMI region

Acid Neutralizing Capacity (ANC) class in μeq/l	Change in Acid Neutralizing Capacity (ANC) in μeq/l between 1991-1995 Base year and 2040		
	A2 strategy	B1 strategy	B3 strategy
< 0	-5.0	0.5	3.9
0 - 20	-7.9	-3.1	4.8
21 - 50	-5.3	-3.1	-3.5
51 - 150	-5.7	-3.9	-2.4

those chemical changes. In SAMI's analyses, changes in soil base saturation, sulfate and nitrate levels soil solutions, and the molar ratio of calcium to aluminum in soil solutions were used as indicators of forest responses to SAMI strategies.

Fourteen forested sites in three forest types (spruce-fir, northern hardwood, and mixed hardwood) were selected for modeling (Figure 6.11, Sullivan, et al., 2002b). The analyses rely on available monitoring data, sites were preferentially selected to represent Class I areas. The spruce-fir forest ecosystem is the forest type most sensitive to acidification and the most likely to receive high levels of acid deposition. Soils in these forests are typically shallow and highly weathered, with low levels of base cations and high levels of nitrate, inorganic aluminum, and organic acidity. Northern hardwood forests occur at elevations below spruce-fir and are less at risk. Elevated levels of nitrate have been observed in streams in some northern hardwood forests, indicating potential risk of soil acidification in future decades. Because mixed hardwood forest generally have larger supplies of soil base cations, these forests are not likely to be adversely impacted by acid deposition in the near future.

Forest Response To SAMI Strategies

Soil acidification is projected to continue at almost all sites. Base saturation, an indicator of soil acidification, is projected to decrease at all sites between 1995 and 2040 under the A2 strategy, and to decrease as well at most of the sites under the B1 and B3 strategies. Changes in sulfate and nitrate in soil solutions in response to SAMI strategies were small at most sites. The molar ratio of calcium-to-aluminum in soil solutions is projected to decrease at most sites under all strategies. Previous studies indicate that forest ecosystems are under increased stress where calcium-to-aluminum ratios in soil solutions fall below a threshold of 1 (Cronan and Grigal, 1995). The modeled spruce-fir forests generally exhibited calcium-to-aluminum ratios in soil solutions near or below 1.0 in the Base year. The model results indicate further reductions of calcium-to-aluminum ratios in future years at the modeled spruce-fir sites, suggesting increased stress to these forests. We cannot interpret

Forest Distribution and Acid Deposition Effects Sites

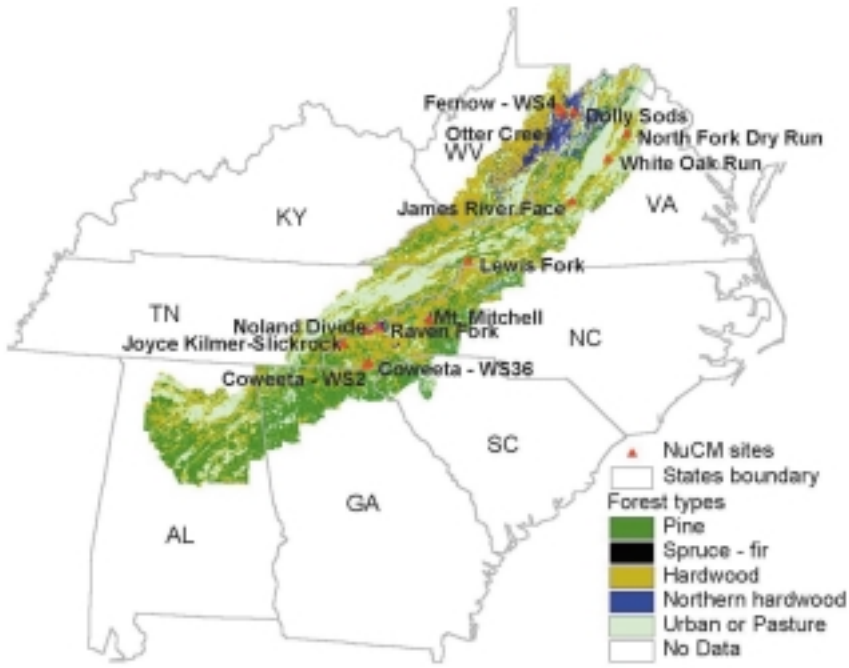


FIGURE 6.11: Map of forest distribution and site locations for modeled sites

how these model results might affect overall forest growth or forest health.

Changes in nitrogen deposition under the SAMI strategies were generally small, so it is not surprising that responses of the modeled spruce-fir forest sites to projected changes in nitrogen deposition were small. Based on previous studies in the United States and Europe, forests with nitrogen deposition levels below about 10 kg/ha/yr are expected to have low risk of adverse impacts from nitrogen saturation. High-elevation spruce-fir forests in the SAMI region are currently receiving significantly greater nitrogen deposition than 10 kg/ha/yr. Nitrogen deposition measured at Noland Divide in the Great Smoky Mountains is currently 32 kg/ha/year. Federal Land Managers have recommended that nitrogen deposition levels of 3-5 kg/ha/yr may be required to protect the most sensitive forests and streams in Class I areas.

UNCERTAINTIES

There are numerous uncertainties associated with this assessment of aquatic and forest effects of changing levels of acid deposition in response to SAMI strategies. These uncertainties derive primarily from:

- Assumptions and validity of the models and procedures used in the emissions inventory, atmospheric model, and stream and forest effects models and in the estimates of deposition and changes in deposition in response to SAMI strategies.
- Quality and quantity of watershed data available to calibrate the MAGIC and NuCM models.
- Current state of scientific knowledge concerning ecosystem processes and responses to changes in deposition as represented in the watershed models.
- Seasonal and year-to-year variability in meteorology, streamwater chemistry and biological responses.
- Errors associated with spatial extrapolation from modeled streams to regional population of streams.

Despite these uncertainties, the results of this assessment are in general agreement with field observations within the region and with current scientific understanding of acidification processes. The effects models have been tested and found to provide reasonably accurate estimates of ecosystem response.

LESSONS LEARNED

- It is important to consider atmospheric influences in projecting deposition responses to changes in emissions. SAMI's atmospheric modeling results indicate geographic differences in the magnitude of both emissions and deposition changes and less than a one-for-one reduction in sulfur and nitrogen deposition from sulfur and nitrogen emission reductions.
- SAMI's assessment demonstrated the difficulty and importance of representing differences in sensitivity and responses across a large geographic region.
- SAMI's assessment synthesized the current scientific understanding and relied on existing watershed data. The current state of science does not allow us to definitively project biological responses of fish or forests to changes in acid deposition. The biological endpoints are areas of future research needs.
- Continued stream and forest monitoring is needed to document whether ecosystems will respond to emissions reductions as projected in the SAMI assessment for future years.

KEY FINDINGS

1. Sulfate deposition is projected to decrease substantially under all SAMI strategies. Changes in deposition of nitrogen and base cations in response to SAMI strategies are projected to be smaller.

2. Base-poor geology (for example, sandstones) and elevations greater than 1000 meters (3250 feet) can be used as indicators of areas of the southern Appalachian Mountains where streams with low acid neutralizing capacity (< 20 μeq/l) are most likely to occur. More streams with low acid neutralizing capacity are found on the Appalachian Plateau of West Virginia and the Ridge and Valley Province in Virginia than in the Blue Ridge Province. The exception is streams draining high elevations forests in eastern Tennessee and western North Carolina. Streams with acid neutralizing capacity greater than 20 μeq/l occur throughout SAMI region.

3. Under the SAMI strategies, few streams are projected to change sensitivity class (defined on the basis of acid neutralizing capacity) in the future in response to SAMI strategies.

4. The largest improvements in acid neutralizing capacity are projected to occur for the streams that currently have low acid neutralizing capacity (less than 20 μeq/l). Streams most likely to improve under the SAMI strategies occur in West Virginia, Virginia, and higher elevations in eastern Tennessee and western North Carolina.

5. If streams conditions are otherwise suitable for supporting native brook trout, increasing acid neutralizing capacity will improve brook trout habitat for some streams in West Virginia, Virginia, Tennessee and North Carolina.

6. Southern Appalachian spruce-fir forests are more responsive to acid deposition than northern hardwood and mixed hardwood forests. Soils in spruce fir forests contain high levels of organic acidity. In addition, nitrogen and sulfur deposition are high, due to the high volumes of precipitation and frequent cloud cover.

7. Changes in forest soil chemistry in response to SAMI strategies are likely to be small. Since changes in nitrogen deposition under SAMI strategies were small, this result is not surprising. SAMI modeling results do not provide levels of nitrogen deposition that might be considered protective for spruce fir forests. A level greater than 10/kg/ha/year of total nitrogen deposition has been suggested to result in nitrate leaching, based on studies in Europe and the northeastern United States.

DIRECT COST OF EMISSIONS REDUCTION STRATEGIES

INTRODUCTION

SAMI estimated the direct cost of the emission reduction strategies in the years 2010 and 2040. Some examples of the activities for which costs were determined are:

- Installing and operating a scrubber on a coal-fired boiler,
- Mass transit alternatives that reduce vehicle miles traveled.
- New practices in animal operations that reduce ammonia emissions.

Cost estimates were developed for the A1 and A2 reference strategies and the B-group alternative reduction strategies. (See Chapter 2 for descriptions of the strategies.) All cost estimates were calculated as total annualized cost in 2010 and 2040 and expressed in year 2000 dollars. The annualized costs cover all cost components (including capital, operating, and fuel) and are generally presented in three ways:

- Aggregate cost of each strategy in the year 2010 and 2040.
- Cost of the reduction of a specific pollutant in each strategy and source sector (performed for oxides of nitrogen, sulfur dioxide, ammonia, volatile organic compounds and particulate matter smaller than 10 microns, because those are the pollutants for which reduction strategies were developed and/or modeled).
- Dollar per ton cost of specific pollutant reduction in each strategy.

The reader can combine these values with the results from the effects assessment to gain insight into the environmental benefit that can flow from the expenditures on emission reductions.

Developing cost estimates on a 20 to 50 year timeframe is highly uncertain. Because the sector controls are very different, costs were developed as point estimates for the utility and industrial sectors and as a range of costs associated with emission reductions for the highway vehicle, area and nonroad source sectors.

METHODOLOGY

Overarching Assumptions

The development of these cost estimates involved the calculation of costs for specific control methods in each of the source sectors. The following overarching assumptions were made in the development of these costs:

- Costs are in annualized Year 2000 dollars and are direct costs only.
- Costs represent changes in annualized costs of control measures in place in 2010 and 2040, from a 1990 baseline, but not total accumulated costs. Where costs include capital costs, those costs have been amortized over a 15-year period.
- NO_X controls for B strategies assume regional trading (modeled separately for utility and industrial point sources).
- Highway vehicle, area and nonroad sectors have a range of costs represented by the high and low ends of the control measure costs.

Utility Sector

Utility sector costs were determined by estimating the costs of controls on existing units and for new units of specific technology and fuel types. Controls designed to reduce NO_X and SO_2 were considered independently. Costs were calculated using formulas that included the capital costs and the operation and maintenance costs amortized over 15 years, at a 7% discount rate. The resulting carry charge rate of 15% includes property tax, insurance and administrative costs. In 2010 all the cost was associated with retro-

fit controls on coal-fired boilers. There was no new unplanned generation capacity needed to meet electricity demand in 2010 based on the assumed electricity demand growth. However, it was recognized that increased demand will eventually necessitate the building of currently unplanned power plants. SAMI assumed that these plants would include a mix of pulverized coal, natural gas, and coal gasification plants in specific ratios. In the A2 and B1 strategies for 2040, it was assumed that the new generation would be represented by a weighted average of: 20% pulverized coal, 40% natural gas combined-cycle, and 40% integrated gasification combined-cycle (IGCC). In both the B2 and B3 strategies for 2040 it was assumed that these would be 0%, 50%, and 50%. It was assumed in the B1 and B2 strategies that large coal fired units that reached 65 years of age, and had not been updated, would add NO_X and/or SO_2 control technology to meet specified emission limits. In the B3 strategy it was assumed that these units would be replaced or "repowered" with a mix of generation represented by 50% natural gas and 50% IGCC like the assumption for new facilities. The majority of utility costs in 2040 is the difference between the estimated costs of standard coal fired plants with 1990 levels of control and the estimated cost of plants operating on the prescribed mix of fuels.

Industrial Sector

Development of the industrial sector costs was similar to the utility sector, except there were many more smaller combustion sources. Controls applied were targeted towards industrial boilers, industrial gas turbines, industrial internal combustion engines and cement kilns. Strategies to reduce oxides of nitrogen and sulfur dioxide were considered. The cost of continuous emission monitors, which are the same regardless of the size of the emission source, were included even though those costs had not been considered in the utility sector. Because there are so many smaller units being controlled in the industrial sector the additional per-unit cost became a substantial portion of the accumulated costs.

Highway Vehicle Sector

For the highway vehicle sector costs were associated with meeting the Tier II emission standards, increasing the numbers of zero emission vehicles, reducing the growth of light duty vehicle miles traveled, meeting the 2007 heavy-duty-vehicle emission standards, transferring freight from truck to rail and reducing sulfur limits. Developing costs for these emission reduction strategies was a very different exercise than the development of point source emission reduction costs. Costs were estimated per mile, per gallon of gasoline, or per vehicle depending on which metric was appropriate and then converted into a total cost. In many situations costs were extrapolated from limited case studies that provided the only information available about the cost of such activities. The cost of reducing the growth of vehicle miles traveled (VMT) is such a case. A study prepared for the Transportation Research Board summarized the cost effectiveness of strategies designed to change travel behaviors in congested areas. This study determined that such alternatives as high-occupancy vehicle lanes (HOV), ride-sharing, increases in mass transit and telecommuting had a range of cost effectiveness. The cost effectiveness of these strategies was used to set the range of cost per vehicle mile reduced in both 2010 and 2040 at from 4 to 35 cents per mile of reduction.

This almost 10 fold range of costs is a major factor in the large range of highway vehicle sector costs. Likewise, a range of zero emission vehicle (ZEV) costs were calculated using existing zero emitting or near-zero emitting vehicles. (see Pechan, 2002b). Figure 7.1 illustrates all the costs associate with the 2040 B3 strategy (the strategy with the most stringent reductions). Clearly the greatest costs and the greatest uncertainty are associated with vehicle miles traveled reduction and zero emission vehicles of light duty vehicles.

Nonroad Engine Sector

Calculating the nonroad engine sector costs was similar to calculating highway vehicle sector costs. Emission controls for which costs were calculated included: conversion of airport service equipment, lawn and garden equipment, and marine and locomotive engines to zero emission equipment; applying the 2007 highway vehicle standards to nonroad diesel engines and sulfur reductions. Specific case studies like airport baggage tractors were used to estimate cost across all airport equipment. Case studies were also used to estimate cost of emission reductions in trains, planes, boats, and other nonroad mobile sources. Costs for applying the 2007 standards to equipment that are currently not regulated by the rule were extrapolated from costs associated with currently regulated locomotive and boat engines. Costs associated with lowering sulfur concentrations in gasoline and diesel fuel were assumed to be the same as for highway fuels.

Area Sector

The area sector includes all the emissions not captured in the other sectors, so it contains a variety of very different emissions and control approaches for which costs were estimated. In most cases, the A2 reference strategy and the B1 strategy involved emission reductions at levels that had been considered or experimented with, so some relevant data existed. The B3 strategy and, in some cases, the B2 strategy involved levels of control that have not been tried and for which the costs are highly speculative. Department of Energy background information was used in calculating combustion costs (EIA, 2000).

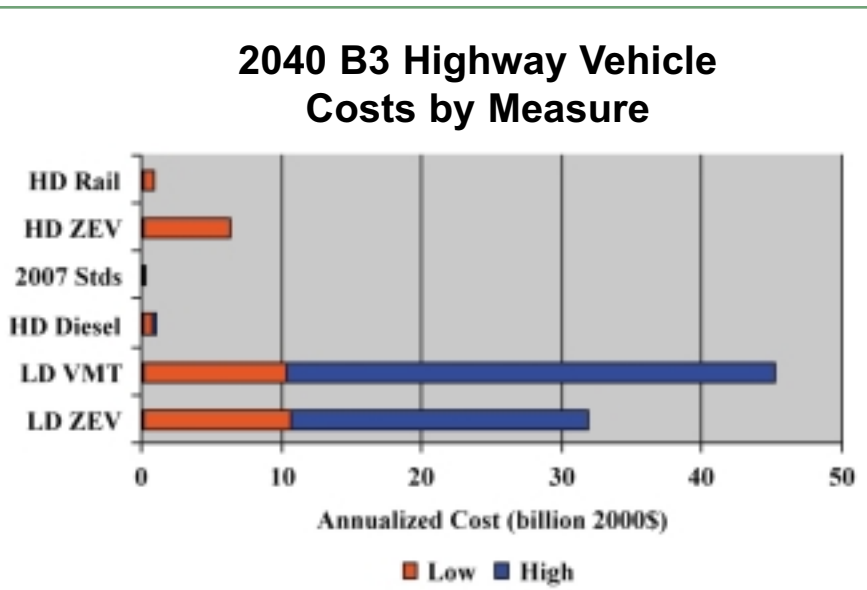


FIGURE 7.1: Cost projection for the 2040 B3 case for the highway vehicle sector illustrates the extreme range in cost projections between the low end of the range (red bar) and the high end of the range (blue bar) in certain subsectors. For example, the SAMI projection in this case is the VMT reductions which are projected to cost between 10 and 45 billion dollars in 2040.

TOTAL ANNUALIZED COSTS

Results

Total annualized strategy costs are presented in Figure 7.2. Both the low end and high end of the cost estimate is presented. It is expected that the best estimate is somewhere between those values. The range in the total annualized costs results from a range of estimates being developed for the highway vehicle, area, and nonroad sectors. Single value estimates were developed for the utility and industrial point source sectors. The annualized costs developed for 2010 represent the difference in cost from a 1990 baseline for controls in place in the year 2010. Likewise, the annualized cost for 2040 is the difference in cost from a 1990 baseline for controls in place in the year 2040. These are not total accumulated costs, but annualized costs that combine capital costs and annual operation and maintenance charges into a stream of equal annual payments over a given period, using standard techniques.

The A1 and A2 reference strategies are projected to cost $4 billion per year and $6 billion per year, respectively, in 2010 and $10 billion per year and $12 billion per year, respectively, in the year 2040. All costs for the reference strategies were point estimates - there were very specific controls in the highway vehicle sector and no controls assumed in the nonroad and area sectors in these strategies. The B-group strategies all have a range of estimated costs. The B1 strategy cost estimate ranges from $10 to $14 billion per year in 2010 and from $24 to $43 billion per year in 2040. The B2 strategy cost estimate ranges from $13 to $22 billion per year in 2010 and $34 to $60 billion per year in 2040. The largest jump in cost is between the B2 and B3 strategies. The B3 strategy cost estimate ranges from $33 to $61 billion per year in 2010 and from $61 to $110 billion per year in 2040. Both the cost and the range are significantly higher for the B3 strategy because this strategy calls for very high emission reductions regardless of technical or practical concerns. Thus, it is not surprising that the associated costs would be high or that it would be difficult to estimate those costs with precision.

2010

Annualized costs of the strategies are shown by source sector in the stacked bar of Figures 7.3 and 7.4. At the low end of the range the utility and highway vehicle sectors contribute most to the cost of air emissions reduction, except in B3 where costs are significant for all sectors. Costs for most sectors approximately double between B2 and B3, except nonroad, which has a ten fold increase, and the area source sector, which has twenty fold increase. Although not visible in the scale of the graphic, there is a cost savings in the area source sector in the B1 strategy as a result of fuel switching from oil to natural gas. At the high end of the cost range, the highway vehicle and area sectors account for most

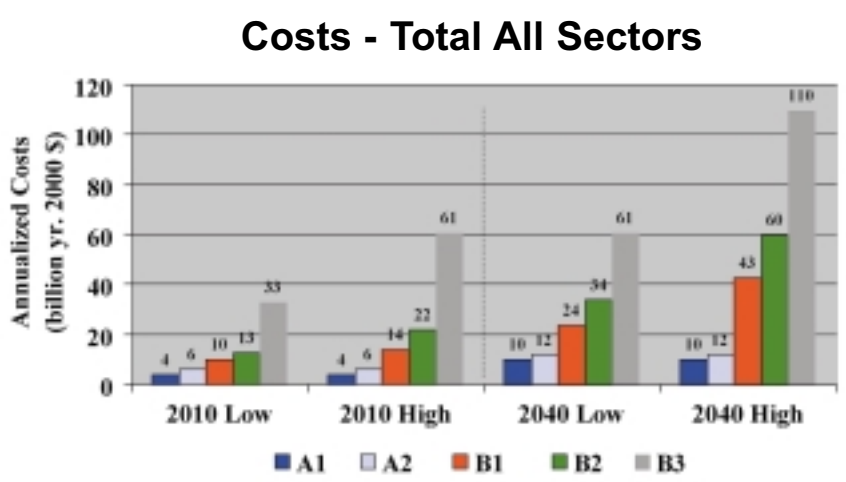


FIGURE 7.2: Cost for all source sectors combined for 2010 and 2040. SAMI projects the cost to between the Low and High ranges.

of the costs, remembering that these two sectors have a range of costs in the analysis while the utility sector does not. The utility, area and nonroad sectors have greatest increase from B2 to B3. The area source sector becomes the largest cost contributor in the B3 strategy. These costs are associated with emission reductions of greater than or equal to 75% across the six major pollutants of: oxides of nitrogen, sulfur dioxide, volatile organic chemicals, ammonia, fine and coarse particulates.

2040

Likewise the 2040 cost estimates can be examined from analogous graphs (Figure 7.5 and 7.6). In general, costs are about double the cost in 2010, except for those in the industrial sector that change little between 2010 and 2040. As in 2010, utility and highway vehicle sectors account for most of the costs in 2040, except in the B3 strategy where the area source costs are very large. A majority of the costs and cost uncertainties in the highway vehicle sector

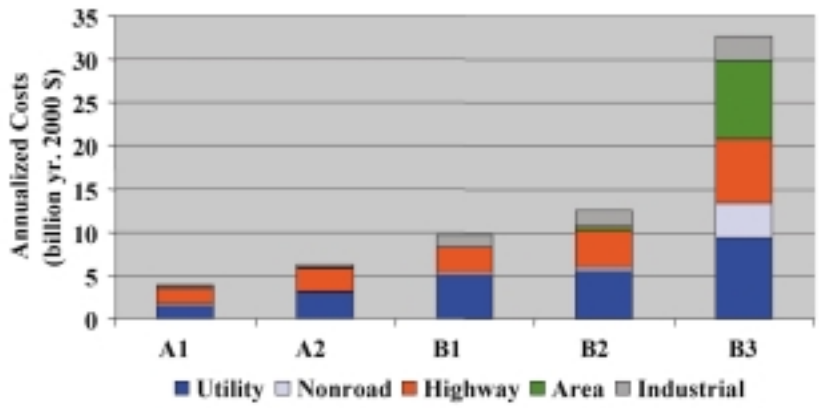


FIGURE 7.3: 2010 Low end of the range of projected costs by source sectors.

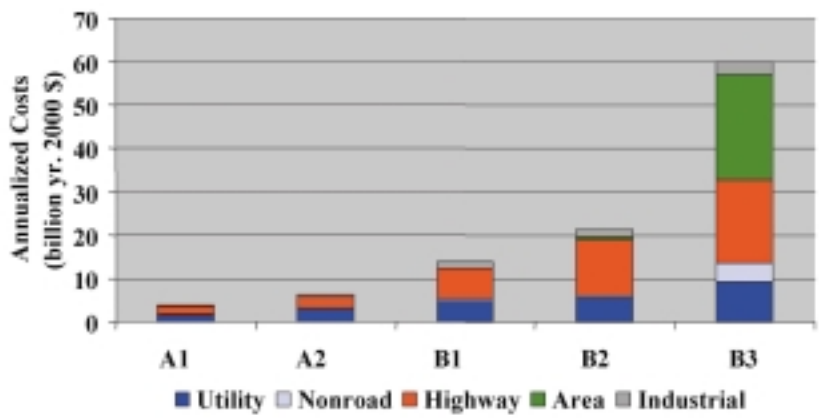


FIGURE 7.4: 2010 High end of the range of projected costs by source sectors.

are from reductions of light duty vehicle miles traveled and conversion of light duty vehicles to zero emissions. Nonroad costs are insignificant except in the B3 strategy where it accounts for about 10% of the total. Examining the difference between the upper end and lower end of the cost range yields the following observations:

- At the low end of the cost range, highway and area sources account for most of the increase from B1 to B2.
- Utility, area and nonroad sectors have the greatest increase from B2 to B3.
- At the high end of the range the highway vehicle sector accounts for most of the total cost in B1 and B2.
- At the high end, the area source sector accounts for the highest percentage of cost in the B3 strategy.

