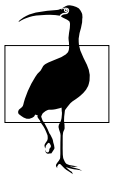
The Southern Appalachian Assessment was accomplished through the cooperation of federal and state natural resource agency specialists. This page displays the logos of the agencies involved. The strong emphasis placed on working together toward a common goal is increasingly recognized as essential to effective government operation. Teamwork has strengthened our interagency understanding and communication. With the assessment as a framework for future action, government policy and management can become more consistent and better coordinated.

The assessment employs the latest technology in geographic information systems and computer communication. These tools make the information more useful to analysts and decision-makers. They should also facilitate future networking and information sharing among government agencies, educators, and the public.

NORTH CAROLINA
Department of Environment, Health, and Natural Resources

APPALACHIAN REGIONAL COMMISSION

US Army Corps of Engineers
South Atlantic Division



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FOR THE U.S. DEPARTMENT OF ENERGY

THE
SOUTHERN
APPALACHIAN
ASSESSMENT

ATMOSPHERIC

TECHNICAL REPORT

Prepared by Federal and State Agencies

Coordinated through Southern Appalachian Man and the Biosphere Cooperative

July 1996

REPORT
3 OF 5

Abstract

This document summarizes data and assesses trends of air quality within and near the Southern Appalachian area. The major topics include: emissions of pollutants which could impact natural resources, current levels of particulate matter, current and historical visibility conditions, acid deposition impacts to aquatic resources, and ground-level ozone impacts to forests. The assessment results indicate air pollution is impacting some natural resources, and current legislative and regulatory efforts may reduce pollution impacts in the future.

Cover photos are by Bill Lea©, Asheville, North Carolina; report designs and layout are by Project Center, Atlanta, Georgia; maps are by agency Geographic Information Systems; other graphics and tables are by Blue Line, Inc., Roanoke, Virginia.

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Preface

Our vision for the Southern Appalachian region is an environment for natural resources management that applies the best available knowledge about the land, air, water, and people of the region. Applied on public lands, this knowledge would provide a sustainable balance among biological diversity, economic uses, and cultural values. All would be achieved through information gathering and sharing, integrated assessments, and demonstration projects.

The Southern Appalachian Assessment takes a major step toward fulfillment of that vision. It is an ecological assessment – a description of conditions that goes beyond state, federal, or private boundaries. In using Southern Appalachian Assessment data, land managers can base their decisions on the natural boundaries of ecosystems rather than on the artificial boundaries of counties, states, or national forests and parks.

The assessment was accomplished through the cooperation of federal and state natural resource agencies within the Southern Appalachian region. It was coordinated through the auspices of the Southern Appalachian Man and Biosphere (SAMAB) cooperative. Members of the cooperative are: U.S. Department of Agriculture, Forest Service; Tennessee Valley Authority; U.S. Environmental Protection Agency; U.S. Department of the Interior, Geological Survey, National Park Service, National Biological Service, Fish and Wildlife Service; Appalachian Regional Commission; U.S. Army Corps of Engineers; Georgia Department of Natural Resources; North Carolina Department of Environment, Health, and Natural Resources; Tennessee Department of Environment and Conservation; U.S. Department of Commerce, Economic Development Administration; and the U.S. Department of Energy, Oak Ridge National Laboratory. This cooperation significantly expanded the scope and depth of analysis that might have been achieved by separate initiatives. It also avoided duplicating work that might have been necessary if each agency had acted independently. The findings in this assessment do not reflect unanimous (unqualified) views of all agencies involved on all points.

Although the Southern Appalachian Assessment is broad and comprehensive in subject matter and geographic scope, there are many opportunities to further expand the analyses based on this data. Urgent demands for the assessment data restricted our time-frame. So, identifying data gaps became as important a task as identifying and gathering existing data. The Southern Appalachian Assessment serves as both a useful reference and as a benchmark for future analyses.

There was no specific statutory requirement for the assessment. However, national forest land and resource management plans authorized under the 1976 National Forest Management Act have been in place for almost 10 years and are therefore subject to revision. Due to the relationship of the national forests and other federal lands

to the biological, social, and economic conditions in the assessment area, more comprehensive and more scientifically credible data are needed to facilitate land management planning. This assessment supports individual forest plans by determining how the lands, resources, people, and management of the national forests interrelate within the larger context of the surrounding lands. The broadly identified pollutants and impacts of concern are not intended as a source of information upon which to base future regulatory or permitting action.

This report is one of five that document the results of the Southern Appalachian Assessment. The reports include a summary report, atmospheric, social/cultural/economic, terrestrial, and aquatic reports.

The five reports are available in printed form and via the Internet. By providing direct access to assessment materials via Internet, we hope that users can obtain information more quickly and at a lower cost than would have been possible otherwise. As with most reference documents, users will need only a small portion of the assessment for their specific projects at any given time. Moreover, an Internet document can be revised or updated when the occasion arises.

In-depth versions of data are available on the SAMAB, Forest Service, and Info South Home Pages on the World-Wide Web (WWW). These versions can be accessed at http://www.lib.utk.edu/samab for SAMAB's Southern Appalachian Home Page, at http://www.fs.fed.us/ for the Forest Service Home Page and at http://wwwfs.libs.uga.edu for the Info South Home Page. Additional materials such as maps and data that support the assessment are described and referenced in each report.