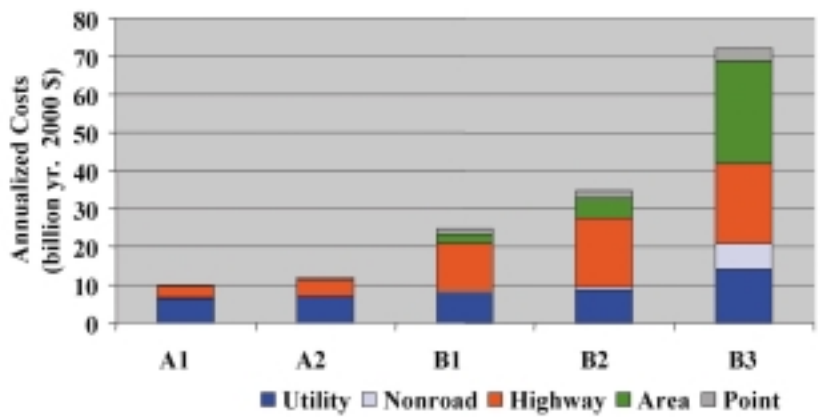


FIGURE 7.5: 2040 Low end of the range of projected costs by source sectors.

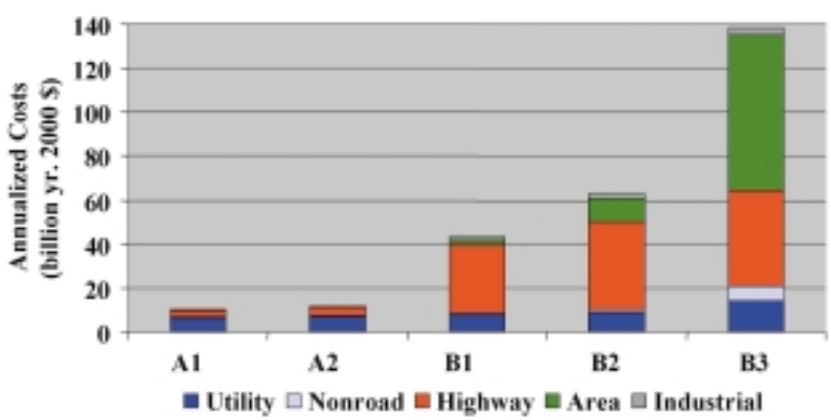


FIGURE 7.6: 2040 High end of the range of projected costs by source sectors.

COST PER POLLUTANT

Annualized costs per ton of pollutant removed were calculated by comparing the B-group strategies to the A2 reference strategy. In order to do this analysis, assumptions were made to allocate costs of certain control measures to specific sectors and pollutants. The allocation assumptions were:

- **Utility and Industrial Sector:**

  Existing units – costs allocated to sulfur dioxide or nitrogen oxides reductions depending on control measure (e.g., selective catalytic reduction costs allocated to nitrogen oxides, scrubber costs allocated to sulfur dioxide).

  New units – costs allocated to sulfur dioxide or nitrogen oxides in proportion to the percentage reduction in emission rates for a given strategy.

- **Highway vehicle sector:** costs associated with light-duty zero emission vehicles or reductions of vehicle miles traveled evenly split between volatile organic compounds and nitrogen oxides; light duty Tier 2 and heavy duty vehicle control measure costs allocated to nitrogen oxides.

- **Nonroad engine sector:** zero emission vehicle costs for gasoline lawn & garden, recreational vehicles, and recreational marine vessels assigned to volatile organic compounds; other zero emitting engine costs, EV controls, aircraft controls, and 2007 diesel highway engine standards assigned to nitrogen oxides; reduced fuel sulfur levels assigned to sulfur dioxide.

- **Area source sector:**

  Costs assigned to nitrogen oxides: natural gas combustion sources; miscellaneous burning; residential wood.

  Costs assigned to sulfur dioxide: coal and oil combustion sources.

  Costs assigned to volatile organic compounds: chemical and allied products; solvent use; storage and transport.

  Costs assigned to particulate matter: fugitive road dust; agricultural crops & livestock; managed burning.

  Costs assigned to ammonia: fertilizers and livestock.

Results

Tables 7.1, 7.2, 7.3 present reductions and cost information for sulfur dioxide, oxides of nitrogen and ammonia for 2010 and 2040. Each table presents: 1) the annualized cost of each strategy relative to the 1990 Baseline, 2) the tons of pollutant removed in each of the B-group strategies relative to the A2 strategy, 3) the cost of the B-group strategy relative to the A2 strategy, and 4) the cost per ton of pollutant removed. The results for each pollutant are discussed below in separate sections. Costs were also calculated for volatile organic compounds and particulate matter (see Pechan, 2002b).

SULFUR DIOXIDE

Figure 7.7 shows the total cost of sulfur dioxide removal by sector for the A2, B1 and B3 strategies. The highway vehicle sector does not appear because there are no controls for SO_2 implemented in that sector. In the A2 reference strategy additional SO_2 controls are only applicable to the utility sector. The greatest total annualized costs are experienced in the utility sector, as are the greatest reductions (Table 7.1).

SO_2 Costs per Ton by Sector and Strategy

TABLE 7.1: Table provides projected annualized cost for SO_2 reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of SO_2 removed for each strategy.

			Annualized Cost of SO_2 Reductions by Strategy (millions of yr.2000 dollars)				SO_2 Emission Reductions from A2 (thousand tons/year)			Incremental Cost Increase from A2 (million dollars)			Cost per ton of SO_2 Reduced from A2 ($/ton)		
Year	Case	Sector	A2	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
2010	Low	Utility	1,163	2,369	2,320	5,557	1,164	1,422	2,934	1,205	1,157	4,394	1,036	813	1,498
		Point	0	966	1,175	1,650	162	227	331	966	1,175	1,650	5,963	5,173	4,991
		Nonroad	0	10	10	9	82	82	104	10	10	9	128	120	90
		Area	0	-280	-511	-692	154	285	369	-280	-511	-692	-1,819	-1,795	-1,874
		Total	**1,163**	**3,065**	**2,994**	**6,524**	**1,561**	**2,016**	**3,737**	**1,902**	**1,831**	**5,362**	**1,218**	**908**	**1,435**
2010	High	Utility	1,163	2,369	2,320	5,557	1,164	1,422	2,934	1,205	1,157	4,394	1,036	813	1,498
		Point	0	966	1,175	1,650	162	227	331	966	1,175	1,650	5,963	5,173	4,991
		Nonroad	0	15	15	14	82	82	104	15	15	14	188	176	131
		Area	0	-280	-511	-692	154	285	369	-280	-511	-692	-1,819	-1,795	-1,874
		Total	**1,163**	**3,070**	**2,999**	**6,529**	**1,561**	**2,016**	**3,737**	**1,907**	**1,835**	**5,366**	**1,222**	**910**	**1,436**
2040	Low	Utility	3,993	4,769	5,167	7,860	396	620	959	776	1,174	3,867	1,962	1,895	4,033
		Point	0	666	977	1,582	70	93	138	666	977	1,582	9,496	10,468	11,505
		Nonroad	0	16	16	8	116	118	172	16	16	8	135	138	47
		Area	0	-841	-851	-851	509	510	510	-849	-851	-851	-1,669	-1,667	-1,667
		Total	**3,993**	**4,610**	**5,309**	**8,599**	**1,090**	**1,341**	**1,779**	**609**	**1,317**	**4,607**	**558**	**982**	**2,590**
2040	High	Utility	3,993	4,769	5,167	7,860	396	620	959	776	1,174	3,867	1,962	1,895	4,033
		Point	0	666	977	1,582	70	93	138	666	977	1,582	9,496	10,468	11,505
		Nonroad	0	23	26	13	116	118	172	23	26	13	197	221	75
		Area	0	-841	-851	-851	509	510	510	-849	-851	-851	-1,669	-1,667	-1,667
		Total	**3,993**	**4,617**	**5,319**	**8,604**	**1,090**	**1,341**	**1,779**	**616**	**1,327**	**4,612**	**565**	**990**	**2,592**

Corrected 2/8/02 (utility 2040 cost)

NO_x Costs per Ton by Sector and Strategy

TABLE 7.2: Table provides projected annualized cost for NO_x reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of NO_x removed for each strategy.

			Annualized Cost of NO_x Reductions by Strategy (millions of yr.2000 dollars).				NO_x Emission Reductions from A2 (thousand tons/year)			Incremental Cost Increase from A2 (million dollars)			Cost per ton of NO_x Reduced from A2 ($/ton)		
Year	Case	Sector	A2	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
2010	Low	Utility	1,845	2,571	3,150	3,753	552	684	763	727	1,304	1,909	1,316	1,907	2,500
		Industrial	165	271	454	1,003	103	153	237	105	289	838	1,021	1,894	3,539
		Highway	1,558	1,712	2,307	4,644	156	389	508	155	749	3,086	992	1,923	6,078
		Nonroad	111	224	358	3,955	25	124	225	113	247	3,845	4,463	1,992	17,058
		Area	5	67	252	2,323	10	48	204	62	247	2,318	5,918	5,104	11,355
		Total	**3,684**	**4,845**	**6,521**	**15,678**	**847**	**1,399**	**1,937**	**1,162**	**2,837**	**11,995**	**1,372**	**2,028**	**6,191**
2010	High	Utility	1,845	2,571	3,152	3,753	552	684	763	727	1,304	1,909	1,316	1,907	2,500
		Industrial	165	271	454	1,003	103	153	237	105	289	838	1,021	1,894	3,539
		Highway	1,558	4,140	7,022	10,965	156	389	508	2,582	5,464	9,407	16,568	14,030	18,528
		Nonroad	111	224	488	4,118	25	124	225	113	377	4,007	4,463	3,040	17,779
		Area	5	112	420	3,664	10	48	204	107	415	3,659	10,228	8,568	17,922
		Total	**3,684**	**7,318**	**11,536**	**23,503**	**847**	**1,399**	**1,937**	**3,634**	**7,849**	**19,819**	**4,291**	**5,612**	**10,230**
2040	Low	Utility	2,851	3,000	3,579	6,393	111	263	440	148	728	3,542	1,341	2,763	8,042
		Industrial	170	556	770	1,723	102	134	197	386	600	1,553	3,766	4,494	7,872
		Highway	2,517	7,289	11,030	14,205	527	709	730	4,772	8,513	11,688	9,047	12,009	16,009
		Nonroad	82	322	412	6,226	124	202	272	241	331	6,144	1,945	1,635	22,583
		Area	5	239	717	3,814	40	131	275	235	712	3,809	5,906	5,416	13,827
		Total	**5,625**	**11,406**	**16,508**	**32,361**	**904**	**1,440**	**1,915**	**5,781**	**10,884**	**26,736**	**6,396**	**7,560**	**13,959**
2040	High	Utility	2,851	3,000	3,579	6,393	111	263	440	148	728	3,542	1,341	2,763	8,042
		Industrial	170	556	770	1,723	102	134	197	386	600	1,553	3,766	4,494	7,872
		Highway	2,517	16,977	22,490	25,398	527	709	730	14,459	19,973	22,881	27,413	28,176	31,340
		Nonroad	82	491	749	6,394	124	202	272	409	667	6,313	3,305	3,299	23,201
		Area	5	411	1,081	6,878	40	131	275	406	1,077	6,873	10,226	8,195	24,949
		Total	**5,625**	**21,435**	**28,669**	**46,786**	**904**	**1,440**	**1,915**	**15,808**	**23,045**	**41,161**	**17,490**	**16,008**	**21,491**

NH_3 Costs per Ton by Sector and Strategy

Table 7.3: Table provides projected annualized cost for NH_3 reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of NH_3 removed for each strategy.

			Annualized Cost of NH_3 Reductions by Strategy (millions of yr.2000 dollars)				NH_3 Emission Reductions from A2 (thousand tons/year)			Incremental Cost Increase from A2 (million dollars)			Cost per ton of NH_3 Reduced from A2 ($/ton)		
Year	Case	Sector	A2	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
2010	Low	Area	0	0	58	884	1	133	461	0	58	884	500	436	1,918
2010	High	Area	0	0	61	4,421	1	133	461	0	61	4,421	501	460	9,590
2040	Low	Area	0	181	751	1,396	391	407	723	188	751	1,396	482	1,843	1,931
2040	High	Area	0	191	3,775	6,982	391	407	723	191	3,775	6,982	489	9,268	9,654

To consider the cost per ton of SO_2 removed examine Figure 7.8. The cost per ton of SO_2 removed in the Industrial Sector is five to six times greater than in the utility sector. The industrial sector costs are higher than utility due to negative economies of scale involved with smaller industrial boilers. Area source reductions are gained through fuel switching and this analysis indicates that there would be a cost savings associated with this control method. The area source sector accounts for approximately 10% of the emission reductions under any given strategy, roughly equivalent to the industrial sector. The tons of sulfur dioxide reduced by each sector are represented by the number above each bar and can be compared to the number above the black bar, which shows the tons reduced by all sectors combined. This value was used to calculate an average removal cost for all sectors. The nonroad and then the utility sectors

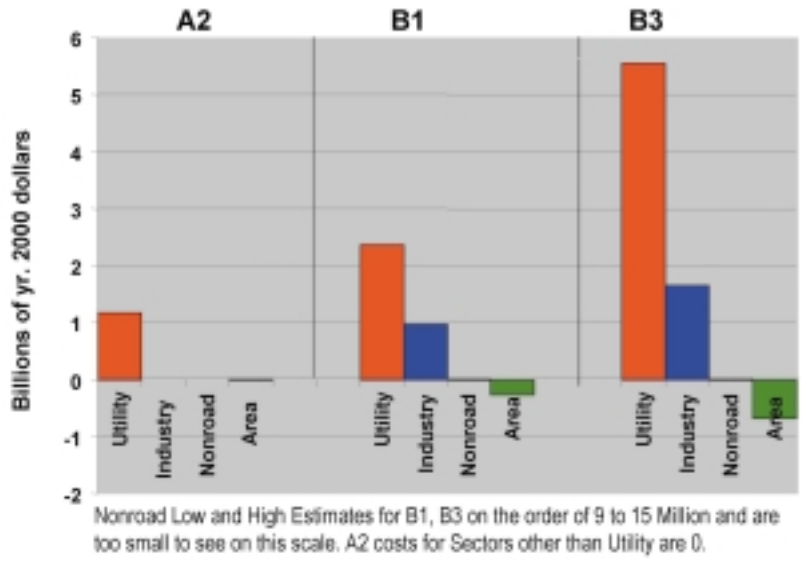


FIGURE 7.7: Annualized cost of SO_2 reductions by strategy and by source sector.

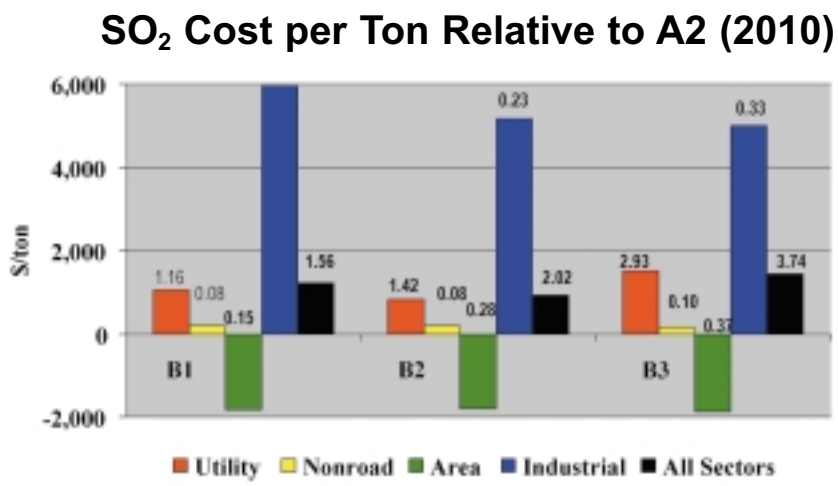


FIGURE 7.8: Cost per ton of SO_2 removed in 2010.

have next lowest per ton costs. The range of costs for SO_2 removal in the nonroad and area sectors is so small that they are not visible within the scale of this graphic. The average costs per ton of sulfur dioxide removed for all sectors (represented by the black bars) in 2010 are: B1 -$1200, B2 - $900, B3 - $1400.

The analysis shows the same pattern of costs in 2040 for SO_2 reductions as was seen in 2010; potential cost savings in the area sector, and extremely high industrial costs. A greater percentage of the sulfur dioxide reduction come from the area sector in 2040, where a 75% reduction in sulfur dioxide is dictated by each of the 2040 strategies (B1, B2 and B3). The amount of sulfur dioxide being reduced in the utility sector goes up in each subsequent strategy as does the cost per ton (Figure 7.9).

OXIDES OF NITROGEN

Figure 7.10 shows the total cost of reductions of oxides of nitrogen by sector for the A2, B1 and B3 strategies. Unlike the costs associated with sulfur dioxide reductions, there is a significant range in cost associated with this pollutant.

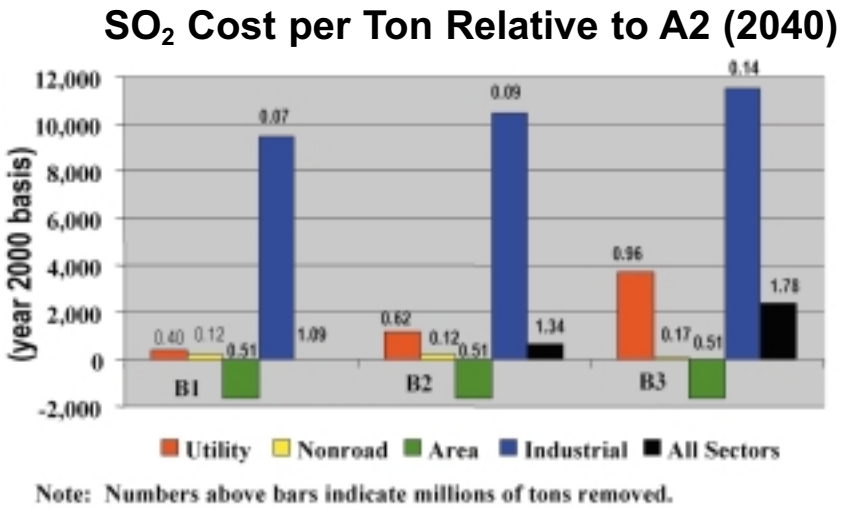


FIGURE 7.9: Cost per ton of SO_2 removed in 2040.

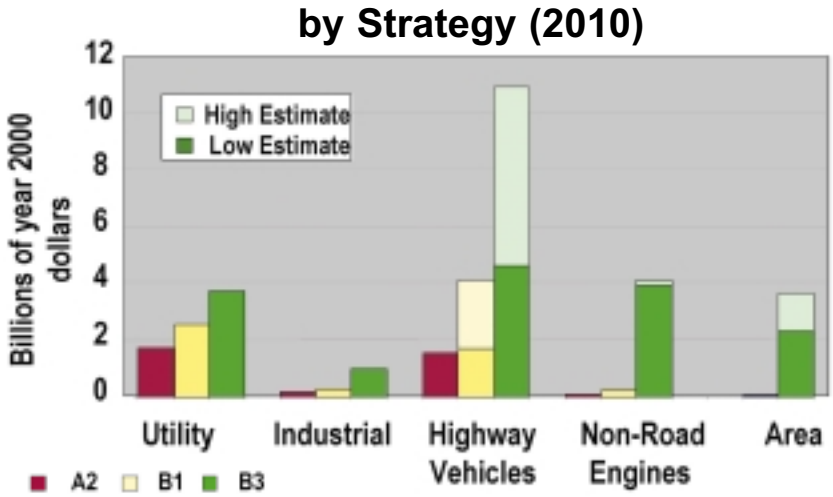


FIGURE 7.10: Annualized cost of NO_X reductions by strategy and by source sector.

Figures 7.11 and 7.12 show the cost per ton of nitrogen oxides controlled compared to the A2 strategy in 2010 and 2040, respectively. The large range of costs adds complexity to the determining of relative costs. For example, at the low end of the range of costs for the B1 strategy the highway vehicle sector has the lowest cost; however, at the high end of the scale it has the highest cost. The extremely large range of highway vehicle sector costs is important in the cost analysis for nitrogen oxide reduction. In addition it can be seen that the utility and industrial sectors have relatively low costs associated with reductions and that the cost of nitrogen oxides reductions on a per ton basis is more than the cost of sulfur dioxide reductions. The average costs per ton of nitrogen oxides removed for all sectors (represented by the black and gray bars) in 2010 are: B1 - $1400 to 4300, B2 - $2000 to 5600, and B3 - $6200 to $10,200. In 2040, the average costs per ton for all sectors are: B1 - $6400, to $17,500, B2 - $7600 to $16,000, and B3 $14,000 to $21,500.

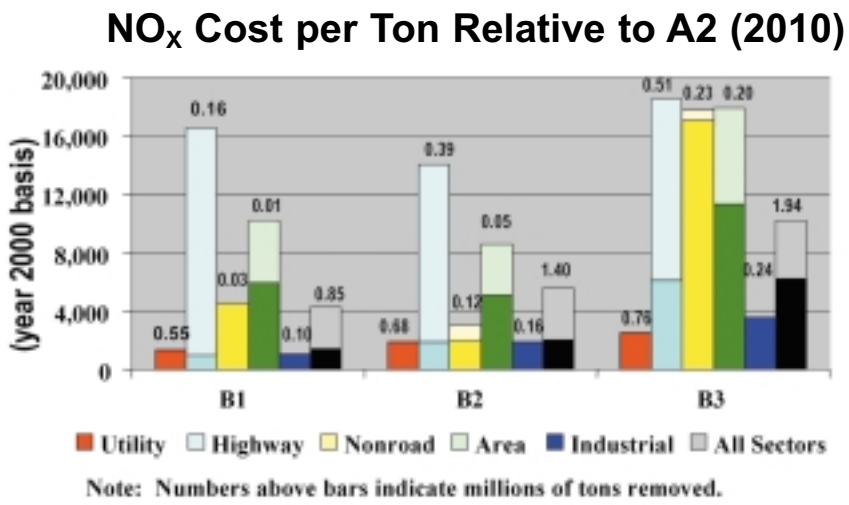


FIGURE 7.11: Cost per ton of NO_X removed in 2010.

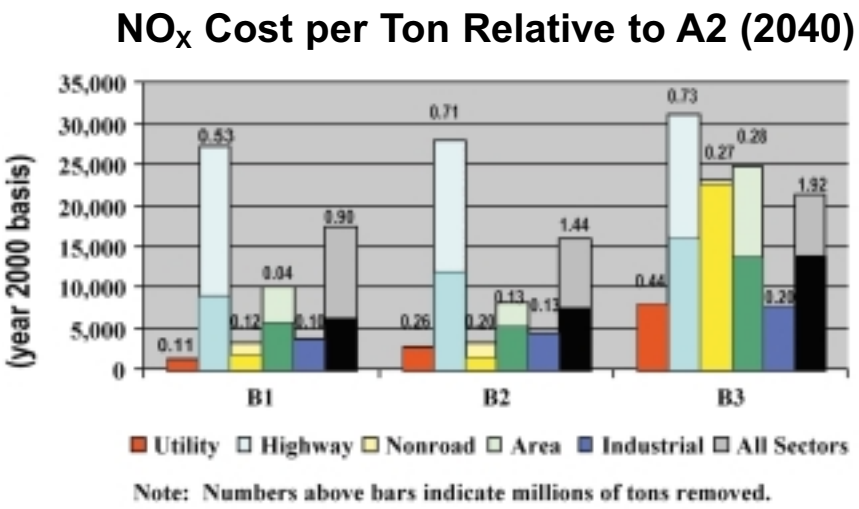


FIGURE 7.12: Cost per ton of NOX removed in 2040.

AMMONIA

All of the ammonia reductions and all of the costs are associated with animal operations and fertilizer production and use in the area sector. Figure 7.13 shows the cost per ton of the B strategies compared to the A2 strategy in both 2010 and 2040. The B3 strategy calls for levels of ammonia reduction which may not be achievable and for which it is extremely difficult to estimate cost.

UNCERTAINTIES

Estimating the cost of emission reductions 20 to 50 years in the future is a difficult and uncertain process. However there are aspects of the analysis that are more certain than others. Utility costs for the B-group strategies in 2010 is the most certain aspect of this analysis ranking a 3 out of 5 on a relative uncertainty scale (Table 7.4). The other sectors: industrial, highway vehicle, area and nonroad received scores of 2.0, 1.5, 1.0 and 0.5, respectively. In all strategies except the B3

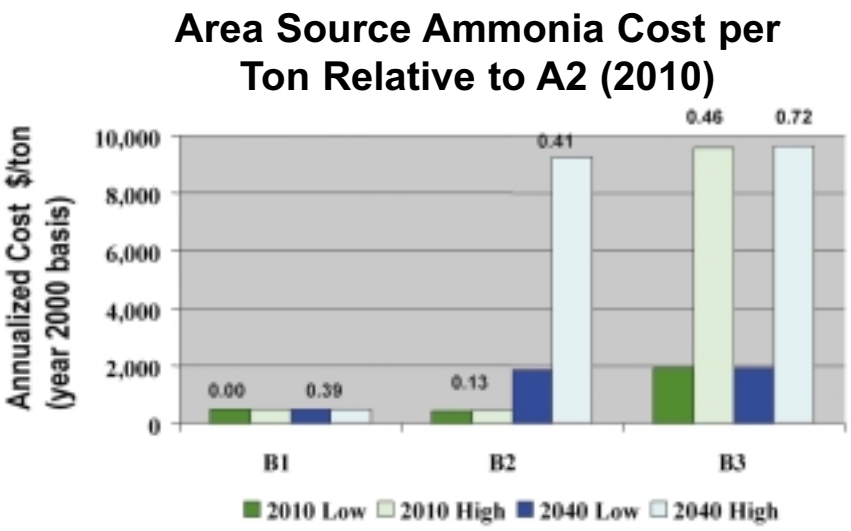


FIGURE 7.13: Cost per ton of NH_3 removed in 2010, all NH_3 reductions and costs are in the area source sector.

Relative Uncertainties of SAMI 2010 Direct Cost Analysis

Table 7.4: Relative Uncertainties of SAMI 2010 Direct Cost Analysis. Based on 5 pluses being the most certain (the - represents half a plus).

	Utility	Industry Vehicles	Highway Engines	Nonroad	Area
Strategy Cost Results	+ + +	+ +	+ -	-	+

strategy, the highway vehicle sector accounts for 30 to 50% of the total cost. Therefore, the uncertainty in that sector is more important in the overall analysis than the uncertainty in the area and nonroad sectors. In the B-3 strategy the relative contribution of the area sector cost is much greater and so the uncertainty is more significant. In 2040 all sectors received scores between 0.5 and 1.5 (Table 7.5). Thus, the estimate of the cost of pollution reduction in the utility sector in 2010 is relatively certain, but all other aspects of the analysis have a high degree of uncertainty.

Relative Uncertainties of SAMI 2040 Direct Cost Analysis

Table 7.5: Relative Uncertainties of SAMI 2040 Direct Cost Analysis. Based on 5 pluses being the most certain (the - represents half a plus).

	Utility	Industry Vehicles	Highway Engines	Nonroad	Area
Strategy Cost Results	+ -	+	+	-	-

KEY FINDINGS

1. In 2010 the costs for each strategy were estimated as: A2 = $6 Billion, B1 = $10 to $14 Billion, B2 = $13 to $22 Billion, and B3 = $33 to $61 Billion.
2. In 2040 the costs for each strategy were estimated as: A2 = $12 Billion, B1 = $24 to $43 Billion, B2 = $34 to $60 Billion, and B3 = $61 to $110 Billion.
3. The utility sector costs are more certain than the other sectors; the nonroad engine sector is the least certain. Results for 2010 are more certain than 2040. And costs associated with the strategies get less certain as the strategies get more stringent and the technology or methodology for accomplishing the reductions becomes more speculative.
4. The cost per ton of reduction in sulfur dioxide are both less than and more certain than the cost per ton of nitrogen oxides reduction.
5. These costs are valuable as indicators, but should not be relied on solely in policy making. The reader can combine these values with the results from the effects assessment to gain insight into the environmental benefit that can flow from the expenditures on emission reductions.

SOCIOECONOMICS

INTRODUCTION

The objective of the socioeconomic assessment is to examine the social and economic implications of the SAMI emissions management strategies (A2, B1 and B3). SAMI decided early in the design of the socioeconomic assessment to focus on a few of the numerous topic areas where socioeconomic effects are likely to be felt. As a result of that decision, the SAMI analysis cannot be considered a comprehensive cost-benefit analysis and costs cannot be compared to benefits.

The socioeconomic assessment was a two-phase process. Phase I produced a listing of potential topic areas including a qualitative estimate of the magnitude of impacts, the potential ability to develop credible estimates of impacts, and costs associated with performing varying levels of effort of analysis. The Phase I report also defined the methodologies available to assess the chosen topics. It enabled the workgroup to select topic areas based on relative impact and feasibility, and to strike a balance across the selected topics in terms of the types of values considered and the interests of various stakeholder groups. In Phase II six topics were selected and reports were drafted. Two topics – mortality risk and competitiveness – were not taken to completion. The contractors fulfilled their obligations, but it was felt that the draft reports on those topics were not comprehensive enough to form conclusions given the uncertainties. Therefore, these two topics did not result in finished reports. The draft reports for Competitiveness (BBC) and Mortality (Mathtech, Inc.) are listed in the Additional Data and Resources section of this report and included in the SAMI archives. The four remaining topic areas and their scopes are outlined below:

Fishing

The extent to which reductions in air pollution may reduce acidification of fishable waters in the SAMI region leads to a variety of quantifiable chemical or biological changes. The workgroup used changes in fish biomass as an indicator and looked at how these changes affect an angler's fishing experience. As the density of the fish population increases so does the probability of catching fish, which provides a value to those who fish. This change in value is estimated for each emissions management strategy.

Visibility

In an area such as the Southern Appalachian Mountains, improved visibility is one of the most noticeable results of improving air quality. When the view is obscured aesthetic and economic consequences occur. People value good visibility within the area where they live (residential visibility) and in recreational areas (recreational visibility). They can define a monetary value that they are willing to pay (WTP) for that improvement.

Sense of Place/Stewardship

Sense of Place refers to values that reflect the mixture of quality-of-life attributes associated with living in a specific area and preservation of those qualities. It explores community values, beliefs and behaviors as they relate to life and the surrounding natural environment. It also includes concerns about cost of living and employment opportunities or losses.

Stewardship refers to the notion that there is a fundamental ethical responsibility for humans to tend to nature and to pass on to succeeding generations a world that reflects a sustainable pattern of consumption of nature's resources.

Lifestyles

If implemented, the SAMI strategies could substantially affect individuals' lifestyles that live in the region. A qualitative assessment was made of both the positive and negative impacts, and "hidden costs", on residents' lifestyles resulting from industrial pollutant regulations.

The following is a more in-depth description of our analysis.

FISHING

Objective

This study estimates the economic gains associated with reductions in acid deposition in streams in the SAMI region. The indicator was the effect on recreational fishing for native brook trout. A stream's acid neutralizing capacity (ANC) is affected by among other things, acid deposition resulting from nitrogen and sulfur emissions (refer to Chapter 6, Acid Deposition and the Effects on Streams and Forests). SAMI's emissions management strategies are designed to reduce these emissions, which should in turn, increase ANC. The benefits that result from improvements in a stream's ANC, lead to an increase in the populations of various recreational fish species. The change in fish population leads to increased economic activity because of greater fishing success rates.

Methods

The Model of Acidification of Groundwater in Catchments (MAGIC) provided by SAMI's effects contractor estimates changes in ANC for the A2, B1 and B3 strategies. This model identified a contiguous eight county area in West Virginia where changes from one ANC classes to another occurred. The estimated changes in water quality chemistry were used to analyze improvements in fishing opportunities to recreational anglers due to increased fish populations. (Refer to the linkage section in Chapter 6). These changes include both increases in the number of fishing sites available and improvements in the quality of existing sites. A benefits transfer method was used to estimate an angler's willingness to pay (WTP) for projected changes in the number and quality of trout fishing sites in the SAMI region.

This study applies only to native brook trout because this species is indigenous to streams more effected by ANC, it is frequently targeted by recreational anglers, and data is available to estimate ANC changes on brook trout density. Changes in fish biomass (the amount of fish) from improved ANC were estimated using a computer model which links ANC and fish biomass. The model looked at changes from one ANC classification to another, not changes within an ANC class. See Chapter 6, Table 6.1.

Results

Table 8.1 shows the estimated brook trout biomass for streams in each of the five ANC classes. Effects of the emissions management strategies on stream ANC categories or classes were specified by ranges of ANC rather than by specific point estimates. Low, mid-point, and high ANC were used to estimate a range of brook trout biomass for each ANC class. The first estimate of brook trout biomass was in kilograms per 0.1 hectare, from which a conversion factor was used to express fish biomass in pounds/acre. The change in fish biomass allowed a monetary value to be placed on increased fishing opportunities for anglers. The resulting estimates for the average that anglers are WTP per trip per amount of fish available to catch (low, medium, high) are given in Table 8.2 for the three SAMI scenarios A2, B1, B3 in the years 2010 and 2040. All dollar amounts in Tables 8.2-8.7 are in year 2000 dollars. WTP angler participation in Tables 8.2 and 8.3 for years 2010 and 2040 was adjusted to reflect changes in demographics in the SAMI region, but not for income growth in 2010 and 2040.

Table 8.1: Conversion of stream ANC to brook trout biomass.

ANC Range (µeq/L)	ANC (µeq/L)			Biomass (kg/.1ha)			Biomass (lbs/acre)		
	Low	Mid-point	High	Low	Mid-point	High	Low	Mid-point	High
Less than 0	0	0	0	0.7	0.7	0.7	1.3	1.3	1.3
0 to 20	0	10	20	0.7	1.0	1.3	1.3	1.8	2.3
20 to 50	20	35	50	1.3	1.6	1.9	2.3	3.0	3.6
50 to 150	50	100	150	1.9	2.7	2.9	3.6	4.9	5.4
Greater than 150	150	150	150	2.9	2.9	2.9	5.4	5.4	5.4

Table 8.2 combined the estimated angler's WTP for brook trout fishery improvements in the SAMI region with the estimated level of angler participation in trout fishing in the SAMI region to estimate the total economic value of trout fishing improvements. Tables 8.2 and 8.3 quantify the WTP for the increase in ANC in the counties in West Virginia shown in Figure 8.1. Using this methodology, it was found that the quantified recreational fishing benefits from changes in acid deposition are substantially lower than benefits from visibility improvements.

Limitations and Uncertainties

Limitations of this fishing study include: (1) the changes within ANC classes are not considered; (2) the focus on only one species—brook trout (Recreational anglers frequently target brown and rainbow trout); (3) the consideration of only one benefit category - recreational trout fishing; (4) the focus on a small geographic area, a contiguous eight county area in West Virginia; (Figure 8.1) where streams were estimated to have larger changes in ANC (Figure 6.2 and 6.3), resulting in shifts into higher ANC classes; (5) the focus on a short period of time (from 1995 to 2040), which may not be enough to adequately capture the benefits of water chemistry improvements because acidification and recovery occur over much longer time periods; (6) the location of actual benefiting streams and anglers is not known and (7) no adjustments were made to the WTP estimates to reflect the growth in real income in 2010 and 2040.

Most of the above factors are likely to result in an underestimation of the total benefits from improvements in ANC. However, overestimates of benefits related to distances anglers are willing to travel are also possible. If the improving streams are farther than the angler's are willing to travel, then the average travel distance benefits will be too high.

Observations

Using the results of the study submitted by the contractor, the SAMI Socioeconomic workgroup observed that:

- Brook trout improvements provide a small incremental benefit to the total value of SAMI strategies compared to visibility.
- Willingness to Pay for water quality improvements in the eight-county region of West Virginia ranges from a low of $500,000 in 2010 to a high of $4.4 million in 2040.
- The benefits analysis focused on a small geographic area where the largest ANC changes occurred.
- The results showed small increases in total WTP across all strategies.
- The estimated economic value of fishery improvement in the SAMI region under strategy B1 is $1.2 million in 2040. (Larger benefits may accrue if shifts within ANC classes were measured). B1 increases are less than half the increase in the value per trip under B3.
- The estimated economic value of fishery improvement in the SAMI region under strategy B3 is $4.4 million in 2040.
- The trend is toward increased fishing benefits as air quality improves.

TABLE 8.2: Average willingness to pay per angler per trip for different levels of biomass (benefit in 2000 $).

	Baseline Average WTP under A2 Biomass			Change in Average WTP under B1 Biomass			Change in Average WTP under B3 Biomass		
Year	Low	Medium	High	Low	Medium	High	Low	Medium	High
2010	$ 56.47	$ 56.77	$ 56.89	$ 0.08	$ 0.08	$ 0.08	$ 0.18	$ 0.18	$ 0.18
2040	$ 58.82	$ 59.05	$ 59.14	$ 0.15	$ 0.15	$ 0.15	$ 0.54	$ 0.54	$ 0.55

TABLE 8.3: Estimated total willingness to pay for water quality improvements in the Northern Plateau Region of West Virginia (benefit in millions of 2000 $)

	Strategy (B1) (Biomass Level)			Strategy (B3) (Biomass Level)		
Year	Low	Medium	High	Low	Medium	High
2010	$0.5	$0.5	$0.5	$1.2	$1.2	$1.2
2040	$1.2	$1.2	$1.2	$4.4	$4.4	$4.4

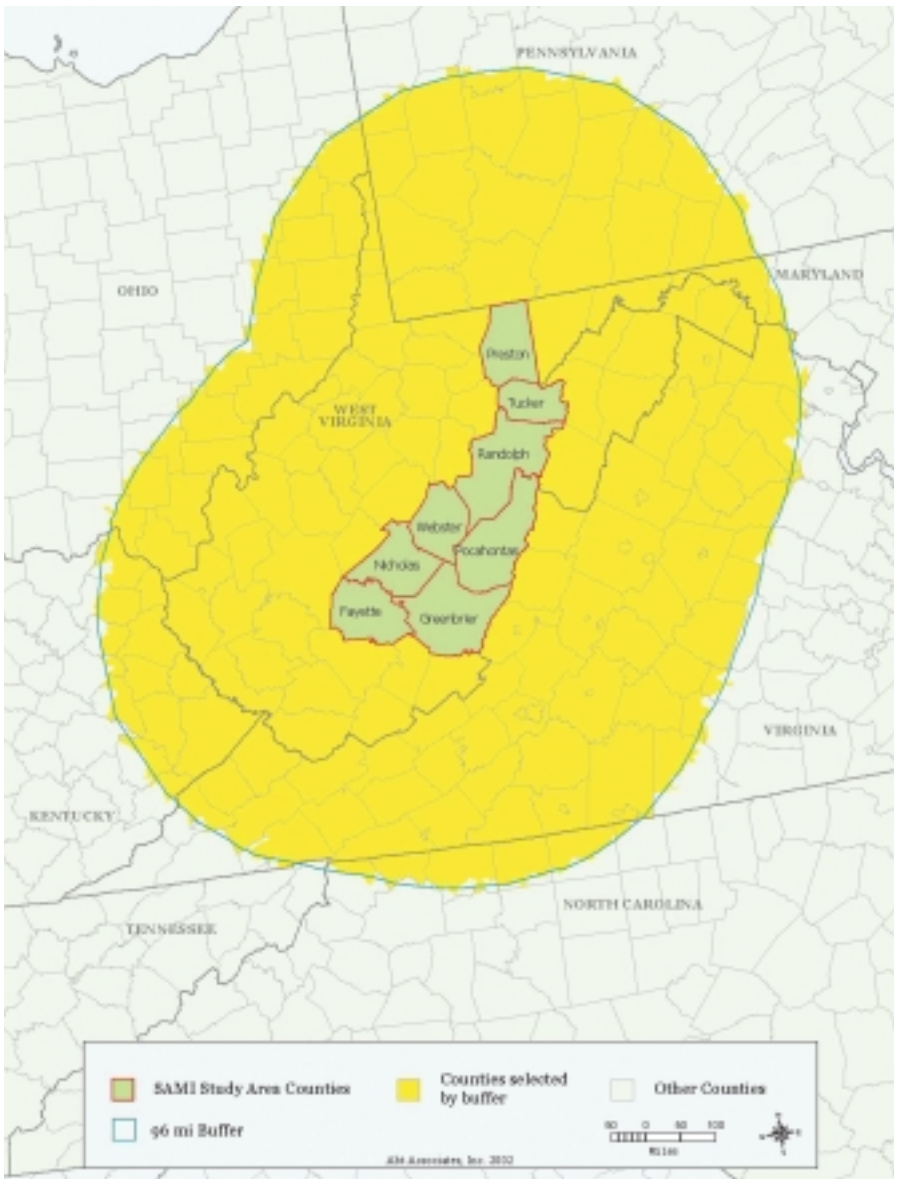


FIGURE 8.1: Fishing study area in the Northern Plateau Region, 8 contiguous counties in West Virginia.

VISIBILITY

Objectives

The objective of the visibility assessment was to evaluate the socioeconomic impacts of visibility improvements from SAMI emissions reduction strategies, in and around the Class I areas. Reductions in emissions were measured in a visual range, light extinction, or Deciview measure (refer to Chapter 4, Visibility). A monetary value on people's desire for clear views (WTP) was calculated by combining the emission reductions from the SAMI strategies with a WTP estimate of unit reduction in emissions. Visibility includes recreational visibility (WTP for visibility improvements in Class I areas), which assumes people everywhere in the country want good visibility in Southeastern U.S. National Parks, whether they plan to visit them or not. An analysis was also done for residential visibility, which measures people's WTP for good visibility where they live.

Methods

SAMI's atmospheric modeling contractor prepared visual air quality profiles for A2, B1 and B3 emissions reduction strategies, in and around the Class I areas. The socioeconomic analysis used a benefit transfer method to estimate the amount of visibility improvement that average households are willing to fund. The benefits transfer methodology estimates the value of such improvements by transferring benefit factors from similar and existing studies.

BENEFIT TRANSFER STUDIES

Though there have been a number of visibility valuation studies, only two gave monetary estimates of the visibility changes in the Southeast. One is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990) at National Parks in the Southeast with particular emphasis on Shenandoah National Park. It was chosen to serve as the basis for the recreational estimate of visibility benefits in the SAMI analysis. The other is a study on residential visibility conducted in 1990 (McClelland et al., 1991), which was chosen as the basis for the estimate of SAMI residential visibility benefits. Both studies chosen for this analysis use a contingent valuation method. Contingent valuation (CV) places a dollar value on people's desire for improved visual air quality by asking them what they are willing to pay for improved views. It must separate this desire from other effects of emission changes. McClelland conducted a CV study of residential visibility in Atlanta. Chestnut and Rowe included a CV study of visibility at parks in the Southeast with particular emphasis on Shenandoah National Park.

BENEFIT TRANSFER FUNCTION

In order to estimate the value of recreational visibility improvements a general relationship between the amount of improvement in visibility and the average value households place on that improvement (based on Chestnut and Rowe) was calculated. This was done for residents of the Southeast, the rest of country, and each of 10 Class I Areas (requiring apportionment of benefits among the Class I Areas and the wilderness areas in the SAMI region based on McClelland et. al.).

Residential visibility was estimated separately. Using the benefit transfer function, the Chestnut and Rowe and McClelland-based WTP parameters, the projected visual air quality for strategies A2, B1, and B3, and the corresponding future year population, an estimate of each household's WTP for visibility improvements was developed. The sum of household WTP for recreational visibility improvements equaled the total estimate of recreational visibility benefits. Similarly, the sum of household WTP for residential visibility improvements equaled the estimate of total residential visibility benefits. The following Table 8.4 illustrates the findings for primary recreational relative visibility benefits.

Results

Table 8.4 shows the total benefits for each control scenario in 2010 and 2040 as well as the portion of total benefits attributed by individuals both within and outside of the SAMI region. Recreational visibility benefits are based on the change in visibility at each of the Class I areas and therefore apply to each park Class I Area (Table 8.5). Estimates of residential visibility benefits within the SAMI region were higher than those of recreational visibility (Table 8.6).

TABLE 8.4: Primary recreational visibility benefits* in the SAMI region and non-SAMI region (millions of 2000$)

Year	Strategy	Region	Benefits
2010	A2 to B1	National	$796
		SAMI 8 State Region	$155
		Non-SAMI Region	$641
	A2 to B3	National	$2,502
		SAMI 8 State Region	$482
		Non-SAMI Region	$2,021

Year	Strategy	Region	Benefits
2040	A2 to B1	National	$1,474
		SAMI 8 State Region	$301
		Non-SAMI Region	$1,173
	A2 to B3	National	$2,705
		SAMI 8 State Region	$555
		Non-SAMI Region	$2,150

* SAMI Region value represents the WTP for visibility improvements from populations within the SAMI 8 State region
** Non-SAMI region value represents the WTP for visibility improvements in Class I areas of the SAMI region that is valued by populations outside the SAMI region.
*** SAMI Region plus non-SAMI region equals National.

TABLE 8.5: Primary recreational visibility benefits* apportioned by Class I Area (millions of 2000$)

Class I Area	2010		2040	
	A2 to B1	A2 to B3	A2 to B1	A2 to B3
Great Smoky Mountains	$561	$1,810	$952	$1,724
Shenandoah	$229	$673	$511	$961
Cohutta	$3.0	$9.3	$5.4	$9.9
Dolly Sods	$0.4	$1.1	$0.6	$1.4
James River Face	$0.1	$0.4	$0.3	$0.5
Joyce Kilmer-Slickrock	$1.3	$3.5	$1.9	$3.4
Linville Gorge	$0.5	$1.3	$0.7	$1.3
Otter Creek	$0.2	$0.5	$0.3	$0.7
Shining Rock	$0.7	$2.3	$1.1	$2.0
Sipsey	$0.3	$1.1	$0.7	$1.1

TABLE 8.6: Supplemental estimate of residential visibility benefits (entire modeling domain).

Year	Strategy	Benefit (Millions 2000$)
2010	A2 to B1	$224
2010	A2 to B3	$1,022
2040	A2 to B1	$791
2040	A2 to B3	$1,463

* The analysis creates a distinction between primary (recreational) and supplemental (residential) visbility benefits to highlight the uncertainty present within each estimate. Primary benefits, though uncertain, are a better estimate of the magnitude of recreational visibility benefits. Supplemental estimates of the value of improvements in residential visbility are more uncertain than the primary benefits.

** Totals do not reflect adjustments for income growth, which would increase benefits in 2010 up to 27% and in 2040 up to 82% using EPA's methods (applies to Tables 8.4, 8.5 and 8.6).

Limitations and Uncertainties

The estimates of recreational and residential visibility valuation are uncertain and controversial. There are many potential sources of information that could shift the results up or down. Assumptions were made using available data to estimate visibility valuation (using techniques from prior Federal visibility assessments) associated with improved visual air quality at Class I areas in the SAMI region under SAMI's strategies. A detailed discussion of the uncertainties is provided in the socioeconomic report on visibility (refer to the ABT Associates in the reference section).

Observations

- Visibility improvements will have a value to both individuals living in the SAMI Region as well as to individuals throughout the U.S. Table 8.4 shows that 80% of the benefits for visibility improvement are for non-residents who live outside the SAMI region.
- The per park recreational visibility benefits show that, across the scenarios, the Great Smoky Mountains National Park and Shenandoah receive the bulk of the visibility improvements benefits.

SENSE OF PLACE/ STEWARDSHIP

Objective

The Sense of Place/Stewardship component of the assessment addressed the quality of life associated with living in a specific area. Its objective was to expand the impact analysis of air pollution policies beyond traditional "endpoints", to explore relationships in the Appalachian mountains between air pollution and "What makes this place this place?" to local residents.

Sense of Place is oriented towards past and present while stewardship addresses preservation for future generations. The topics of Sense of Place and Stewardship share common components, such as personal experience and opinions, as well as facts, myths, and individual values. Many elements are intertwined such as: people's sense of family, community and history. The environment is just one aspect. The economy (types of employment, income, cost of living and unemployment levels) is another variable.

Sense Of Place

The U.S. Environmental Protection Agency developed a broad definition of Sense of Place in the Community Social and Cultural Profiling Guide (1997): "[the] local values, beliefs, and behaviors as they relate to community life and the surrounding natural environment." These include: community capacity and activism; community interaction and information flow; demographic information; economic conditions and employment; education; environmental awareness and values; geographic and administrative boundaries; governance; infrastructure and public services; local arts, history, and tradition; local identity; local leisure and recreation; natural resources and landscape; property ownership, management, and planning; public safety and health; and religious and spiritual practices.

Stewardship

Stewardship involves a set of distinct values often associated with unique, irreplaceable, environmental assets that people want to maintain for future generations. It further involves accepting or assigning continuing responsibility for preserving what residents' value about the place they live.

Methods

Information on residents' feelings about Sense of Place/Stewardship was gathered through six focus groups held at three locations. Three locations in the Southern Appalachian region were chosen to represent different perspectives. These were:

- Traditional Appalachian economy, Madison, WV, a small coal mining town in Boone County, located 35 miles southwest of Charleston, WV.

- Tourist and recreation destination, Asheville, NC, a rapidly growing small city that is an important tourism and recreation center in the Carolina Mountains. Asheville is also a growing retirement destination.

- Growing metropolitan area, Knoxville, TN, a medium size city in the immediate mountain area. Knoxville has a diverse economy, with tourism (as a major gateway to the Smoky Mountain recreational destinations), a high tech sector (through the University of Tennessee, Oak Ridge National Laboratory, and the Tennessee Valley Authority), and traditional Appalachian manufacturing.

Two focus groups were held in each location. Participants were recruited via random telephone solicitation in Madison and newspaper advertisements in Asheville and Knoxville. A topic guide was developed and followed in the discussion process. It was divided into 4 key sections:

- What makes this place, this place?,
- Where do you see this place heading in a generation?,
- What are the essential aspects of the economy, and
- What about the environment makes "this place, this place"?

Participants were instructed not to try to agree, but to express their own thoughts. As with all focus group research, the small sample size (3 locations, 48 people) does not represent the full population, but is an illustrative sample. The focus group sessions were recorded and transcribed.

Results

Focus group participants seemed to understand the concepts of quality of life and environmental stewardship. They spoke about responsibility, preservation, and conservation of both the environment and quality of life. Madison focus group participants talked about stewardship in terms of "putting things right" with respect to the environment and "restoration" with respect to their way of life, and preserving jobs for the future. They wanted to make sure that coal-mining companies that altered the land left it in usable condition (not necessarily its original condition) after they were through with it. This implied a kind of social contract between area residents and these industries. Most of all, Madison participants wanted to retain their way of social life as a close knit, caring community. They were concerned about young people staying in their community and deeply pessimistic, even fearful about the future of their town. They were doubtful that new jobs would be created and wanted coal mining to continue, as mining wages are higher than other wages. Few non-mining "good jobs" exist in Madison.

Asheville participants talked about stewardship issues in terms of the conflict between individual rights and the good of the community in land-use zoning. They saw zoning as a "hugely contentious issue," with large consequences for preservation of Asheville residents' quality of life. The dominant view was that land use regulations or zoning is a good thing, in order to prevent Asheville from turning into a "giant trailer park," or a little Atlanta, "where you have convenience store, grocery store, house, house, house." Asheville participants also spoke about effective planning on the local level: how this had already paid off in an aesthetically pleasing urban area, and how it would continue to work to preserve Asheville residents' quality of life. A number of participants talked about a "gardening mentality" which cultivates now for benefits in the future.

Focus group participants' sense of Knoxville revolved around (1) the Smoky Mountains and other mountains in the area, (2) the University of Tennessee, and (3) a feeling of division, or dualism, that splits the city in various ways. Throughout the discussions, participants expressed an understanding that the environment, economy, and culture are all interrelated.

In particular, the influence of the mountains can be seen in "the independence of the people – they're stubborn." In addition, the people are "neighborly ... and there's a lot of good in that," "very caring," "hospitable [and] friendly." Participants perceived other regional traits: "When you need somebody to do something and you need a volunteer to step forward, this part of the world

is there." And: "the people seem to have more of a sense of self in this area … knowing where they came from. The history … you have a big comfort and a sense of where you belong and where you're going."

Though there are individual differences, the six focus groups' discussion of stewardship were similar in the following views:

- Not all area residents would agree on all the elements that would make up a desirable future. Participants felt that the probable way their area's environment or way of life or both would be preserved was political. All six focus groups had a significant political content although politics was not included in the topic guide. The Knoxville discussions were a good example. Participants perceived a lack of effective future city planning. Poor communication between government and citizens and fighting between city and county contributed to Knoxville residents' lack of confidence in planning for the future. As one person said, "You've got those two separate entities that are fighting when what they should [do] is come together for the better of the community."
- If the environment is going to be properly protected, it will be "government" that will have to do the job. There were differences regarding which level of government – City, County, State, Regional, National – ought to be the responsible party. In Knoxville, University of Tennessee educational programs were also anticipated to influence the future.
- Respondents' felt they were not personally responsible for environmental and social problems, others were. In Madison, these "others" were industry and government. In Knoxville, the "others" were tourists, whose cars bring pollution; Oak Ridge; power plants in other States; and developers. In Asheville, the city of Charlotte, N.C.; out-of-State power plants; and anti-zoning residents were the primary culprits. Focus group participants did accept that their own automobiles helped cause pollution.
- All respondents were concerned about economic matters like jobs, more than the environment, but generally they would prefer to have both be in good shape.

Observations

Sense of Place/Stewardship has implications for SAMI region air policies. It is a complex issue as diverse as the residents of the mountain region. Based on the results the Socioeconomic work – group observed that:

- The Southern Appalachians are very diverse, and residents differ deeply in their opinions.
- The environment is an important element in Appalachian resident's Sense of Place. The outdoors, especially the mountains, hold a special place in people's sense of what makes their place special. Air quality is seen as critical for tourism and recreation.
- There is a strong awareness of locale, geography: all groups "situated themselves" emphatically in Southern Appalachia and strongly identified with the mountain region.
- There is a deep preoccupation with economic issues and economic trends that were perceived to be distinctive to each locale.
- The cost of living and job losses are major concerns. In some areas the loss of good paying, working class jobs is already felt. There is concern that more will be lost in the future and worry that the "little guy" will be forced out. The "new economy" may hurt long time residents. Lower income people are worried that they may be priced out of their areas
- Focus group participants' general belief is that air pollution is caused somewhere else and is not "home grown".
- Residents are aware of Local, State and Federal governments' role in protecting the quality of life. Air pollution and other environmental issues were mentioned in all focus groups. An example is in Madison where participants accepted the environmental damage from coal mining, but insist that mining com-

panies "follow all the rules." They had harsh criticism for "bad" mining companies and those in the lumbering industry that are seen as causing excess damage.

- The concern for future generations focused on growth (too much or too little), maintaining cultural values of the area (the feel of the area and the Appalachin heritage) and ways to inspire younger generations to stay or return to the area.

LIFESTYLES

Objective

The Lifestyles topic qualitatively assessed the potential impacts of SAMI strategies on household lifestyle changes associated with air emissions regulation. Improving air quality requires restrictions on emission generating activities of both consumers and producers. Restricting consumer activities affects household well being directly because individuals must seek alternatives to activities (including the consumption of goods and services) that are affected by emission reduction strategies. Restricting the activities of producers affects households' well being indirectly through effects on prices and employment.

Methods

Lifestyles is a qualitative and not comprehensive study that was developed from reviewing the SAMI strategies and developing types of effects:

- Direct effects affect consumer goods or activities generating emissions.
- Indirect effects affect producers of goods and services generating emissions.

SAMI strategies were used in order to characterize the qualitative effects on consumer lifestyles.

Case study companies were chosen for the competitiveness topic and linked to lifestyles, before it was decided to drop the competitiveness topic. They represent industries (listed under indirect impacts) that must make large emission reductions that would possibly negatively impact households. Air quality improvements resulting from implementing the SAMI strategies are also likely to have positive effects such as potential improvements in health, visibility, and opportunities for recreation. Some of these benefits have been estimated and described in other components of SAMI's Integrated Assessment and are not described further in this lifestyles assessment.

Direct Impacts on Consumers

The SAMI strategies assume emission reductions for vehicles and residential fuel combustion. Reduced vehicle emissions are to be achieved by more stringent emission controls for onroad vehicles, the gradual market penetration of onroad zero emission vehicles (ZEVs), reductions in the growth of onroad vehicle miles traveled (VMTs), and substituting ZEVs for nonroad gasoline lawn, garden, and recreational vehicles. Plans for reducing emissions from residential fuel combustion include efficiency improvements for residential natural gas combustion, and substituting natural gas for residential wood and coal combustion. Each of these measures will directly affect household well being by requiring changes in consumer behavior.

Consumers will incur additional costs associated with higher emission standards for onroad vehicles and replacing conventional vehicles with ZEVs. Given the current state of technology, the performance of ZEVs is inferior to that of conventional vehicles and raises safety concerns. Nonroad ZEVs have lower operating costs than gasoline vehicles, however, the up front cost of these ZEVs is currently higher.

From the perspective of consumers, there are both potential advantages and disadvantages associated with strategies to reduce VMT growth rates. Advantages include the amenities and lower expense of telecommuting, ridesharing and public transportation, and the convenience of high occupancy vehicle lanes. Reducing VMT growth rates will also reduce highway congestion. Potential disadvantages include possible loss in worker productivity, loss of workplace amenities, the inconvenience of ridesharing and public transportation, and the tax burden of subsidies to public transportation.

There are also potential advantages and disadvantages associated with strategies to reduce emissions from residential fuel combustion (fireplaces, wood stoves etc.). The potential advantages include cleanliness, convenience, reliability, and efficiency improvements. Potential disadvantages include the costs of switching to natural gas and loss of aesthetics and aromatics. Localized unavailability of natural gas supplies is another potential problem.

Indirect Impacts: Price and Employment Impacts

The analysis of potential price and employment impacts focused on ten "case study" industries. These include: electric utilities, textiles, paper and paperboard, chemicals, primary metals, natural gas transmission, coal mining, liquid fuel providers, and railroads. Each of these industries is expected to be affected by the SAMI strategies.

The SAMI strategies have the potential for causing price increases in the following industries: electric utilities, textiles, paper and paperboard, chemicals, primary metals, and natural gas transmission. Each of these industries is expected to have higher production costs and may attempt to pass on some of these costs through price hikes. Their ability to do so will be limited by the availability of substitutes and by competition from producers outside the SAMI region.

Coal prices are more likely to decrease than increase under the SAMI strategies. The demand for coal is likely to fall because the SAMI strategies call for switching away from coal combustion to fuels with lower emissions, particularly natural gas. The exception is if scrubbers can clean local coal and it is more advantageous to use due to lower transportation costs.

Price effects for railroads, trucking and liquid fuel providers are uncertain. The demand for rail services is likely to increase because of converting truck traffic to rail. However, this effect will be offset, at least partially, by lower demand for coal traffic. The trucking industry is expected to incur increased operating costs because of higher emission standards and conversion to heavy duty ZEVs. These higher costs will tend to increase prices in this industry. In contrast, converting truck traffic to rail will decrease demand for trucking services, and tend to depress prices. The demand for liquid fuel will likely fall because of market penetration of ZEVs and reductions in VMT growth rates. However, the reduction in demand, especially under strategy B3, is substantial enough to change the structure of the industry, reduce spatial competition, and possibly increase distribution costs. The effects of the strategies on liquid fuel prices are uncertain at this point in time.

Employment losses resulting from the SAMI strategies could occur in the following industries: electric utilities, textiles, paper and paperboard, chemicals, and primary metals since each of these industries is expected to incur higher production costs as a result of the strategies. Higher prices could reduce the demand for their products, causing firms to reduce output and employment. Also, some firms in these industries could become unprofitable and close down operations. Employment losses in the coal mining, liquid fuel provider, and trucking industries are also possible because of reduced demand.

The employment impacts on the natural gas transmission and railroad industries are uncertain. As noted earlier, the natural gas transmission industry is expected to incur higher operating costs. However, the demand for transmission services is likely to increase as a result of fuel switching strategies. Railroads will pick up new traffic diverted from trucking, but are likely to lose coal traffic.

Of the ten case study industries, projected baseline employment for the SAMI region is largest in the trucking industry. However, employment in the coal mining industry is concentrated largely in two States, Kentucky, and especially West Virginia. This raises the potential for adverse impacts on local economies.

While this analysis focuses on employment losses, we note that the SAMI strategies are also likely to generate positive employment impacts. Examples

include potential employment gains in the tourist industry (due to improved air quality) and increases in employment associated with manufacturing, installing, operating, and maintaining emission controls.

Observations

Across all sources, strategy B3 calls for larger emission reductions than B1. As a result B3 will have larger impacts on households in 2010 and 2040. Restrictions on consumer activities and price impacts may be smaller in the long run. Over time, consumers have better opportunities to adapt and to find substitutes for higher priced goods and services. Employment impacts may be small in the long run. While length of unemployment spells are likely to vary considerably depending on individual circumstances, the economy tends to absorb available labor resources in the long run though not always with equivalent employment. An example would be with mining towns or manufacturing towns where the industries have shut down.

While these factors tend to mitigate impacts in the long run, other factors may worsen impacts. Both strategies B1 and B3 call for progressively larger emission reductions over time, suggesting larger impacts on households. Also, employment impacts may be increased in the long run if producers outside the SAMI region, both domestic and abroad, increase capacity in industries affected by the strategies.

UNCERTAINTIES

Uncertain technological advances may mitigate some of the impacts of the strategies by providing more environmentally friendly consumer goods and more efficient low-emission production technologies. The rate at which States outside the SAMI region adopt strategies for emissions generated by producers is also uncertain. International competition adds uncertainty about jobs leaving the area. The employment impacts of the SAMI strategies will be mitigated if producers outside the region face similar emission controls. Long-run expansion of capacity outside the SAMI region might mitigate price impacts, but have negative employment impacts inside the region if energy prices are not competitive.

KEY FINDINGS

1. SAMI decided early in the socioeconomic assessment to focus on a few topic areas of the dozens possible where socioeconomic effects are likely to be felt in response to emissions management decisions. The SAMI analysis cannot be considered a comprehensive cost-benefit analysis and costs cannot be compared to benefits. Socioeconomics is a complex topic and whatever topics you pick will limit your study. Stakeholders are needed with expertise in the topics chosen to work with the contractors. Start planning in the beginning of your overall study though data may not be available to contractors until late in the process. Be as prepared as you can beforehand. Determine your budget early in the process. Time and resources are needed to be as comprehensive as possible.
2. Since the inception of SAMI different rules and regulations have been promulgated. As other programs are implemented, the impacts on costs, benefits and lifestyle will be less. The total estimate of the monetary benefits of visibility and fishing improvements ranged from 796.5 million 2000$ to 3.9 million 2000$.
3. Communication with citizens is important. The SAMI analysis suggests both positive and negative effects are likely to be felt in communities throughout the SAMI region.

INCENTIVE PROGRAMS

INTRODUCTION

Incentive-based approaches may offer an alternative to command and control regulation and possibly achieve earlier and larger reductions in emissions. These approaches can, at least theoretically, offer opportunities for achieving emissions reductions at lower cost and with greater flexibility than specific control requirements. They offer more implementation choices, and reward those who do more than is required. However, since incentive-based approaches rely upon market mechanisms and voluntary behavioral responses, the outcomes from such approaches can be more difficult to predict than traditional control mandates.

SAMI, with contractor assistance, investigated incentive-based approaches to air quality management in the hope that all stakeholders could agree on an approach to improving air quality outside the traditional regulatory framework. Two areas were examined – incentives to affect consumer behavior (ICF Consulting, 2001) and incentives to affect the behavior of organizations responsible for air emissions (BBC Research and Consulting, 2002). The consumer study looked at two main areas: transportation policies to reduce emissions and building technologies to reduce energy use. The organizational study examined a wide range of programs that provide incentives to companies/organizations to reduce their emissions.

While SAMI does not recommend any particular incentive-based approach, the information contained in this chapter may be useful to States and other stakeholders considering various emission management options. It is difficult to predict and quantify the results of incentive-based approaches because of uncertainties related to the underlying assumptions and because it is difficult to predict individual or organizational behavior. Anyone interested in adopting the incentives discussed in this chapter should carefully review the assumptions employed and develop local data for estimating the relative costs and benefits of the programs being considered.

CONSUMER INCENTIVES

Transportation Policies/Incentives

Transportation demand is projected to continue to grow at a rapid pace if current vehicle use and settlement patterns continue. In the SAMI region, vehicle use (measured in vehicle miles traveled, or VMT) is growing at a faster rate than population. By 2010, vehicle use is predicted to increase 70% from 1990 levels. Highway vehicles and utilities are the largest human sources of nitrogen oxides, and highway vehicles are the largest human sources of volatile organic compounds. Incentives that affect transportation demand could have a significant impact on air quality.

Fourteen different strategies were analyzed for their potential to reduce VMT and emissions. All the strategies were judged to be technically feasible and likely to affect emissions, either by affecting vehicle travel or motor vehicle technologies. All of them can be implemented by creating incentives for individuals to change their behavior. The types of strategies examined include: market-based incentives; investments to encourage alternative modes/reduced traffic congestion; land-use or development-focused strategies; and incentives to purchase cleaner vehicles.

MARKET-BASED INCENTIVES

1. **Road pricing –** Convert major bridges, tunnels, and limited access highways into toll roads; implement tolls on new limited access highways.

2. **Parking pricing–** A variety of mechanisms for increasing parking costs, and for making existing fixed parking costs variable. Parking pricing programs tend to discourage automobile trips -- a $2 to $4 increase in parking costs can result in a 10 to 25% decrease in VMT. Parking Cash Out offers the value of parking (paid by employer) to employees in cash, turning a subsidy to driving into an incentive not to drive. (Note – about 95% of all commuters who drive receive free parking.)

3. **Increase gas tax –** Increase the tax on motor vehicle gasoline and diesel fuel. The effectiveness of this incentive depends on consumer reaction to the increased price. Estimates of elasticity of fuel demand to fuel price show that a 10% increase in fuel price produces a 2 to 8% decrease in fuel consumption.

4. **VMT-based fees or pay-at-the-pump auto insurance –** Implement a program to partially or fully charge vehicle insurance on a per-mile basis, thus converting one of the largest fixed costs of vehicles into a variable cost. VMT fees can cause reductions in congestion and pollution because the only way to reduce one's cost is to drive less. The fees can be tied to vehicle registration or auto insurance and can be paid based on VMT or at the gas pump.

INVESTMENTS TO ENCOURAGE ALTERNATIVE MODES/REDUCED TRAFFIC CONGESTION

1. **Improve transit service, speeds and/or reliability –** Increase bus (and rail, where applicable) transit service coverage and frequency. Introduce exclusive bus lanes. Improve transit service using technologies such as signal prioritization, queue jumping, and Intelligent Transportation System (ITS) elements, such as vehicle tracking for headway control. Case studies in various U.S. cities have shown daily decreases in VMT between 18 and 55% after mass transit improvements were made.

2. **Reduce transit fares –** Lower transit fares and/or provide free transit service routes. Restructure fares to maximize mode shift from Single Occupant Vehicles (SOVs), especially for congested periods and corridors.

3. **Improve bicycle and pedestrian infrastructure –** Improve intersections and retrofit existing facilities during major rehabilitations, in accordance with recent American Association of State Highway and Transportation Officials (AASHTO) guidelines. Increase investments in sidewalks, bicycle lanes, signage, bicycle parking, and off-road walking/biking trails. Emissions benefits can be quite large because cold start and hot soak emissions comprise a large proportion of emissions from a vehicle trip.

4. **Increase ridesharing-oriented infrastructure –** Increase number of high-occupancy vehicle (HOV) lanes, especially through conversion of existing lanes. Increase the number of associated park-and-ride facilities. HOV lanes are mainly effective on heavily congested roadways during peak travel times. The effectiveness of park-and-ride lots is particularly tied to available transit and ride sharing options.

5. **Coordination/Information/Marketing for SOV Alternatives –** Develop a comprehensive program to promote alternatives to driving alone, including marketing to promote transportation alternatives, information to facilitate ridesharing, guaranteed ride home programs, flexible hours, telework, etc. Note – this was not analyzed quantitatively due to the difficulty of determining promotional efforts impacts on VMT and emissions.

6. **Aggressive employer-provided Transportation Demand Management (TDM) programs –** State and/or local governments provide tax incentives and/or matching funds for employers who implement commute benefit programs (provision of transit benefits, parking cash-out, ridesharing services, etc.). The effectiveness varies widely with employer commitment, but most employers see excellent results with moderate commitment.

LAND USE / DEVELOPMENT-FOCUSED STRATEGIES

1. **Transit-oriented/center-and-corridor focused development –** Provide incentives to developers that focus growth near transit stations, and pursue a "town center-and-corridor" structure for new growth. Also use disincentives to discourage development in vegetated, undeveloped natural area.

INCENTIVES TO PURCHASE CLEANER VEHICLES

1. **Vehicle efficiency taxes / feebates –** Implement a tax on vehicles that have high emission rates/low fuel-economy, or implement a "feebate" program that taxes high-emission vehicles and offers rebates that lower the purchase price of fuel-efficient vehicles. Substantial rebates could be implemented to encourage purchase of alternative fueled vehicles (AFVs) / low-emission vehicles.

2. **Vehicle retirement / buyback programs –** Implement a program that offers a financial incentive to voluntarily remove a high-emissions vehicle from use.

3. **Provide alternative fuel vehicle (AFV) infrastructure –** Develop fueling stations for AFVs to facilitate increased use; a substantial barrier to purchasing an AFV is that facilities are not widely available to refuel vehicles that do not run on gasoline or diesel fuel.

The SAMI Public Advisory Committee chose nine of the above approaches and the use of Clean Diesel Fuel Technology for ICF to model and evaluate.

TRANSPORTATION INCENTIVES – EMISSIONS RESULTS

The transportation sector emissions Baseline was developed based on emissions inventories already developed by SAMI for highway vehicles as part of its Integrated Assessment. VMT growth was estimated based on the Federal Highway Administration's VMT data from 1990 to 1995; VMT growth factors from EPA were applied to each Metropolitan Statistical Area (MSA); and annual growth rates from 2010 to 2040 were assumed to be the same as those indicated for 2010 to 2020.

ICF began with the Baseline VMT and emissions database prepared by E.H. Pechan. ICF developed a spreadsheet model for each of the incentives that included input costs, response elasticity and other factors. The model then calculated the estimated VMT reductions. Table 9.1 shows the strategies along with a brief description of key assumptions and the expected reductions in VMT for 2010 and 2040.

From this analysis it appears that an aggressive AFV program has the best potential for long-term substantial emissions reductions. VMT-based pricing shows the second highest potential short- and long-term emissions reductions. After these, clean diesel and an increased gas tax show the highest potential reductions. To put these emissions reductions in perspective, SAMI estimates that total NO_X emissions in 2040 will be 2.75 million tons (Table 9.2). A half million tons represents a reduction of almost 20% of the total estimated emissions, which is substantial.

Building Technologies

RESIDENTIAL BUILDING TECHNOLOGIES

ICF identified the following ten energy efficient technologies as most promising for new and existing residential buildings. They are listed below in order of approximate energy savings potential.

1. **Duct Tightening –** Duct leakage is the most significant cause of energy losses in most houses.

2. **Air Sealing and Weatherization –** Air leakage through the home's envelope is the second largest cause of energy losses in most residential buildings.

3. **Increased Attic Insulation –** One of the more effective (and easy) energy efficiency upgrades is to add insulation to the attic of a home, especially for older poorly insulated homes. This upgrade reduces both cooling and heating energy use.

4. **High Efficiency A/C Equipment / Systems –** Space cooling is one of the largest energy end-uses in the southern States. Thus, high efficiency air conditioning equipment is one of the more effective upgrades.

TABLE 9.1: Potential Reductions in Vehicle Miles Traveled (VMT) for 2010 and 2040

Policy	Brief description of assumed stringency	2010 VMT reduction	2040 VMT reduction (or equivalent for fuels policies)
Increase Parking Pricing	$3/day increase	3.4%	4.2%
Gas Tax	$0.50/gallon increase	5.3%	6.6%
VMT-Based Pricing	$0.10/mile (doubles the marginal cost of driving)	17.5%	26.2%
Transit, Bicycle, and Pedestrian-Oriented Development	10% of urban areas affected by 2010, 40% by 2040	1.5%	6.0%
Employer-based TDM	Cuts average commuting by 12% by 2010, by 20% by 2040	1.8%	3.0%
Lower Transit Fares and Improve Service	Fares decrease 50%, service improves 25%	2.4%	2.4%
Aggressive AFV Program (includes incentives to purchase AFVs, refueling infrastructure and mandates)	• By 2010: 10% of travel converted to LEV, 5% to ZEV • By 2040: 50% of travel converted to LEV, 25% to ZEV. • 40% VMT-equivalency of LEV II to conventional vehicles in 2010. • 20% VMT-equivalency of LEV II to conventional vehicles in 2040.	5.6%	32.7%
Increase Rideshare-Oriented Infrastructure	Ridesharing attracts 20% of urban highway trips	1.0%	1.0%
Clean Diesel-Fuel Technology (includes a combination of improved engines, emission controls, fuel improvement or alternative fuels)	• By 2010: 50% of public sector heavy duty VMT penetrated by clean diesel vehicles, 5% of private sector heavy duty VMT • By 2040: 100% of public sector heavy duty VMT penetrated by clean diesel vehicles, 20% of private sector heavy duty VMT	.8%	10%
Aggressive Inspection and Maintenance Program	EPA-estimated benefits of IM240 applied to all SAMI VMT	6.2%	?%

TABLE 9.2: Potential Reductions in NO_X Emissions for 2010 and 2040*

Policy	2010 emission reduction, tons NO_X	2040 emission reduction, tons NO_X
Increase parking pricing	37,483	65,412
Gas tax	58,429	102,791
VMT-based pricing	192,925	408,048
Transit, Bicycle, and Pedestrian-Oriented Development	16,536	93,446
Employer-based TDM	19,844	46,723
Lower Transit Fares and Improve Service	26,458	37,378
Aggressive Alternative Fuel Vehicle (AFV) program	61,736	510,060
Increase Rideshare-Oriented Infrastructure	11,024	15,574
Clean Diesel-Fuel Technology	8,819	155,744
Inspection and Maintenance	68,902	n.a.

* **Note:** The emission reductions cannot be added without taking care not to double count emission reductions. For example, a particular trip may be affected by more than one incentive but the emissions reduced remain tied to that single trip.

5. **High Efficiency Heating Equipment –** Space heating is a significant energy end-use, even in some southern States. High efficiency space heating equipment offers a significant potential to reduce energy use.

6. **High Efficiency Windows –** Solar heat gain through windows is one of the most significant causes of space cooling energy use in southern States. High efficiency (i.e., low-E) windows can reduce solar gains by more than 50%.

7. **Water Heating System Improvements –** Heating hot water can be the second largest energy end-use in some homes. There are several effective upgrades for water heating systems, including: low flow faucets and shower heads, insulated water heater tank wrap, and reduced hot water temperature.

8. **High Efficiency Appliances –** There are several high efficiency appliances available in the market. Refrigerators and clothes washers are two of the more significant energy consuming appliances in homes. High efficiency models can reduce energy use by as much as 50%.

9. **High Efficiency Lighting –** Lighting is a relatively small energy end-use in homes. However, compact fluorescent lamps (CFLs) use less than 20% of the energy consumed by incandescent lamps. Thus, in selected applications, CFLs are highly effective in reducing energy use.

10. **Cool Roofs –** Attics can become as hot as 150 degrees in the summer. Light colored roofs and effective ventilation have been shown to significantly reduce attic temperatures. Cool roofs are gaining recognition for effectively reducing energy use for space cooling.

COMMERCIAL BUILDING TECHNOLOGIES

ICF identified the most effective energy saving technologies for both new and existing commercial buildings. These are listed below in approximate order of energy savings potential.

1. **Commissioning, Auditing, and Baseline Benchmarking –** The process of testing the energy performance of newly installed energy end-use equipment is called "commissioning". This process ensures that equipment is installed properly and is performing as intended. The term "commissioning" is also used to describe a longer term process whereby the energy use of a building is closely tracked over time, and the efficiency of the energy systems are continuously refined. An assessment of current and historical energy use is an effective starting point in an energy efficiency program. When historical energy use is compared to "industry-average benchmarks", the potential for energy saving upgrades becomes immediately apparent. Further, when a building is audited for energy use, many obvious causes of energy waste / losses are readily identifiable. Many of these "problems" are easy one-time fixes that result in significant energy savings.

2. **High Efficiency Lighting Systems –** High efficiency fluorescent lighting systems (i.e., T-8 lamps, electronic ballasts, with reflectors) are the most cost effective upgrade for most commercial buildings. Compact fluorescent lamps (CFLs) are also recognized as an effective alternative to incandescent lighting in commercial buildings. Occupant sensors have been proven to reduce lighting energy use in some facilities by as much as 30%.

3. **Envelope Improvements –** Some commercial buildings have relatively large amounts of surface area. Improvements to roof insulation and windows can significantly reduce energy use in these facilities.

4. **High Efficiency Fan, Pump & Motor Systems –** Fan energy use is the third largest energy end-use in many commercial buildings. High efficiency motors with variable speed drives can reduce fan energy use by as much a 50%.

5. **High Efficiency A/C Equipment / Systems –** Space cooling is the second largest energy end-use in most commercial buildings. Further, high efficiency space cooling equipment is readily available and cost effective. Thus, cooling systems upgrades are effective means of reducing energy use, especially in the southern States.

6. **High Efficiency Heating Equipment –** Significant improvements are available in space heating equipment. These technologies are effective in the southern States with colder climates.

7. **Control Strategies –** The on-off operation of every piece of energy end-use equipment must be controlled. Numerous control strategies are available for each type of equipment. A careful review of available control strategies for the primary energy-use equipment usually reveals significant opportunities for improvement. Common controls include optimal heating and cooling start and stop and improved outdoor air damper controls.

8. **Cool Roofs –** Roofs on commercial buildings are typically very large. Light colored roofs have been shown to significantly reduce summer heat gain through roofs. Thereby, cool roofs are gaining recognition for effectively reducing space cooling energy use in commercial buildings.

9. **Combined Heat and Power Systems (Microturbines) –** A recent trend has been to establish on-site electrical power generation capabilities. This technology is primarily used to assure power availability/reliability. However, it is also used in facilities that require significant amounts of heat (e.g. manufacturing processes).

10. **Photovoltaics (PV) –** Integral wall/envelope panels with PV are becoming increasingly cost-effective. Use of these PV systems is likely to grow in the next couple of decades.

BUILDING TECHNOLOGIES – POLICIES / STRATEGIES

Three general types of policies to promote the voluntary adoption of energy efficiency were evaluated. These policies/strategies may include both programmatic activities (e.g., marketing and implementation support and tracking) and incentives. A detailed market assessment is needed to determine the best mix for any given market. The three types of policies are described below:

Passive Strategies – Program administrative costs are low ($100/home for residential programs, and $0.10/square foot (SF) for commercial programs). Primary program activities include: consumer outreach; contractor education; no consumer incentives; and no contractor incentives. Residential technologies promoted include: duct tightening; air sealing; increased attic insulation; and whole house design. Commercial technologies promoted include: commissioning; high efficiency lighting; and envelope improvements. Example programs include: regional utility programs (with limited funds); and national programs like ENERGY STAR.“

Active Strategies – Program administrative costs are moderate ($400/home for residential programs, and $0.35/SF for commercial programs). Primary program activities include: consumer outreach; contractor education; multi-media advertising campaign; marketing and technical training; no consumer incentives; and moderate contractor incentives (e.g., $250/home for residential programs, and $0.20/SF for commercial programs). Residential technologies promoted include: duct tightening, air sealing, increased attic insulation, high efficiency HVAC; whole house design; and water heating system improvements. Commercial technologies include: commissioning, high efficiency lighting, envelope improvements, high efficiency motor systems, and high efficiency HVAC equipment. Example programs include: regional utility programs (moderately funded), and State programs with Public Benefits Funds (moderately funded).

Aggressive Strategies – Program administrative costs are high ($1,000/home for residential programs, and $0.75/SF for commercial programs). Primary program activities include: consumer outreach, contractor education, multi-media advertising campaign, marketing and technical training, large consumer incentives, and large contractor incentives (e.g. $800/home for residential programs, and $0.55/SF for commercial programs). Residential technologies promoted include: duct tightening, air sealing, increased attic insulation, high efficiency HVAC, whole house design, water heating system improvements, high efficiency windows, high efficiency appliances, high efficiency lighting, and cool roofs. Commercial technologies promoted include: commissioning; high efficiency lighting; envelope improvements; high efficiency motor systems; high efficiency HVAC equipment; and control system improvements. Example programs include State programs with Public Benefits Funds (well funded).

Each of the different scenarios has different technology mixes and different penetration rates. The SAMI study assumed penetration rates for each package of strategies based on the year evaluated, energy efficiency of construction, and whether the building was new or existing. ICF developed a model to calculate energy use for the Baseline case ("business as usual") and each of the three energy efficiency scenarios. Emission factors for Baseline and the scenarios were based on efficiency of the technology, cleanliness of fuel and proportion of energy from different generation possibilities. Dissimilarities exist between the energy use, emissions factors and hence emissions by the above method verses the method used by E.H. Pechan and Associates, which was used in all other areas of the SAMI assessment. Therefore, emission reductions estimated in the building technology incentives analyses should not be directly compared to emission reduction estimates in other sections of this report. The emissions factors were defined for each State for each of the two main pollutants of interest: sulfur dioxide (SO_2) and oxides of nitrogen (NO_X). Then the emissions from the Baseline and each energy efficiency scenario were calculated. The emissions reductions of SO_2 and NO_X for each of these scenarios were the differences between the Baseline and the given energy efficiency scenario.

BUILDING TECHNOLOGIES – RESULTS

Three primary types of results were generated for residential and commercial buildings in the eight-State SAMI region. The first was the total potential SO_2 and NO_X emissions from all of the residential/commercial buildings in the SAMI region for each of the three penetration scenarios. An example of the output for SO_2 emissions is provided in Figure 9.1. Relative to the Baseline emissions in the year 1990, the emissions are fairly stable in time with the "active" energy efficiency scenario. Reductions from the 1990 reference point are only achieved with the "aggressive" energy efficiency scenario. These general trends are similar for the NO_X results (not shown).

The second type of result produced in this study was the potential percent reduction in SO_2 and NO_X emissions from the residential/commercial Baseline in any given year. An example output for SO_2 emissions is presented in Figure 9.2. For any given energy efficiency scenario (e.g., "passive"), the percent value of the reductions increases over time since the penetration rate of upgrades in the building stock will increase in time. The greatest percent reductions in SO_2 occur in the "aggressive" energy efficiency scenario – approaching 40 percent by the year 2040. These general trends are similar for the NO_X results (not shown).

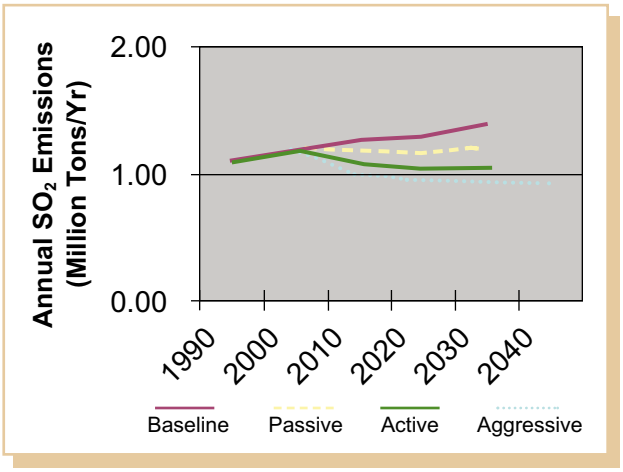


FIGURE 9.1: Potential Annual SO_2 Emissions from Residential Buildings in the SAMI Region

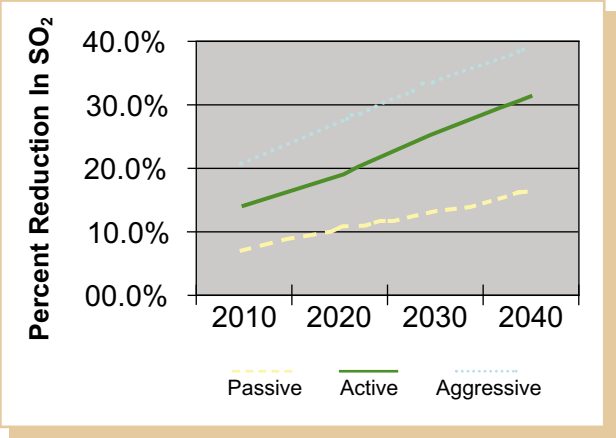


FIGURE 9.2: Potential Annual Percent Reduction in SO_2 Emissions from Residential Buildings in the SAMI Region (Relative to Baseline)

The third type of result was the assessment of the cost-effectiveness of the energy efficiency scenarios. Although the more active and aggressive levels of energy efficiency provide greater savings, they are not more cost-effective. Fairly substantial incentives (up to $800 per home or $0.75/SF of floor area) are required to make these options attractive to consumers.

INCENTIVES FOR ORGANIZATIONS/ INSTITUTIONS

Background and Observation

In September 2001, SAMI contracted with BBC Research & Consulting (BBC) to assist SAMI in developing and evaluating potential incentive-based approaches to reducing emissions in the SAMI region. The focus of this work was on institutional (e.g. firm and organizational) emissions and incentives; consumer incentives were examined by SAMI in a separate effort.

The incentives evaluation was based around a series of workshops with the SAMI Policy and Technical Oversight Committees and, ultimately, with the SAMI Operations Committee. An e-mail survey of SAMI stakeholders was conducted that compiled information from interviews with industry representatives concerning incentive-based approaches. Research on the topics of discussion was through a review of existing reports and studies, telephone interviews with State and Federal administrators of relevant programs and a limited amount of modeling using SAMI's existing emissions inventory and strategy cost estimates.

Key observations from this effort are described in the bullets below:

- **Definition of incentives –** There is more than one definition of what is meant by an incentive-based approach. After reviewing alternative definitions, SAMI participants chose to focus on a broad definition, based on one from the U.S. Environmental Protection Agency, for purposes of this evaluation. It includes any type of mechanism that uses financial means to motivate emission-reducing behavior. Both positive and negative incentives and flexible compliance options such as trading programs are included in this definition and study.
- **Pros and cons of incentive-based approaches –** In general, there are potential advantages and disadvantages of incentive-based approaches relative to more traditional command and control type regulation:

  Pros: Potential advantages include lower cost of reducing emissions, encouraging those who can do more than comply with existing requirements to do so and recognizing that businesses may be able to identify opportunities and more efficient methods of emission reduction.

  Cons: Potential disadvantages are that effectiveness and compliance costs are difficult to predict and monitoring requirements can be intensive. Many, though not all, incentive-based approaches could be expected to have a relatively modest impact on emissions relative to the levels of reduction found in SAMI's potential strategies.

- **SAMI stakeholder priorities –** Based upon the survey of SAMI participants, stakeholders have both hopes and concerns regarding incentive-based approaches. Stakeholders were generally in agreement that the most important criteria in evaluating any incentive-based approach was the environmental benefit it could provide at the Class I sites in the region. Stakeholders differed in terms of other criteria, with industry representatives focused on the importance of low cost to emitters, environmental representatives prioritizing the amount of aggregate emissions reduced and governmental representatives focusing on feasibility of implementation and administration.

- **Industry interviews –** Approximately 25 face to face interviews were held with representatives of 10 of the largest emitting industries in the SAMI region. In general, these representatives were more supportive than not of voluntary incentive programs, though they cautioned that the incentives must be tangible from the firm's perspective and that some existing incentive programs have not delivered as hoped. Financial incentives, such as tax and rebate programs, got more mixed reviews. While many in industry view trading programs as a flexible compliance mechanism rather than a true incentive-based approach, these representatives were strongly supportive of trading programs if mandatory emission reductions are to be established.

Alternatives Studied

SAMI narrowed the list of potential options down to seven varied alternatives that fall into essentially three groups. These groups might be described as low cost and moderate reductions, high cost and high reductions and flexible compliance options.

1. **Low cost and moderate reductions –** Two voluntary incentive-based mechanisms were developed and analyzed in some detail. These alternatives are based upon the most successful voluntary programs to date in the U.S., but each would face a number of challenges in the SAMI context. Potential SO_2 and NO_X emission reductions from either program were estimated at 500,000 combined tons per year or less. Potential incentives include public recognition, expedited or extended permitting and/or State income tax credits. Utility sources may be less responsive to voluntary programs than other industries given more extensive regulation of utility emissions up to this point.

   Alternative A. *Sector Based Voluntary Incentive Program.* Key elements include formation of sector specific groups to identify best practices for reducing emissions and desired regulatory or compliance incentives for the sector.

   Alternative B. *Targeted Emitter Voluntary Incentive Program.* Key elements include specific targeting of the largest emitters in the SAMI region and efforts to generate strong positive public relations regarding participation in the program.

2. **High cost and high reductions –** Three alternatives were analyzed that involve either facilitating the pass through of emission control costs to industry customers, or generating tax revenues and using those revenues to rebate a substantial portion of control costs. These alternatives could be designed to achieve the magnitude of emission reductions envisioned in the SAMI strategies. There is some international, but little U.S., experience with such mechanisms and there would be a number of institutional and political challenges in implementing these alternatives.

   Alternative C. *Utility Cost Recovery Program.* Modeled upon the North Carolina Clean Smokestacks Bill (S1078). Key elements of this alternative include automatic pass-through of allowable emission control costs to utility customers outside of the traditional public utility commission review process. Note – the bill that was passed in North Carolina (in June 2002) utilizes freezing the current rate structure for five years to finance the emission control costs.

Alternative D. *Sector Tax and Rebate Program.* Key elements include the establishment of new taxes on SO_2 and NO_X emissions with the revenues used to defray documented abatement costs in the same sector.

Alternative E. *Cross Sector Tax and Rebate Program.* Key elements include additional taxes on the sale of gasoline in the SAMI region, with the revenues used to defray documented abatement costs for utility and industrial point sources.

3. **Flexible compliance approaches –** Two alternatives based on trading programs were analyzed. Each alternative would primarily serve to reduce the costs and economic impacts if SAMI were to establish a legally mandated regional cap on SO_2 and NO_X emissions.

Alternative F. *Cap and Trade Program.* Key elements include the establishment of a regional cap on emissions and trading rules to allow the creation of a regional allowance market. This alternative was designed to essentially reflect the trading assumptions built into the existing SAMI strategies.

Alternative G. *Cross Sector Trading Program.* In addition to the elements included in Alternative F, this alternative envisions the establishment of rules to allow mobile source credits to be used in the trading program. While this alternative could potentially further reduce the costs to industry, there is little successful precedent for this approach in the U.S.

SUMMARY OF INCENTIVES POTENTIAL EFFECTS ON EMISSIONS

Both the consumer and organization incentives offer potential for significant emissions reductions and are worth considering. For example, if the top two transportation incentives (in terms of emissions reductions) were implemented along with a moderate set of building incentives, annual NO_X emissions could potentially be reduced by about 8% by 2010 and 28% by 2040 (See Table 9.3). The 2040 reductions in this scenario are estimated to be over 1 million tons. SO_2 emissions would also be reduced significantly, by approximately 4% in 2010 and almost 12% in 2040. Other scenarios, using a different combination of incentives/strategies can be estimated from the projections provided in the ICF report.

BBC analyzed each of the organizational incentive options in terms of approximate costs (administrative and implementation/industry) and benefits, with documented assumptions on things such as industry participation and emissions caps. Many of the alternatives offer the potential for significant reductions.

TABLE 9.3. Potential emissions reductions from selected consumer incentives

	NOx reductions (tons/yr)		SO_2 reductions (tons/yr)	
	2010	2040	2010	2040
Transportation Incentives (top two)				
Aggressive AFV program	61,736	408,048	n/a	n/a
VMT-based pricing	192,925	510,060	n/a	n/a
Building incentives (active strategy)				
Residential	70,000	170,000	170,000	440,000
Commercial	30.000	100.000	80.000	250.000
Total emissions reductions	354,661	1,188,108	250,000	690,000
Reductions as % of baseline emissions (approximate)	**8.4%**	**28.3%**	**4.2%**	**11.7%**

Source: ICF Consulting, Demand Management Incentive Strategy Evaluation. Final Report, September 6, 2001.

Table 9.4 shows potential emission reductions with each of the strategies. BBC's analysis combines NO_X and SO_2 reductions for most strategies. Alternatives D, F and G show potential for the largest amount of emission reductions, equivalent to reductions estimated with the B1 strategy. Note that F and G are really flexible compliance strategies for implementing emissions cap and trading programs. After these, Alternative C, modeled after the North Carolina Clean Smokestacks Bill, offers the largest amount of potential reductions. The last column shows the estimated amount of reductions as a percentage of 1990 (Baseline) total emissions for NO_X and SO_2.

Data from both of these incentives studies show that incentives can play an important role in reducing emissions and should be considered for implementation along with regulatory measures.

UNCERTAINTIES

It is difficult to predict individual and organizational behavior, and thus difficult to quantify costs and benefits for the various incentives without making a set of assumptions. The reader should carefully consider the assumptions that were used to estimate potential emission reductions while reviewing the analyses and considering the various incentives.

Some of SAMI's peer reviewers and committee members expressed doubt about ICF's predicted energy savings from building and transportation incentives and emission reductions associated with the energy savings. Additionally, the methods used by E.H. Pechan and Associates and ICF to project future emissions are not identical, so users of this information should compare the Pechan emissions with ICF emissions only after taking note of the additional uncertainty that this comparison introduces. Comparisons between various Pechan estimates or between various ICF estimates are unaffected by this problem.

Table 9.4: Potential emissions reductions from organizational incentives.

	2010 NOx and SO_2 reduction (tons/yr)			Reductions as % of total 1990 emissions
	Utilities	Other Industries	Total	
Organizational Incentives Approaches				
Alt. A - Sector-Based Voluntary Program	212,000	55,000	267,000	2.6%
Alt. B - Targetted Emitter Voluntary Program	489,000	44,000	583,000	5.2%
Alt. C - Utility Cost Recovery	1,556,000	0	1,566,000	15.2%
Alt. D - Sector Tax and Rebate	3,770,000	565,000	4,335,000 *	42.1%
Alt. E - Cross-Sector Tax and Rebate	511,000	175,000	686,000	6.7%
Alt. F - Cap and Trade Program	3,770,000	565,000	4,335,000 *	42.1%
Alt. G - Cross-Sector Trading Program	n/a	n/a	4,335,000*	42.1%

*These reductions are equivalent to reductions for the B1 strategy.
Alt. G requires Alt. F and just shifts the reductions between industrial sectors.

Source: BBC Research & Consulting, Air Emission Reduction Incentives Program Development. Final Report, April 17, 2002

KEY FINDINGS

A few conclusions can be drawn from the consumer incentives analyses:

1. An aggressive alternative fuel vehicle (AFV) program has the best potential for long-term, substantial emission reductions (potential 20% reduction in estimated 2040 NO_X emissions).

2. VMT-based pricing shows the second highest potential short- and long-term emissions reductions. Clean diesel fuel and an increased gas tax show the next highest potential reductions.

3. For the building technology incentives, the greatest NO_X and SO_2 emissions are likely to occur under the aggressive strategies, although potential for significant reductions exists with just the employment of passive strategies.

4. Active and aggressive strategies for building technology incentives offer more potential emission reductions but are not more cost-effective than the passive strategies.

Based upon BBC's research and input from the SAMI committees during this evaluation, several conclusions can be drawn regarding incentive-based approaches focused on institutional participants:

There is no "silver bullet" – There are tradeoffs involved with any of the incentive-based approaches. Generally, those with the lowest costs also offer lower potential benefits (in terms of reductions) and high levels of uncertainty. The study team recognized that SAMI encountered difficulties with an earlier effort to encourage voluntary reductions among regional industries because of concerns that making voluntary reductions would raise the cost of subsequent mandatory reductions to meet forthcoming Federal requirements. Similar issues could arise with new SAMI voluntary programs.

Appropriate incentive-based mechanisms depend on SAMI's objective – If SAMI wishes to use incentive-based approaches as an alternative to mandatory regulation of emitters, the alternatives in the first or second group might be most appropriate. If SAMI wishes to use incentive-based approaches as a means of implementing its strategies, alternatives in either the second or the third group might be the most useful.

Implementation issues – The majority of the alternatives might be most effective if implemented region-wide, though Alternative B and C could be reasonably implemented on a State-by-State basis. While administrative implementation is easier, most of the alternatives may require passage of State legislation in order to be implemented.

Now may not be the time – The SAMI Operations Committee indicated concerns that industry retrenchment during the current economic climate may discourage the success of incentive-based approaches. Individual States may wish, however, to consider developing programs based upon one or more of the seven alternatives at appropriate points in the future.

New taxes difficult to implement in current political climate – Alternatives D and E involve new taxes, and Alternative C implies an increase in utility rates charged to customers. All of these will be difficult to “sell” with current political attitudes.

Incentives may be applicable to other pollutants and other sources – This study only looked at incentives that might reduce emissions of SO_2 and NO_X and focused on larger industries/emitters. Similar incentives may work to reduce other pollutants, especially ones that have not been so heavily regulated, and/or for other or smaller industries/sources.

It also may be easier for States to work together on incentives than on specific regulations. Incentive approaches provide an opportunity for industry and regulators to work together to achieve air quality goals.

CONCLUSIONS AND RECOMMENDATIONS

DEVELOPING RECOMMENDATIONS

Over the years of SAMI's work, its three main committees – technical, policy, and public advisory – appointed subcommittees to closely advise staff and contractors in running various parts of the Integrated Assessment model. They were:

- Emissions Inventory,
- Atmospheric,
- Effects,
- Socioeconomic, and
- Incentives.

These subcommittees met weekly over several years to evaluate the early results of the various modeling contractors and to guide them in refining the Integrated Assessment.

As the subcommittees developed the linked computer models of the Integrated Assessment, the Policy Committee outlined two sets of strategies to run through the atmospheric model. The strategies are described in Chapter 2 – Emissions Inventory. In general, strategies A1 and A2 are reference strategies – A1 covering the Clean Air Act requirements, as they existed in the early 1990s when SAMI began and A2 added requirements like the NO_X SIP call that arose as SAMI was developing its model. Strategies B1 through B3 were designed to "bracket" the likely range of possible future controls. B1 included existing state-of-the-art controls applied to all sources taking into account logistic and other practical considerations. Strategy B3 included emerging prototype controls with the assumption that they would be widely available by the modeling test years of 2010 and 2040. Practical considerations were minimized in the description of strategy B3.

As modeling neared completion, the SAMI Technical and Policy Committees met jointly to guide a systematic process (Figure 10.1) to move from the analyses of the computer models to the recommendations that are intended to guide State and Federal policy makers. Each of the subcommittees provided a series of observations based on the modeling work that they managed. The joint Policy/Technical Committee drew conclusions based on these observations. The conclusions were presented to the SAMI Governing Body, which developed and adopted the recommendations contained later in this chapter.

SAMI's goal was for each recommendation to be directly based on sound scientific analysis. With this systematic process, the thousands of model findings were reduced to the four recommendations listed below that the SAMI Governing Body adopted and intends to implement. Subcommittee observations are found in the Appendix along with a comprehensive list of conclusions, each supported by a set of those observations.

SAMI CONCLUSIONS

Summary Conclusions

- To improve visibility, it is most important to reduce sulfur dioxide emissions.
- To improve visibility, it could become necessary, under certain future sulfur dioxide control strategies, to reduce ammonia emissions.

FIGURE 10.1: Recommendation development process

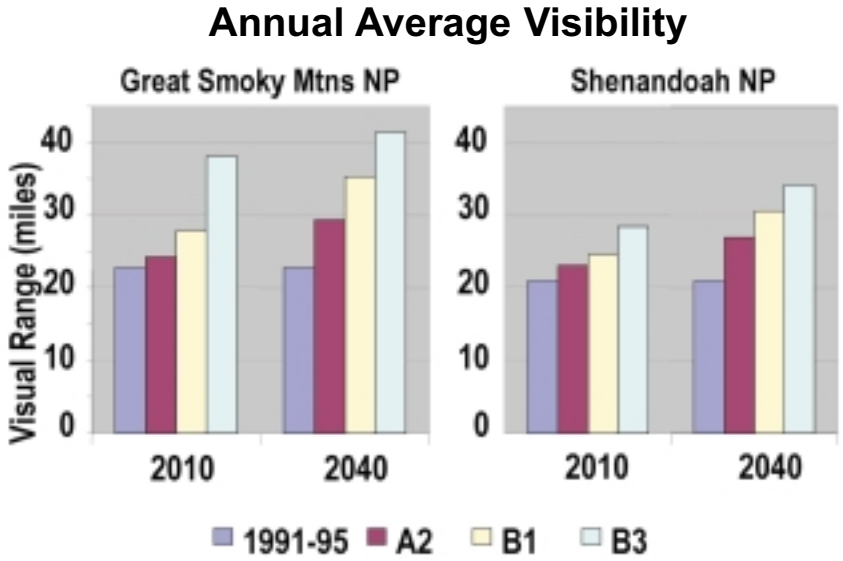
- To reduce acid deposition affecting streams in the central and northern part of the SAMI region, it is important to reduce sulfur dioxide emissions.
- To reduce acid deposition affecting streams in geographically limited areas, it is important to reduce nitrogen oxides and ammonia emissions.
- For high-elevation spruce-fir forests, it is important to reduce nitrogen oxides and ammonia emissions.
- Ozone exposure does not produce a regionwide effect on forest basal area, so nitrogen oxides or volatile organic compounds reductions are not needed for this purpose. However, site-specific ozone effects to certain forest species are a concern for Federal Land Managers and other stakeholders. Nitrogen oxides emission reductions are important to address that concern.
- For SAMI to accomplish its mission, emissions reductions are essential both inside and outside the SAMI region.

Conclusions – Source Attribution

- All States in the SAMI region as well as States outside the SAMI region affect the SAMI Class I areas.
- The effect of nitrogen oxide emissions varies between elevated and low level sources.

Conclusions – Visibility

- Sulfur dioxide emission reductions are the highest priority.
- As sulfur dioxide is controlled in the future, ammonia emissions reductions will become more important. Ammonia can react with nitrogen oxides to form ammonium nitrate, which scatters light similarly to ammonium sulfate. Ammonium nitrate formation is generally limited by the availability of ammonia except in certain winter episodes.
- Volatile organics, elemental carbon, and soil contribute to haze under certain circumstance but they are less important than the emissions discussed above.
- Visibility will improve immediately when emission reductions take place.
- Reductions beyond the A2 strategy (description in Chapter 2) will be required to significantly improve annual visibility. (Figure 10.2).



*based on IMPROVE data and URM modeled change for strategies

FIGURE 10.2: Annual average visual range for the Great Smoky Mountains National Park and the Shenandoah National Park in 2010 and 2040.

- Strategy B1 improves visibility on hazy days from one deciview (Dv) to 2.3 Dv.
- Strategy B3 improves hazy days by up to 5.5 Dv (Figure 10.3)

Conclusions – Ozone Effects To Forests

- SAMI modeling indicates that forest basal area does not greatly change in response to changes in ozone exposures. Some species show a competitive advantage as ozone exposures change and some species are at a disadvantage. These changes in competitiveness did not produce any change in forest type over the range of conditions tested by the SAMI strategies.
- A change in abundance of certain species in Class I areas remains a concern to some SAMI stakeholders. The strategies tested by SAMI did not reduce exposures to approach natural conditions. Nitrogen oxide emissions reductions will be required if ozone exposures are to be reduced.
- The response to the ozone changes produced by the SAMI strategies is small and occurs in the context of other species composition changes that occur naturally over time.
- The ozone changes modeled by SAMI did not significantly alter forest basal area or forest type.

Conclusions – Acid Deposition Effects On Streams And Forests

- Streams in the Central and northern part of the SAMI region that flow over geology that imparts little buffering capacity are at risk from acid deposition.
- Sulfur dioxide emission reductions will generate benefits for aquatic resources in West Virginia, Virginia, and high elevation areas along the Tennessee and North Carolina border. Nitrogen oxide and ammonia reductions will benefit certain sensitive streams in these same areas.

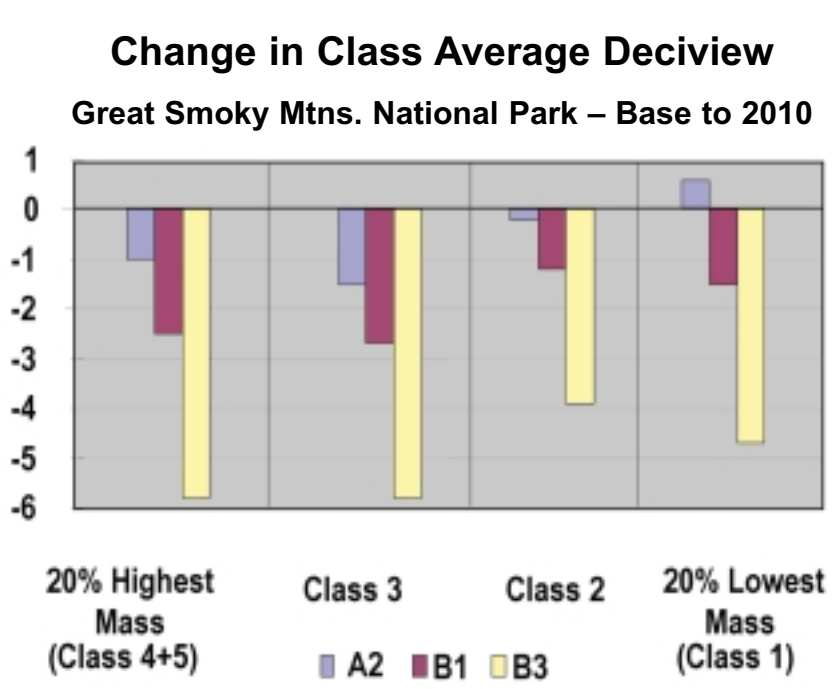


FIGURE 10.3: Change in Class Average deciview for the Great Smoky Mountains National Park

- Most forests in the SAMI region are not at risk from acid deposition. High elevation, slow-growing forests on soils with low buffering capacity are at risk in limited areas of the central and northern parts of the SAMI region. Sulfur dioxide, nitrogen oxide, and ammonia reductions are needed to reduce the impacts to sensitive forests in these areas. The high elevation spruce-fir forests in these areas are the most sensitive to the deposition of nitrogen compounds.
- Stream response to changes in emissions that produce acid deposition occurs over decades and results in small changes in the number of streams that are at risk from acid deposition. Streams with very low ability to neutralize the acid in acid deposition will benefit the most from the changes projected by the SAMI modeling.

Conclusions – Direct Costs Of Emissions Reduction Strategies

- The annualized cost of the strategies for sulfur dioxide reductions modeled by SAMI ranged from $1.2 billion for A2 in 2010 to $8.6 billion per year for B3 in 2040. The total cost per ton for all source sectors ranged from $1218 for B1 in 2010 to $2592 for B3 in 2040.
- The annualized cost of the strategies for nitrogen oxide reductions modeled by SAMI ranged from $3.7 billion for A2 in 2010 to $47 billion per year for B3 in 2040. The total cost per ton for all source sectors ranged from $1372 for B1 in 2010 to approximately $21,500 for B3 in 2040.
- The annualized cost of the strategies for ammonia reductions modeled by SAMI ranged from $0.8 billion for B3 in 2010 to $6.9 billion for B3 in 2040. The cost per ton ranged from $500 to approximately $9600 per ton.
- Mobile sources and ammonia sources control costs are particularly uncertain.

Conclusions – Socioeconomics

- Southern Appalachian residents have a strongly developed sense of place. The also have strongly held opinions from diverse perspectives. Air quality is seen as critically important for tourism and recreation. The cost of living and jobs are important to residents. They are aware of the importance of a government role in protecting quality of life.
- Over time the impact of controls on lifestyles tends to be smaller as consumers have time to adjust. Employment impacts also tend to be temporary as the economy absorbs available labor resources. Uncertainties exist with regard to technology mitigating lifestyle impacts, the participation of surrounding States in similar emission controls, international competition, and expansion capacity.
- Fishing benefits are lower than other topics assessed.
- Residential visibility benefits are projected to be from $224 million to $1.46 billion and recreational visibility benefits range from $796 million to $2.7 billion annually depending on the year and strategy of interest.

Conclusions – Incentive Programs

- Incentives appear capable of implementing emissions reductions in the same order of magnitude as the B1 or B3 strategies.
- Incentives alone are not likely to produce the full emission reductions called for in B1 or B3.
- Incentives are likely to have a larger impact when applied regionally, both because of greater total emission reductions and by avoiding State-to-State inequities for the organizations or individuals affected by the incentives.
- Area and mobile sources may be particularly well suited to incentive approaches.
- Incentive approaches provide an opportunity for industry and regulators to work together to achieve air quality goals.

SAMI RECOMMENDATIONS

Upon consideration of the conclusions presented above, the SAMI Governing Body adopted the recommendations listed below on April 18, 2002 by consensus among the State representatives. These recommendations are not fully endorsed by some electric utilities and by some environmental organizations. Their reservations are described in the SAMI archive (see Additional Data and Resources on page 8).

> The SAMI States support and will promote strong national multi-pollutant legislation for electric utility plants to assure significant sulfur dioxide and nitrogen oxides reductions both in and outside the SAMI region. This national multi-pollutant legislation should result in no less than the reductions for sulfur dioxide and for nitrogen oxides represented by the Administration's Clear Skies Initiative. Reductions from other source categories should also be considered in national legislation, and such national legislation should contain sufficient measures to protect Class I areas. Should the national legislation fail to materialize, the States that participated in SAMI will work together to consider regulatory alternatives and to encourage non-SAMI States to participate. Leadership by States ahead of national legislation is encouraged.
>
> Each SAMI State should seek ways to reduce ammonia emissions from animal feeding operations. Also support should be given in future work such as VISTAS to improve the understanding of the sources of ammonia, to develop better inventories, and to seek more effective control approaches.
>
> Where States have control strategy option choices in their eight hour ozone and fine particle State Implementation Plans, that also have co-benefit for the environmentally sensitive Class I areas, they should choose them. Ambient ozone monitoring should be conducted near all Class I areas in the future.
>
> Each SAMI State should encourage energy efficiency, conservation, and use of renewable energy to reduce the emissions from stationary and mobile sources.

Recommendations Rationale

Strong National Multipollutant Legislation – SAMI concluded that each SAMI State will benefit the most from emission reductions in that State. Surrounding States and many States outside the SAMI region contribute to air quality effects in one or more of the SAMI Class I areas (Figure 10.4). SAMI also concluded that both sulfur dioxide and nitrogen oxides contribute to these adverse effects through acid deposition, ozone and haze. SAMI concludes that a national approach is needed, particularly to ensure participation by States outside the eight SAMI States. SAMI concludes that its mission cannot be accomplished without emission reductions in States outside the SAMI region.

Ammonia from animal feeding operations – SAMI concluded that sulfur dioxide emission reductions are the highest priority for improving visibility. As sulfur dioxide is controlled in the future, ammonia emissions reductions will become more important. Ammonia reacts with sulfur dioxide to form ammonium sulfate and with nitrogen oxides to form ammonium nitrate. Both ammonium compounds scatter light effectively. Ammonium nitrate formation is generally limited by the availability of ammonia except in certain winter episodes. Ammonium compounds also contribute significantly to acid deposition. Since SAMI's emission inventory indicates that many of the ammonia emissions are the result of animal feeding operations, emission reductions from that source

sector are needed. National research is underway which may improve ammonia emission estimates. A collaborative approach with the agricultural community is needed to improve the ammonia emissions inventory and to develop the most effective approaches to controlling agricultural ammonia emissions. SAMI concluded that all States should seek opportunities to reduce ammonia from animal feeding operations and from agricultural fertilizers.

State Implementation Plans (SIPs) – Over the next several years, the individual SAMI States will develop plans to meet revised ozone standards and fine particle standards to protect human health and welfare. While protecting human health is not a principal focus of SAMI's analyses, some of the same pollutants are likely to be controlled by States in meeting those requirements that SAMI concluded needed to be controlled to protect air quality in Class I areas. As States prepare their SIP's, they will consider opportunities to provide air quality benefits to the Class I areas as well.

Energy Efficiency, Conservation and Renewables – SAMI concluded that need for energy and for transportation are likely to continue to grow faster than the population in the SAMI States. While emissions controls on tailpipes and stacks are likely to be needed, using energy and transportation more efficiently with more reliance on renewables will blunt the impact of growth on our air quality as the physical controls are implemented.

IMPLEMENTATION OF SAMI RECOMMENDATIONS

Through this report and its recommendations, SAMI has completed its mission and has officially closed its operations. By adoption of the final technical report, the SAMI States recognize the value and importance of our Class I areas and agree to work towards the implementation of SAMI recommendations. Each SAMI State will determine the most appropriate strategy for its own unique circumstances that will lead to successful achievement of SAMI's final recommendations.

Geographic Source Regions

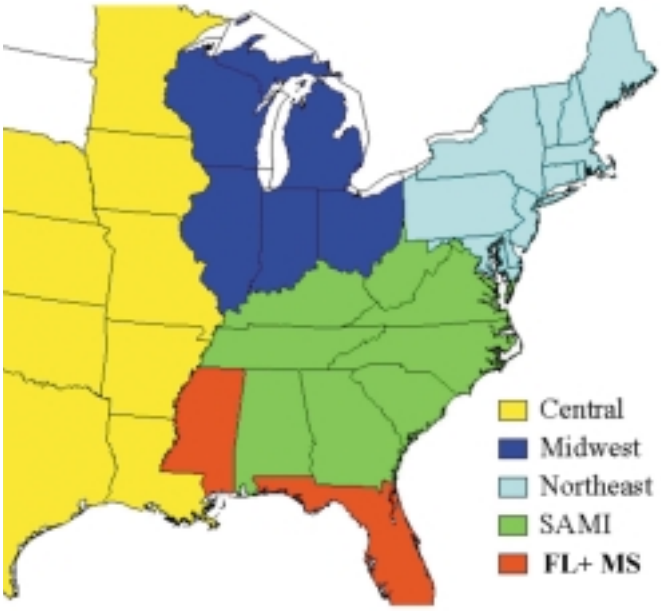


Figure 10.4: Geographic areas considered in SAMI geographic sensitivity analyses.

LESSONS LEARNED FROM THE SAMI EXPERIENCE

This chapter offers suggestions to others that may be undertaking a project like SAMI in the future. In general these view are widely held by SAMI participants but not every item listed here was adopted by consensus. Using these thoughts as a general guide, more detailed information should be sought from those that actively participated in the SAMI process.

1. Consensus decisions by a stakeholder group are possible for high stakes, highly complex environmental decisions but participants should be prepared for the process to take longer than it would for a single organization with a similar assignment.

2. SAMI's general advice, if faced with repeating the SAMI experience, is to use a "better managed" stakeholder process to assure more success in a shorter period of time. Specific suggestions include:

a) Allow time for participants to become acquainted with other participants and to develop enough trust to be able to do work as a group.

b) Decide and move on. When consensus fails to arrive in a fairly short time, provide a routine method of deciding an issue and moving on, perhaps involving the policy makers in the organization.

c) Have a plan for the entire process that is "owned" by all committees and at all levels of the organization. SAMI found that the "plan" sometimes varied from committee to committee and from the subcommittees to the Governing Body.

d) Involve stakeholders but realize that the process will move more quickly if the goal of stakeholder consensus is balanced with specific goals for products and schedules.

e) Have real deadlines. Deadlines are important in moving the process forward. The absence of the regulatory deadlines that typically are present with these sorts of processes allowed the schedule to slip.

f) Use "off the shelf" modeling approaches in contrast to "cutting edge" approaches if the group needs to move quickly.

g) Move more quickly. A shorter process may avoid the need to continually adapt to new regulatory initiatives and to reassess which reference strategy to use as the basis of comparison for model results.

h) Use public involvement committees throughout the process rather than asking that they wait until the modeling was completed as SAMI did.

i) Have funding committed in advance. Lacking committed funds at the outset produced a need for a series of fund-raising campaigns that were time-consuming and distracting.

j) Decide how important the project is in advance and commit the needed staff time for the duration. Competing regional efforts such as OTAG and VISTAS slowed progress for SAMI. Changing committee membership over the 10 years of SAMI required continual reeducation of members as the priorities of participating organizations shifted and their representatives changed.

k) Acquire needed modeling tools and data before starting the process. The absence of a broad based data set for fine particles and modeling tools for topics like dry deposition, for example, restricted SAMI analyses. Alternatively, the group could agree early on which topics are to be examined and which are not.

l) Be clear on environmental objectives and the conceptual approach at the outset. SAMI participants disagreed repeatedly on this topic. Some stakeholders saw "targets" as essential. Others believed that the process must avoid specific numeric environmental objectives.

m) Disseminate results as they develop to ensure that people outside the process are aware of the progress that is being made.

n) Provide for a more active role by top policy makers to ensure their understanding of the issues and their ownership of the results. This involvement could provide more regular feedback to modeling committees.

3. Allowing information to flow freely in the organization increases trust and promotes open dialog. All stakeholders had access to all information as SAMI proceeded. All meetings were open. All e-mail lists were open to all. While stakeholder caucuses at breaks and between meetings were common, SAMI discussions were direct, in part because all participants shared a common base of information.

4. High level State and Federal gatherings such as the Governors' Air Summits and the twice yearly SAMI meetings were effective at gradually informing public policy as new technical information emerged. Throughout the SAMI decade, policy makers were aware of the questions that SAMI was addressing, the progress being made, and when the final answers were expected. A number of new regulatory initiatives occurred during this period but the initiating organizations were aware of the unfolding new SAMI information as their regulations were developed and announced.

5. Virtual organizations can be effective. SAMI participants spread over a wide area developed the ability to identify hundreds of other participants over the telephone and to work together as if they were face-to-face. Conference calls plus simultaneous access to contractor results on websites proved very effective in moving through and approving large bodies of technical information. Policy discussions, in contrast, seemed to be more effective face-to-face.

6. The work of SAMI built relationships and understanding that allowed progress to be accelerated in other related forums. Examples may include the Southern Air Principles initiative, VISTAS, and the North Carolina Clean Smokestacks Bill.

7. Given that States are autonomous governments, others should consider an approach that does not create an expectation that a consensus process will develop specific regulatory controls for each of several states. From state to state the regulatory and cultural settings are sufficiently different that each state must determine the most appropriate strategy for its own unique circumstances that will lead to successful implementation of group recommendations.

8. The ultimate success of SAMI will be measured by air quality trends and how well SAMI met its mission to remedy the adverse air quality impacts in parks and wilderness areas in the southeast.

LISTS OF FIGURES

FIGURE 1.1: The Geographic domain of the Southern Appalachian Mountains Initiative and location of Class I Areas.

FIGURE 1.2: Federal Legislation & Class I Areas.

FIGURE 1.3: Flow chart of each level component of the Integrated Assessment.

FIGURE 1.4: Recommendation development process.

FIGURE 2.1: Projections of population, electricity demand and vehicle miles traveled in the SAMI States from 1990 to 2040.

FIGURE 2.2: Comparison of Base Year and reference strategy emissions for five key pollutants in the SAMI States.

FIGURE 2.3: Relative SO_2 emissions by State, note that SO_2 emissions are projected to rise between 1990 and 2010 in NorthCarolina, South Carolina and Virginia.

FIGURE 2.4: Four-pollutant comparison of emission levels between 1990, 2010 and 2040 selected strategies in the SAMI States.

FIGURE 2.5: Comparison of annual SO_2 emissions by source sectors.

FIGURE 2.6: Comparison of annual oxides of nitrogen emissions, broken out by source sectors.

FIGURE 2.7: Projections of daily NO_X levels in the SAMI States during the summer months (May through September).

FIGURE 2.9: Comparison of annual Nitrogen emissions, calculated from the oxides of nitrogen and ammonia emissions as Nitrogen.

FIGURE 2.8: Comparison of annual ammonia emissions, broken out by source sectors.

FIGURE 3.1: Atmospheric modeling domain for the urban-to-regional multiscale – one atmosphere (URM-1-ATM) model.

FIGURE 3.2: Modeled maximum hourly ozone values in SAMI region for July 12-15, 1985.

FIGURE 3.4: Change in fine particle mass on July 15, 1995, In response to SAMI strategies.

FIGURE 3.3A: Hourly ozone values at look rock in Great Smoky Mountains National Park for July 11-19 1995 and modeled changes in hourly ozone values in response to SAMI strategies.

FIGURE 3.3B: Hourly ozone values at Big Meadows, Shenandoah National Park for July 11-19, 1995 and modeled changes in hourly ozone values in response to SAMI strategies.

FIGURE 3.5A: Changes in Fine Particle Mass on Example Modeled Days at Great Smoky Mountains National Park in Response to SAMI Strategies in 2010.

FIGURE 3.5B: Changes in Fine Particle Mass on Example Modeled Days at Shenandoah National Park in Response to SAMI Strategies in 2010.

FIGURE 3.6: Changes in Sulfate Wet Deposition during the week of July 23-31, 1991, in Response to SAMI Strategies in 2010.

FIGURE 3.7: Geographic areas considered in SAMI geographic sensitivity analyses.

FIGURE 3.8: Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for the SAMI, Midwest, Northeast, and Central regions and from Mississippi and Florida.

FIGURE 3.9: Sulfate fine particle mass modeled for July 15, 1995, using emissions for the 2010 A2 strategy and changes in sulfate fine particle mass in response to 10% reductions in sulfur dioxide emissions from the 2010 A2 strategy for each of the eight SAMI states.

FIGURE 3.10: Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in SAMI states and non-SAMI states.

FIGURE 3.11: Annual Sulfate Fine Particle Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions.

FIGURE 3.12: Annual Sulfate Wet Deposition Responses at SAMI Class I areas to 10% Sulfur Dioxide reductions from 2010 A2 strategy in each SAMI state and surrounding regions.

FIGURE 3.13: Nitrogen oxide emissions in the 2010 A2 strategy modeled for July 12, 1995 for elevated (utility and industrial point sources) and ground-level (highway vehicle, nonroad engines, and area) sources.

FIGURE 3.14: Growing season ozone responses at SAMI Class I areas to 10% reductions in nitrogen oxide emissions in the 2010 A2 strategy for each SAMI state and surrounding regions.

FIGURE 4.1: Illustration of SULFATE and NITRATE FINE PARTICLE molecules (Malm, 1999).

FIGURE 4.2: Measurement scales for, extinction, visual range, and deciview.

FIGURE 4.3: Map of SAMI region and locations of IMPROVE monitors in SAMI Class I areas.

FIGURE 4.4: Visual Range at SAMI Class I area based on IMPROVE MONITORING data and assumptions for calculating light extinction (a) Annual "median" (more accurately the mean of the central 20% of all data), (b) Annual "median", 20% haziest and 20% clearest days at Great Smoky Mountains National Park, (c) Annual "median", 20% haziest and 20% clearest days at Shenandoah National Park.

FIGURE 4.5: Fine particle mass at Shenandoah National Park for modeled days in each of five visibility classes based on improve monitoring data.

FIGURE 4.6: Monthly average ratio of ammonium to sulfate ions measured at IMPROVE monitoring sites at Great Smoky Mountains, Shenandoah, and Dolly Sods from 1997 to 1999.

FIGURE 4.7: Annual emissions of sulfur dioxide, nitrogen oxides, volatile organic compounds, and ammonia in eight SAMI states.

FIGURE 4.8: Annual Average Fine Particle Mass at Great Smoky Mountains and Shenandoah National Parks in 1991-1995 and in 2010 and 2040 in response to SAMI strategies.

FIGURE 4.9: Annual Average Light Extinction at Great Smoky Mountains and Shenandoah National Parks in 1991-1995 and in 2010 and 2040 in response to SAMI strategies.

FIGURES 4.10 A AND B: Changes in Visibility in 2010 in response to SAMI strategies for modeled days in five classes based on fine particle mass at (a) Great Smoky Mountains and (b) Shenandoah national Parks.

FIGURE 4.11: Changes in Annual Average Visibility between 1991-1995 and 2010 at 10 Class I areas in response to SAMI Strategies.

FIGURE 4.12: Changes in visual range between 1991-1995 and 2010 for the 20% highest mass days at 10 Class I areas in response to SAMI Strategies.

FIGURE 4.13: Changes in Summer Average Visibility between 1991-1995 and 2010 at six Class I areas in response to SAMI Strategies.

FIGURE 4.14: Visibility on July 15, 1995, illustrated using the software program WINHAZE, assuming emissions on July 15, 1995 and assuming emissions in 2010 under the A2, B1, and B3 strategies.

FIGURE 5.2: Daily ozone exposure patterns (average for 1993 through 1995) differ depending on elevation: (a) low elevation site (Sipsey, AL), (b) middle elevation site (Look Rock, TN– an exposed ridge-top site in Great Smoky Mountains National Park), and (c) high elevation site (Cranberry, NC).

FIGURE 5.5: Ozone sensitivity of tree species based on growth response in controlled exposure studies (Chappelka et al., 1996 and Lefohn, 1998).

FIGURE 5.3: Growing season ozone exposures at several forested sites in the SAMI region.

FIGURE 5.4: Average 1993-1995 growing season ozone exposures (W126) across the SAMI region.

FIGURE 5.6: The dark stipple on the upper leaf surface of two of the yellow-poplar leaves is attributed to ozone exposures.

FIGURE 5.7: Location of SAMI ozone regions displayed on top of a digital elevation model.

FIGURE 5.8: Cumulative growing season (April-October) ozone exposures (W126) in 1993-1995 and in response to SAMI strategies at example forested sites in the SAMI's region.

FIGURE 5.9: Percent reduction in the growing season ozone exposures (W126) from the 1993 through 1995 average (Base) in response to SAMI strategies at example low, middle, and high elevation monitoring sites.

FIGURE 5.10: Frequency distributions at the Cranberry, North Carolina, monitoring site comparing hourly ozone data for April-October, 1993 through 1995, with hourly data projected for the SAMI strategies in 2040.

FIGURE 5.11: Frequency distributions at the Sipsey, Alabama, monitoring site comparing hourly ozone data for April-October, 1993 through 1995, with hourly data projected for the SAMI strategies in 2040.

FIGURE 5.12: In response to SAMI strategies, changes in basal area of species with known sensitivity to ozone are projected to be small.

FIGURE 6.1A: Annual average of sulfate at monitoring sites in the SAMI region operated by the national atmospheric deposition program.

FIGURE 6.1B: Annual average of nitrate at monitoring sites in the SAMI region operated by the national atmospheric deposition program.

FIGURE 6.1C: Annual average of ammonium wet deposition at monitoring sites in the SAMI region operated by the national atmospheric deposition program.

FIGURE 6.2: Areas in the SAMI region most likely to have streams with acid neutralizing capacity (ANC) LESS THAN 20 microequivalents per liter (meq/l).

FIGURE 6.3: Percentage of stream lengths in SAMI region in each of five classes of Acid Neutralizing Capacity (ANC), based on 1985-1986 National Stream Survey (Turner, et al., 1990).

FIGURE 6.4: Locations of spruce-fir forest ecosystem in SAMi region.

FIGURE 6.5: Emissions of sulfur dioxide, nitrogen oxides, and ammonia in eight SAMI states in 1990 and in 2010 and 2040 in response to SAMI strategies.

FIGURE 6.6: Total annual average Sulfur Deposition in 1991-1995 and in 2010 under SAMI strategies for 5 example sites in SAMI Class I areas.

FIGURE 6.7: Total annual average Nitrogen Deposition in 1991-1995 and in 2010 under SAMI strategies for 5 example sites in Class I areas.

FIGURE 6.8. Physiogeographic provinces in SAMI region and locations of streams modeled in SAMI analyses.

FIGURE 6.9: Average Stream Acid Neutralizing Capacity (ANC) for modeled streams in SAMI region in response to SAMI strategies.

FIGURE 6.10: Stream Acid Neutralizing Capacity (ANC) for upper node stream in SAMI region in 2040 under SAMI strategies.

FIGURE 6.11: Map of forest distribution and site locations for modeled sites.

FIGURE 6.12: Simplified summary of forests results.

FIGURE 7.1: Cost projection for the 2040 B3 case for the highway vehicle sector illustrates the extreme range in cost projections between the low end of the range (red bar) and the high end of the range (blue bar) in certain subsectors. For example, the SAMI projection in this case is the VMT reductions which are projected to cost between 10 and 45 billion dollars in 2040.

FIGURE 7.2: Cost for all source sectors combined for 2010 and 2040. SAMI projects the cost to between the Low and High ranges.

FIGURE 7.3: 2010 Low end of the range of projected costs by source sectors.

FIGURE 7.4: 2010 High end of the range of projected costs by source sectors.

FIGURE 7.5: 2040 Low end of the range of projected costs by source sectors.

FIGURE 7.6: 2040 High end of the range of projected costs by source sectors.

FIGURE 7.7: Annualized cost of SO_2 reductions by strategy and by source sector.

FIGURE 7.8: Cost per ton of SO_2 removed in 2010.

FIGURE 7.9: Cost per ton of SO_2 removed in 2040.

FIGURE 7.10: Annualized cost of NOx reductions by strategy and by source sector.

FIGURE 7.11: Cost per ton of NOx removed in 2010.

FIGURE 7.12: Cost per ton of NOx removed in 2040.

FIGURE 7.13: Cost per ton of NH_3 removed in 2010, all NH_3 reductions and costs are in the area source sector.

FIGURE 8.1: Fishing study area in the Northern Plateau Region, 8 contiguous counties in West Virginia.

FIGURE 9.1: Potential Annual SO_2 Emissions from Residential Buildings in the SAMI Region.

FIGURE 9.2: Potential Annual Percent Reduction in SO_2 Emissions from Residential Buildings in the SAMI Region (Relative to Baseline).

FIGURE 10.1: Recommendation development process.

FIGURE 10.2: Annual average visual range for the Great Smoky Mountains National Park and the Shenandoah National Park in 2010 and 2040.

FIGURE 10.3: Change in Class Average deciview for the Great Smoky Mountains National Park.

FIGURE 10.4: Geographic areas considered in SAMI geographic sensitivity analyses.

LIST OF TABLES

TABLE 2.1: Relative Confidence Levels in the SAMI 1990 Base Year Inventory (5 stars is most confident).
TABLE 2.2: Annual summary data for the eight SAMI States in total.
TABLE 2.3: SAMI emissions inventory assumptions for the utility sector in 2010 and 2040 for B1, B2, and B3 strategies.
TABLE 2.4: SAMI emissions inventory assumptions for the industrial sector in 2010 and 2040 for B1, B2, and B3 strategies.
TABLE 2.5: SAMI emissions inventory assumptions for the highway vehicle sector in 2010 and 2040 for B1, B2, and B3 strategies.
TABLE 2.6: SAMI emissions inventory assumptions for the nonroad engine sector in 2010 and 2040 for B1, B2, and B3 strategies.
TABLE 2.7: SAMI emissions inventory assumptions for the area sources sector in 2010 and 2040 for B1, B2, and B3 strategies.
TABLE 2.9: Relative Confidence Levels in SAMI 2040 Base Case Emission Inventories (A1/A2).
TABLE 3.1: Percent of days (or weeks in the case of wet and dry deposition) falling into each Class based on the severity of pollutant levels at Great Smoky Mountains and Shenandoah National Parks (Deuel and Douglas, 1998, Odman, et al., 2002a).
TABLE 3.2: Error in using modeled days and episode weightings to recreate annual and season air quality averages for Great Smoky Mountains and Shenandoah National Parks for the period 1991-1995.
TABLE 3.3: Nine episodes selected for air quality modeling and description of meteorological characteristics (Doty, et al., 2002; Odman, et al., 2002a).
TABLE 3.4: Data used for performance evaluation of the Urban-to-Regional One-Atmosphere (URM-1ATM) model and performance results (Odman, et al., 2002a).
TABLE 4.1: Classification of Days based on combined fine particle mass at Great Smoky Mountains and Shenandoah National Parks during 1991-1995 (Deuel and Douglas, 1998).
TABLE 4.2: Data sources for calculating visibility at SAMI Class I areas for 1991 to 1995.
TABLE 5.1: Elevation for each of the 13 ozone monitoring sites used in the SAMI analysis, and the 1993 through 1995 average (Base) for growing season ozone (W126) and numbers of hours greater than 0.100 ppm ozone (N100).
TABLE 5.2: Three year totals or averages shown by SAMI strategies in 2040 for Cranberry, North Carolina, and Sipsey, Alabama, ozone-monitoring sites. Data presented includes: number of hours greater than or equal to (>=) 0.060 ppm, 0.080 ppm, 0.100 ppm, average W126, and maximum average hourly ozone values in the 1993-1995 record.
TABLE 5. 3: A summary of the area within the SAMI region modeled in the ozone analysis.
TABLE 5.4: Forest types with modeled measurable (positive and/or negative) percentage changes (greater than 3%) in basal area (BA) between the Base (1993 – 1995) and A2, B1, and B3 SAMI strategies (Weinstein, et al., 2002).
TABLE 5.5: Summary of the number of modeled species predicted to show measurable increasing and decreasing changes in percent1 of basal area by the year 2040, comparing SAMI strategies Base (1993 – 1995) to A2, B1, and B3 in the seven SAMI region Class I areas.
TABLE 6.1: Stream Acid Neutralizing Capacity (ANC) as an indicator of stream suitability to support brook trout (Sullivan, et al., 2002a).
TABLE 6.2: Numbers of streams modeled in each acid neutralizing class in each of three physiogeographic provinces (used for the regional assessment) and additional special interest streams in Class I areas.
TABLE 6.3: Stream Acid Neutralizing Capacity (ANC) in response to SAMI strategies for 130 modeled streams.
TABLE 6.4: Projected changes in class average acid neutralizing capacity (ANC) between 1991-1995 and 2040 in response to SAMI strategies for upper stream reaches In the SAMI region.
TABLE 7.1: Table provides projected annualized cost for SO_2 reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of SO_2 removed for each strategy.
TABLE 7.2: Table provides projected annualized cost for NOx reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of NOx removed for each strategy.
TABLE 7.3: Table provides projected annualized cost for NH_3 reductions, projected emission reductions, cost per strategy from the cost of the A2 strategy, and then cost per ton of NH_3 removed for each strategy.
TABLE 7.4: Relative Uncertainties of SAMI 2010 Direct Cost Analysis. Based on 5 pluses being the most certain (the - represents half a plus).
TABLE 7.5: Relative Uncertainties of SAMI 2040 Direct Cost Analysis. Based on 5 pluses being the most certain (the - represents half a plus).
TABLE 8.1: Conversion of stream ANC to brook trout biomass.
TABLE 8.2: Average willingness to pay per angler per trip for different levels of biomass (benefit in 2000 $).
TABLE 8.3: Estimated total willingness to pay for water quality improvements in the Northern Plateau Region of West Virginia (benefit in millions of 2000 $).
TABLE 8.4: Primary recreational visibility benefits* in non-SAMI region and out of the region (millions of 2000$).
TABLE 8.5: Primary recreational visibility benefits* apportioned by Class I Area (millions of 2000$).
TABLE 8.6: Supplemental estimate of residential visibility benefits (entire modeling domain).
TABLE 8.7: Supplemental estimate of residential visibility benefits.
TABLE 9.1: Potential Reductions in Vehicle Miles Traveled (VMT) for 2010 and 2040.
TABLE 9.2: Potential Reductions in NO_X Emissions for 2010 and 2040.*
TABLE 9.3. Potential emissions reductions from selected consumer incentives.
TABLE 9.4: Potential emissions reductions from organizational incentives.

REFERENCES

Air Resources Specialists, Inc. 2002. Visibility Analysis. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Atmospheric Integrated Research Monitoring Network at Illinois State Water Survey. (AIRMoN), 2000. http://nadp.sws.uiuc.edu

Baker, J. P., Bernard, D. P., Christensen, S. W., Sale, M. J., Freda, J., Heltcher, K., Marmorek, D., Rowe, L., Scanlon, P., Suter, G., Warren-Hicks, W., Welbourn, P., 1990. Biological effects of changes in surface water acid-base chemistry. Report 13 in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Boylan, J. W., Odman, M. T., Wilkinson, J. G., Russell, A. G., Doty, K. G., Norris, W. B., and McNider, R. T., 2002. Development of a Comprehensive Multiscale "One Atmosphere" Modeling System: Application to the Southern Appalachian Mountains. Accepted for publication in Atmospheric Environment.

Baumgardner, R. E., Lavery, T. F., Rogers, C. M., Isil, S. S., 2002. Estimates of Atmospheric Deposition and Sulfur and Nitrogen Species: Clean Air Status and Trends Network, 1990- 2000. Environmental Science and Technology, 36, pp. 2614-2629.

Chappelka, A. H., Samuelson, L. J., Skelly, J. M., and Lefohn, A. S., 1996. Effects of ozone on forest trees in the Southern Appalachians: An assessment of the current state of knowledge. Report to Southern Appalachian Mountains Initiative. 114 pp.

Cohn, R.D., and Dennis, R. L., 1994. The Evaluation of acid deposition models using principal component spaces. Atmospheric Environment, 28, pp. 2531-2543.

Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, 2000. Spatial and Seasonal Patterns and Temporal Variability of Haze and Its Constituents in the United States: Report III, ISN: 0737-5352-47.

Cosby, B. J. and Sullivan, T., 1999. Application of the MAGIC Model to Selected Catchments: Phase I Final Report to Southern Appalachian Mountains Initiative

Cronan, C.S. and Grigal, D.F., 1995. Use of Calcium/Aluminum Ratios as Indicators of Stress in Forest Ecosystems. Journal of Environmental Quality, 24:209-226.

Dennis, R. L., Barchet, W. R., Clark, T. L., Seilkop, S. K., 1990. Evaluation of regional acidic deposition models (Part I.), Report Number 5, in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Deuel, H.P., and Douglas, S.G., 1998. Episode selection for the integrated analysis of ozone, visibility, and acid deposition for the Southern Appalachian Mountains. Systems Applications International, Inc., San Rafael, CA. SYSAPP_98/07r1.

Doty, K. G., Tesche, T.W., McNally, D.E., Timin, B., and Mueller, S.F., 2002. Meteorological Modeling for the Southern Appalachian Mountains Initiative (SAMI). Final report, Southern Appalachian Mountains Initiative, Asheville, NC.

Driscoll, C.T., Lawrence, G. B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., and Weathers, K.C. 2001. Acidic deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. Bioscience, 51, pp. 180-198.

Eagar, C., Van Miegroet, H., McLaughlin, S.B., and Nicholas, N.S. 1996. Evaluation of Effects of Acidic Deposition to Terrestrial Ecosystems in Class I Areas of the Southern Appalachians. Report to SAMI.

E.H. Pechan & Associates, Inc., 1997. Evaluation of the SAMI Inventory Using the Data Attribute Analysis System (DARS), Report prepared for the Southern Appalachian Mountains Initiative, Asheville, NC.

E. H. Pechan & Associates, Inc., 1999. Development of the SAMI 1990 Base Year Emissions Inventory, Report prepared for the Southern Appalachian Mountains Initiative, Asheville, NC.

E. H. Pechan & Associates, Inc., 2002a. Southern Appalachian Mountains Initiative (SAMI) Emissions Projections to 2010 and 2040: Growth and Control Data and Emission Estimation Methodologies, Report prepared for the Southern Appalachian Mountains Initiative, Asheville, NC.

E.H. Pechan and Associates, Inc., 2002b. Control Strategy Cost Analyses for the Southern Appalachian Mountains Initiative, Report prepared for the Southern Appalachian Mountains Initiative, Asheville, NC.

EIA, 2000: Energy Information Administration's Annual Energy Outlook 2001, DOE/EIA 0383 (2001), Washington, DC.

Fenn, M.E., Poth, M.A, Aber, J.D., Baron, J.S., Bormann, B.T., Johnson, D.W., Lemly, A.D., McNulty, S.G., Ryan, D.F., and Stottlemyer, R. 1998. Nitrogen Excess in North American Ecosystems: predisposing factors, ecosystem responses, and management strategies. Ecological Applications 8(3): 706-733.

Georgia Institute of Technology, 2001. The SAMI Atmospheric Modeling Home Page at Georgia Institute of Technology. http://environmental.gatech.edu/SAMI

Grimm, J. W., and Lynch, J. A., 1997. Enhanced wet deposition estimates using modeled precipitation Inputs. Final report to the USDA Forest Service, Northeast Forest Experiment Station, Northern Global Change Research Program (report number 23-721).

Hansen, M. H., Frieswyk, T., Glover, J. F., and Kelly, J. F. 1992. The Eastwide forest inventory database: Users manual. Gen. Tech. Rep. NC-151. St. Paul, MN: US Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Herlihy, A.; Kaufmann, P.; Stoddard, J.; Eshleman, K.; Bulger, A. 1996. Effects of Acidic Deposition on Aquatic Resources in the Southern Appalachians with a Special Focus on Class I Wilderness Areas; report for the Southern Appalachian Mountains Initiative, Asheville, NC.

ICF Consulting, 2001. SAMI Demand Management Options. Report to the Southern Appalachian Mountains Initiative, Asheville, NC.

Imhoff, R. E., and Jackson, W., 2001. The application of a simplified methodology for applying SAMI air quality model results to produce continuous 3-year hourly ozone concentrations for sites of interest. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC. www.saminet.org

Interagency Monitoring of Protected Visual Environments (IMPROVE), 2002. Cooperative Institute for Research in the Atmosphere (CIRA), National Park Service Visibility Program, Colorado State University, Fort Collins, CO. http://vista.cira.colostate.edu/improve/Data/IMPROVE

Johnson, D.W. and Lindberg, S. E., editors, 1992. Atmospheric deposition and nutrient cycling in forest ecosystems – a synthesis of the Integrated Forest Study. Springer-Verlag, New York.

Kaufmann, P. R., Herlihy, A. T., Elwood, J. W., Mitch, M. E., Overton, W. S., Sale, M. J., Messer, J. J., Cougar, K. A., Peck, D. V., Reckhow, K. H., Kinney, A. J., Christie, Brown, D. D., Hagley, C. A., and Jager, H. I. 1988. Chemical Characteristics of Streams in the Mid-Atlantic and Southeastern United States. Volume I: Population Descriptions and Physico-Chemical Relationships. EPA/600/3-88/021a. U.S. Environmental Protection Agency, Washington, D. C.

Lefohn, A.S. and Runeckles, V.C. 1987. Establishing a Standard to Protect Vegetation – Ozone Exposure/Dose Considerations. Atmospheric Environment, 21, pp. 561-568.

Lefohn, A. S., Jackson, W., Shadwick, D. S. and Knudsen H. P. 1997. Effect of Surface Ozone Exposures on Vegetation Grown in the Southern Appalachian Mountains: Identification of Possible Areas of Concern. Atmos. Environ. 31: 1695-1708

Lefohn, A. S. 1998. The Identification of Ozone Exposures that Result in Vegetation Visible Injury and Growth Loss for Specific Species Grown in the Southern Appalachian Mountain region. Report to Southern Appalachian Mountains Initiative. 54 pp.

Lefohn A. S., Shadwick D. S. and Ziman S. D. 1998. The difficult challenge of attaining EPA's new ozone standard. Environmental Science & Technology 32(11):276A-282A.

Lynch, J. A., Bowersox, V. C., and Grimm, J. W., 2000a. Acid rain reduced in Eastern United States. Environmental Science and Technology, 34, pp. 940-949.

Lynch, J. A., Bowersox, V. C., and Grimm, J. W., 2000b. Changes in sulfate deposition in Eastern USA following implementation of Phase I of Title IV of the Clean Air Act Amendments of 1990. Atmospheric Environment, 34, pp. 1665-1660.

Malm, W.C., 1999. Introduction to Visibility. Cooperative Institute for Research in the Atmosphere (CIRA), National Park Service Visibility Program, Colorado State University, Fort Collins, CO. Under cooperative agreement CA2350-97-001: T097-04, T098-06

Malm, W.C., Molenar, J.V., Eldred, R.A., Sisler, J.F., 1996. Examining the relationship among atmospheric aerosols and light scattering and extinction in the Grand Canyon area, Journal of Geophysical Research, Vol. 101, No. D14, pp 19,251 - 19,265.

Molenar, J. V., Malm, W.C., and Johnson, C. E., 1994. Visual Air Quality Simulation Techniques. Atmospheric Environment, 28, pp. 1055-1063.

Munson, R. 1999. Application of the NuCM Model to Noland Divide, White Oak Run, and Shaver Hollow. Phase I report to Southern Appalachian Mountains Initiative. Asheville, NC.

National Atmospheric Deposition Program (NADP), 2000. network at Illinois State Water Survey. http://nadp.sws. uiuc.edu

NPS, 2000. National Park Service Air Quality Research Division, Fort Collins, CO. ftp://alta_vista.cira.colostate. edu in data/improve.

Odman, M.T., Boylan, J.W., Wilkinson, J. G., Russell, A. G., Mueller, S.F., Imhoff, R.E., Doty, K. G., Norris, W. B., and McNider, R. T., 2002a. SAMI Air Quality Modeling Final Report. Southern Appalachian Mountains Initiative, Asheville, NC.

Odman, M.T., Hakami, A., Boylan, J. W., Russell, A.G. 2002b. Acid Deposition Linkage. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Pitchford, M.L., Malm, W.C., 1994. Development and Applications of a Standard Visual Index, Atmospheric Environment, Vol. 28, No. 5, pp. 1049 – 1054.

Russell, A. G., and Dennis, R. L., 2000. NARSTO Critical Review of photochemical models and modeling. Atmospheric Environment, 34, pp. 2283-2324.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Atmospheric Technical Report. Report 2 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Saxena, P. Andrews, E., Musarra, S., 1998. Southeastern Aerosol and Visibility Study (SEAVS). Report for Electric Power Research Institute, Palo Alto, CA. Report number TR-111063.

Southeastern Aerosol Research and Characterization, SEARCH, 2002. http://www.atmospheric-research.com, SEARCH Home Page

Seigneur, C. 2001. Current status of air quality models for particulate matter. Journal of Air and Waste Management Association, 51, pp.1508-1521.

Shannon, J.D., 1998. Calculation of Trends from 1900 through 1990 for Sulfur and NO_X-N deposition, Concentrations of Sulfate and Nitrate in Precipitation, and Atmospheric Concentrations of SOx and NO_X Species over the Southern Appalachians, Report to Southern Appalachian Mountains Initiative

Sullivan, T. J., Cosby, B. J., Munson, R. K., Webb, J. R., Synder, K. U., Herlihy, A. T., Bulger, A. J., Gilbert, E. H., Moore, D., 2002a. Assessment of the effects of acidic deposition on aquatic resources in the Southern Appalachian Mountains. Final report to the Southern Appalachian Mountains Initiative, Asheville, NC.

Sullivan, T. J., Munson, R. K., Johnson, D. W., and Joslin, J. D., 2002b. Assessment of the effects of acidic deposition on forest resources in the Southern Appalachian Mountains. Final report to the Southern Appalachian Mountains Initiative, Asheville, NC.

Timin, B. Doty, K. G., Tesche, T.W., McNally, D.E., Timin, B., and Mueller, S.F., 2002. Episode Selection, Meteorological Modeling for the Southern Appalachian Mountains Initiative (SAMI). Final report, Southern Appalachian Mountains Initiative, Asheville, NC.

Trijonis, J. C., Malm, W. C., Pitchford, M., White, W. H., Charlson, R.J., Husar, R. B., 1990. Visibility: Existing and Historical Conditions- Causes and Effects. Report Number 24 in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Turpin, B. J., and Lim, H.J., 2001. Species contributions to $PM_{2.5}$ mass concentrations: Revisiting common assumptions for estimating organic mass. Aerosol Science and Technology. 35 (1), pp. 602-610.

Urban, D. L., Bonan, G. B., Smith, T. M., and Shugart, H. H. 1991. Spatial applications of gap models. For. Ecol. Manage. 42:95-110.

USEPA 1991. Guidance for Regulatory Application of the Urban Airshed Model (URM), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

USEPA. 1996. Review of the National Ambient Air Quality Standards for ozone assessment of scientific and technical information. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA450/2-92-001.

USEPA, 2001a. Guidance for demonstrating attainment of air quality goals for $PM_{2.5}$ and regional haze. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

USEPA, 2001b. EPA AIRS Data. U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Information Transfer and Program Integration Division, Information Transfer Group. www.epa.gov/airsdata.

U.S. Department of Commerce, 1995. BEA Regional and State Projections of Economic Activity and Population to 2045: Volume 1: States.

Watson, J.G., 2002. Critical Review Visibility: Science and Regulation. Journal of the Air & Waste Management Association,. Volume 52. pp 628-713.

Weinstein, D. A., Beloin, R. M., and Yannai, R. D. 1991. Modeling changes in red spruce carbon balance and allocation in response to interacting ozone and nutrient stresses. Tree Physiol. 9:127-146.

Weinstein, D. A., Gollands, W., and Retzlaff, W. A. 2000. The effects of ozone on a lower slope forest of the Great Smoky Mountain National Park: Simulations linking an individual tree model to a stand model. Forest Science 47(1): 29-42.

Weinstein, D. A., Woodbury, P. B., Gollands, B., King, P., Lepack, L., Pendleton, D. 2002. Assessment of effects of ozone on forest resources in the Southern Appalachian Mountains. Report to Southern Appalachian Mountains Initiative, Asheville, NC. 47 pp.

ADDITIONAL DATA AND RESOURCES

The SAMI data, tools and reports will be available to anyone who is interested in a couple of different formats. A set of CDs has been created that contains almost all of the data, tools and reports created for SAMI. Additionally, much of the information is also available online, at a few websites (see below for more details):

- The SAMI Final Technical Report, the Public Summary Report, contracted reports and main PowerPoint presentations are available for viewing and downloading on the SAMI website (www.saminet.org) through December 2002 and thereafter on the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) website (www.vistas-sesarm.org).
- The atmospheric modeling data, results, and documentation are available on Georgia Institute of Technology's website (http://environmental. gatech.edu/SAMI).
- GIS datasets developed for SAMI and visibility and emissions tools are available through the VISTAS website (www.vistas-sesarm.org).

The archive CD set includes:

- The SAMI Technical Final Report, contracted reports and main PowerPoint presentations
- The Georgia Institute of Technology's SAMI website and associated files that are available from the website.
- GIS datasets developed for SAMI
- Two visibility and one aerosol emissions tools and associated data.

The CD-archive is being distributed to all the organizations and agencies that participated in SAMI and to the Federal Depositories in the eight SAMI states. Orders for additional copies may be placed through the VISTAS website (www.vistas-sesarm.org).

The Georgia Institute Of Technology Website On Atmospheric Modeling

The Georgia Tech website - http://environmental.gatech.edu/SAMI - contains information on the atmospheric modeling component of an integrated assessment study conducted by the Southern Appalachian Mountains Initiative (SAMI). The modeling system consists of:

- Emission Modeling System (EMS-95) for emissions
- Regional Atmospheric Modeling System (RAMS) for meteorology
- Urban-to-Regional Multiscale (URM) model for transport and chemistry.

Georgia Tech performed air quality simulations using the meteorology of 9 episodes, each about 10 days long, that characterize a typical year (or season) between 1991 and 1995. The results for the base and future year (2010 and 2040) simulations as well as an emission impact study are available on this web along with interim and final reports.

VISTAS

The Visibility Improvement State and Tribal Association of the Southeast (VISTAS) is a collaborative effort of state governments, tribal governments, and various federal agencies established to initiate and coordinate activities associated with the management of regional haze, visibility and other air quality issues in the Southeastern United States. The VISTAS website is www.vistas-sesarm.org.

VISTAS is comprised of the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia as well as the Eastern Band of Cherokee Indians. Local air pollution control agencies in the Southeast are currently represented by the Knox County, Tennessee, Department of Air Quality Management.

The agencies participating in VISTAS are committed to a sound and thorough scientific analysis of regional haze problems, impacts from natural and man-made pollutants, and potential solutions. Stakeholders are encouraged to participate at the workgroup level in order that all aspects of the problem and possible strategies may be given consideration.

List Of SAMI Contractor And Staff Reports Not Cited In References

Abt Associates Inc, 2002. The Value of Improved Recreational Fishing From Reduced Acid Deposition in the Southern Appalachian Mountain Region. Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Abt Associates Inc, 2002. The Value of Visibility Improvements in the Southern Appalachian Mountains Region. Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Abt Associates Inc, with Prof. Pamela Mason, 2002, Sense of Place and Stewardship Focus Group Report. Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Air Resources Specialists, Inc. 2002. Visibility Analysis. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Air Resources Specialists, Inc. 2002. Visibility Analysis. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Atmospheric Integrated Research Monitoring Network at Illinois State Water Survey. (AIRMoN), 2000. http://nadp.sws.uiuc.edu

Baker, J. P., Bernard, D. P., Christensen, S. W., Sale, M. J., Freda, J., Heltcher, K., Marmorek, D., Rowe, L., Scanlon, P., Suter, G., Warren-Hicks, W., Welbourn, P., 1990. Biological effects of changes in surface water acid-base chemistry. Report 13 in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Baumgardner, R. E., Lavery, T. F., Rogers, C. M., Isil, S. S., 2002. Estimates of Atmospheric Deposition and Sulfur and Nitrogen Species: Clean Air Status and Trends Network, 1990-2000. Environmental Science and Technology, 36, pp. 2614-2629.

BBC Research and Consulting, 2001. Competitiveness Assessment. Draft Report to Southern Appalachian Mountains Initiative, Asheville, NC.

BBC Research and Consulting, 2002. Air Emission Reduction Incentives Program Development. Final Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Bentley, J.T., Horst, R., Wise, D. 2002. Assessment of Lifestyle Impacts of Alternative SAMI Air Quality Strategies. Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Boylan, J. W., Odman, M. T., Wilkinson, J. G., Russell, A. G., Doty, K. G., Norris, W. B., and McNider, R. T., 2002. Development of a Comprehensive Multiscale “One Atmosphere” Modeling System: Application to the Southern Appalachian Mountains. Accepted for publication in Atmospheric Environment.

Boylan, J., Wilkinson, J., Yang, Y-J, Odman, T., and Russell, A. G., 2000. Particulate Matter and Acid Deposition Modeling for the Southern Appalachian Mountains Initiative. In Proceedings of the Annual Meeting of the Air and Waste Management Association, Salt Lake City, UT.

Brewer, P. F., 1999. Southern Appalachian Mountains Initiative, A Regional Partnership for Air Quality Management, In Proceedings of Annual Meeting of Air and Waste Management Association, St. Louis, Missouri.

Brewer, P., Sullivan, T., Cosby, B. J., Munson, R., 2000. Acid Deposition Effects to Forests and Streams in the Southern Appalachian Mountains. In Proceedings of Air and Waste Management Association, Salt Lake City, UT.

Cohn, R.D., and Dennis, R. L., 1994. The Evaluation of acid deposition models using principal component spaces. Atmospheric Environment, 28, pp. 2531-2543.

Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, 2000. Spatial and Seasonal Patterns and Temporal Variability of Haze and Its Constituents in the United States: Report III, ISN: 0737-5352-47.

Copeland, Scott, 1999. Phase I Visibility Effects Analysis Cooperative Institute for Research in the Atmosphere (CIRA), National Park Service Visibility Program, Colorado State University, Fort Collins, CO Final report, Southern Appalachian Mountains Initiative, Asheville, NC.

Cronan, C.S. and Grigal, D.F., 1995. Use of Calcium/Aluminum Ratios as Indicators of Stress in Forest Ecosystems. Journal of Environmental Quality, 24:209-226.

Dennis, R. L., Barchet, W. R., Clark, T. L., Seilkop, S. K., 1990. Evaluation of regional acidic deposition models (Part I.), Report Number 5, in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Driscoll, C.T., Lawrence, G. B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., and Weathers, K.C. 2001. Acidic deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. Bioscience, 51, pp. 180-198.

Duke University, Nicholas School for the Environment, 1997. Recommendations for Reducing Ozone Formation in the Southern Appalachian Mountains Region: An examination of Alternative Fuels and Other Policy Options for Reducing Mobile Source Emissions, and Supplemental Report and Final report, Southern Appalachian Mountains Initiative, Asheville, NC.

E. H. Pechan & Associates, Inc., 1996. SAMI – Collection & Evaluation of Existing Emission Inventory Data Pechan Report No. 96.10.005/538, Report for the Appalachian Mountains Initiative, Asheville, NC.

EIA, 2000: Energy Information Administration's Annual Energy Outlook 2001, DOE/EIA 0383 (2001), Washington, DC.

Fenn, M.E., Poth, M.A, Aber, J.D., Baron, J.S., Bormann, B.T., Johnson, D.W., Lemly, A.D., McNulty, S.G., Ryan, D.F., and Stottlemyer, R. 1998. Nitrogen Excess in North American Ecosystems: predisposing factors, ecosystem responses, and management strategies. Ecological Applications 8(3): 706-733.

Georgia Institute of Technology, 2001. The SAMI Atmospheric Modeling Home Page at Georgia Institute of Technology. http://environmental.gatech.edu/SAMI

GHL Incorporated, and Mathtech, Inc, 1998. Phase I Final Report: Options for Performing SAMI's Socioeconomic Assessment, Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Grimm, J. W., and Lynch, J. A., 1997. Enhanced wet deposition estimates using modeled precipitation inputs. Final report to the USDA Forest Service, Northeast Forest Experiment Station, Northern Global Change Research Program (report number 23-721).

Hansen, M. H., Frieswyk, T., Glover, J. F., and Kelly, J. F. 1992. The Eastwide forest inventory database: Users manual. Gen. Tech. Rep. NC-151. St. Paul, MN: US Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Huber, C., Brewer, P. F., Ducharme, D., 2000. Visibility Analyses for the Southern Appalachian Mountains, In Proceedings of Air and Waste Management Association, Salt Lake City, UT.

Interagency Monitoring of Protected Visual Environments (IMPROVE), 2002. Cooperative Institute for Research in the Atmosphere (CIRA), National Park Service Visibility Program, Colorado State University, Fort Collins, CO. http://vista.cira.colostate.edu/improve/Data/IMPROVE

Johnson, D.W. and Lindberg, S. E., editors, 1992. Atmospheric deposition and nutrient cycling in forest ecosystems – a synthesis of the Integrated Forest Study. Springer-Verlag, New York.

Kaufmann, P. R., Herlihy, A. T., Elwood, J. W., Mitch, M. E., Overton, W. S., Sale, M. J., Messer, J. J., Cougar, K. A., Peck, D. V., Reckhow, K. H., Kinney, A. J., Christie, Brown, D. D., Hagley, C. A., and Jager, H. I. 1988. Chemical Characteristics of Streams in the Mid-Atlantic and Southeastern United States. Volume I: Population Descriptions and Physico-Chemical Relationships. EPA/600/3-88/021a. U.S. Environmental Protection Agency, Washington, D. C.

Lumina Decision Systems, Inc, and Resources for the Future, Inc., 1996. Phase I Report: Design for Integrated Assessment Framework for the Southern Appalachian Mountain Initiative. Report to Southern Appalachian Mountains Initiative, Asheville, NC.

Lynch, J. A., Bowersox, V. C., and Grimm, J. W., 2000a. Acid rain reduced in Eastern United States. Environmental Science and Technology, 34, pp. 940-949.

Lynch, J. A., Bowersox, V. C., and Grimm, J. W., 2000b. Changes in sulfate deposition in Eastern USA following implementation of Phase I of Title IV of the Clean Air Act Amendments of 1990. Atmospheric Environment, 34, pp. 1665-1660.

Malm, W.C., 1999. Introduction to Visibility. Cooperative Institute for Research in the Atmosphere (CIRA), National Park Service Visibility Program, Colorado State University, Fort Collins, CO. Under cooperative agreement CA2350-97-001: T097-04, T098-06

Malm, W.C., Molenar, J.V., Eldred, R.A., Sisler, J.F., 1996. Examining the relationship among atmospheric aerosols and light scattering and extinction in the Grand Canyon area, Journal of Geophysical Research, Vol. 101, No. D14, pp 19,251 - 19,265.

Mathtech, Inc. 2001. Mortality Risk Reductions and economic Benefits of Alternative SAMI Air Quality Strategies. Report to Southern Appalachian Mountains Initiative. Asheville, NC.

Molenar, J. V., Malm, W.C., and Johnson, C. E., 1994. Visual Air Quality Simulation Techniques. Atmospheric Environment, 28, pp. 1055-1063.

National Atmospheric Deposition Program (NADP), 2000. network at Illinois State Water Survey. http://nadp.sws.uiuc.edu

Neeley, D., Brantley, W. P., and Brewer, P. F., 2000. Southern Appalachian Mountains Initiative: An Overview. In Proceedings of Annual Meeting of Air and Waste Management Association, St. Louis, Missouri.

Nicholas, N. S., Brewer, P.F., Weinstein, D. A., 2000. An Assessment of Ozone Effects in the Southern Appalachians Using a Multi-Stakeholder Process Paper #463, Southern Appalachian Mountains Initiative, Asheville, NC

Norris, W.B.; Doty, K.G., 1998. The Southern Appalachians Mountain Initiative: Meteorological Modeling Protocol; University of Alabama in Huntsville,

NPS, 2000. National Park Service Air Quality Research Division, Fort Collins, CO. ftp://alta_vista.cira.colostate.edu in data/improve.

Odman, M. T., Boylan, J. W., Wilkinson, J. G., Yang, Y-J., Russell, A. G., Doty, K. G., Norris, W. B., and McNider, R. T., 2002. Development of a Comprehensive Multiscale "One Atmosphere" Modeling System: Application to the Southern Appalachian Mountains. Accepted for publication in Atmospheric Environment.

Odman, T., Boylan, J., Wilkinson, J., Yang, Y-J, and Russell, A. G., 2000. Ozone Modeling for the Southern Appalachian Mountains Initiative. In Proceedings of the Annual Meeting of the Air and Waste Management Association. Salt Lake City, UT.

Ogburn, C., Boothe, L., Mullen, M., Brewer, P.F., 2000. Emissions Inventories for the Southern Appalachian Mountains Initiative. In Proceedings of Annual Meeting of the Air and Waste Management Association, Salt Lake City, UT.

Pechan-Avanti Group. 1997. Projections Background Document II: Source Sector Workgroup Implementation. Report to Southern Appalachian Mountains Initiative, Asheville, NC

Pitchford, M.L., Malm, W.C., 1994. Development and Applications of a Standard Visual Index, Atmospheric Environment, Vol. 28, No. 5, pp. 1049 – 1054.

Russell, A. G., and Dennis, R. L., 2000. NARSTO Critical Review of photochemical models and modeling. Atmospheric Environment, 34, pp. 2283-2324.

Russell, A.G., McNider, R., Moody, J., Wilkinson, J.G., 1997. Air quality Modeling Protocol, Prepared for Southern Appalachian Mountains Initiative.

Russell, A.G., McNider, R., Moody, J., Wilkinson, J.G., 1998, Emissions Modeling Protocol, Prepared for Southern Appalachian Mountains Initiative.

Saxena, P. Andrews, E., Musarra, S., 1998. Southeastern Aerosol and Visibility Study (SEAVS). Report for Electric Power Research Institute, Palo Alto, CA. Report number TR-111063.

Seigneur, C. 2001. Current status of air quality models for particulate matter. Journal of Air and Waste Management Association, 51, pp.1508-1521.

Southeastern Aerosol Research and Characterization, SEARCH, 2002. http://www.atmospheric-research.com, SEARCH Home Page

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Atmospheric Technical Report. Report 2 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Systems Applications International, Inc. and ICF Kaiser, 1996. Evaluation of Existing Information on the Effects of Air Pollutants on Visibility in the Southern Appalachians. Prepared for the Southern Appalachian Mountains Initiative, Asheville, NC.

Systems Applications International, Inc., 1998. Episode Selection for the Integrated Analysis of Ozone, Visibility, and Acid Deposition for the Southern Appalachian Mountains. Prepared for the Southern Appalachian Mountains Initiative, Asheville, NC

Trijonis, J. C., Malm, W. C., Pitchford, M., White, W. H., Charlson, R.J., Husar, R. B., 1990. Visibility: Existing and Historical Conditions- Causes and Effects. Report Number 24 in Irving, P. M., Editor, Acidic Deposition: State of Science and Technology, National Acid Precipitation Assessment Program, Washington, D.C.

Turpin, B. J., and Lim, H.J., 2001. Species contributions to $PM_{2.5}$ mass concentrations: Revisiting common assumptions for estimating organic mass. Aerosol Science and Technology. 35 (1), pp. 602-610.

U.S. Department of Commerce, 1995. BEA Regional and State Projections of Economic Activity and Population to 2045: Volume 1: States.

Urban, D. L., Bonan, G. B., Smith, T. M., and Shugart, H. H. 1991. Spatial applications of gap models. For. Ecol. Manage. 42:95-110.

USEPA 1991. Guidance for Regulatory Application of the Urban Airshed Model (URM), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

USEPA, 2001a. Guidance for demonstrating attainment of air quality goals for $PM_{2.5}$ and regional haze. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

USEPA, 2001b. EPA AIRS Data. U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Information Transfer and Program Integration Division, Information Transfer Group. www.epa.gov/airsdata.

USEPA. 1996. Review of the National Ambient Air Quality Standards for ozone assessment of scientific and technical information. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA450/2-92-001.

Watson, J.G., 2002. Critical Review Visibility: Science and Regulation. Journal of the Air & Waste Management Association,. Volume 52. pp 628-713.

List of Federal Depositories

A list containing website links to the depositories is available at:<http://www.isu.edu/~woodstep/States_ 1.htm>

Alabama:
Samford University Library
Auburn University Library
Spring Hill College Library
Jacksonville State University
University of Alabama, Huntsville
University of Alabama
Birmingham Public Library

Georgia:
Georgia Institute of Technology
Kennesaw State University
Medical College of Georgia
Emory University Libraries
State University of West Georgia Library
University of Georgia Libraries-Government Documents-Regional
Mercer University Main Library
University of Georgia Libraries-Map Collection
Valdosta State University
Georgia State University

Kentucky:
Centre College
University of Louisville Library
University of Kentucky Libraries-Regional
Western Kentucky University Library
Eastern Kentucky Library

North Carolina:
Wake Forest University Library
University of North Carolina at Greensboro, Library
University of North Carolina at Chapel Hill, Regional Depository Library
University of North Carolina at Asheville Library
East Carolina University Library
Duke University Library
Appalachian State University
North Carolina Agricultural and Technical State University
University of North Carolina at Wilmington
University of North Carolina, Charlotte
Western Carolina University Library
North Carolina State University

South Carolina:
Furman University Library
University of South Carolina-Columbia-Regional
Clemson University Library-Regional
Coastal Carolina University Library
University of South Carolina-Aiken
Villanova University School of Law Library
Winthrop University Library
College of Charleston
University of South Carolina-Lancaster
Citadel

Tennessee:
Middle Tennessee State University
Tennessee Technological University Library
Fisk University
University of the South Library
University of Tennessee, Martin
East Tennessee State University
University of Memphis Law Library
Belmont University
Vanderbilt University Library
University of Tennessee, Knoxville Libraries
University of Memphis Libraries-Regional

Virginia:
Bridgewater College
Virginia Commonwealth University
Virginia Tech
Roanoke College
Old Dominion University
Washington & Lee University
Mary Washington College
James Madison University
University of Virginia Library-Maps Collection
University of Virginia Library-Regional
Norfolk Public Library
Hampden-Sydney College Library
George Mason University Libraries
College of William & Mary Library

West Virginia:
West Virginia University Libraries-Regional
Marshall University
Mary H. Weir Public Library
West Virginia University-Patent Library

S·A·M·I

SOUTHERN APPALACHIAN
MOUNTAINS INITIATIVE

www.saminet.org

Printed on
recycled paper