The Southern Appalachian Assessment is presented in five separate reports. The reports can be cited as follows:

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Summary Report. Report 1 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Aquatics Technical Report. Report 2 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Atmospheric Technical Report. Report 3 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Social/Cultural/Economic Technical Report. Report 4 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Terrestrial Technical Report. Report 5 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Table of Contents

Acknowledgments

The Atmospheric Team planned, wrote, and reviewed this report. The Team was composed of people who work for the U.S. Environmental Protection Agency; U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, National Biological Service and National Park Service; and Tennessee Valley Authority. Team members are listed in appendix A.

The lead authors for the chapters in this report were: Bruce Bayle (Executive Summary and Chapter 7), Scott Copeland (Chapter 4), Cindy Huber (Chapter 4), Bill Jackson (Executive Summary and Chapters 1, 2, and 6), Dr. Kathy Tonnessen (Chapter 5), and Dave Wergowske (Chapter 3). The Team began holding public meetings in November 1994. We appreciate the efforts of Terry McDonald, Bob Miller, Karen Greene, Terry Seyden, and Carol Milholen in arranging meeting locations, and lodgings, and in preparing the minutes from those meetings. We are grateful to the people who took time to provide external review and comment on the following chapters:

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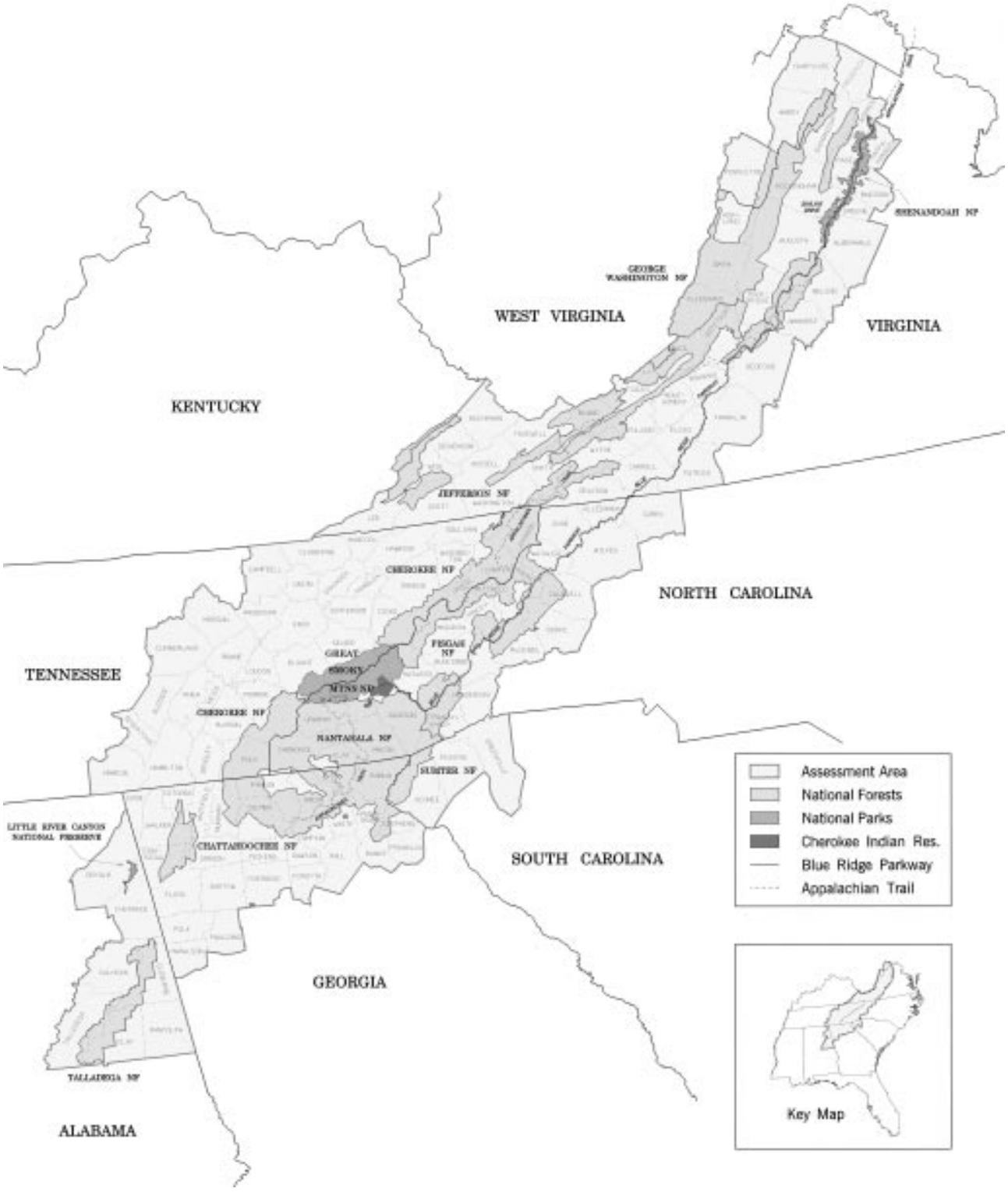
The Team also is grateful to: 1) Dr. Kent Norville and Dr. Mark Schaaf, CH2M Hill (Portland, OR), for acquiring the major point source data; 2) Dr. Allen Lefohn, A.S.L. and Associates (Helena, MT), for the assistance provided on ozone effects to vegetation; and 3) Dr. Jim Lynch and associates for producing the information used to make figures 5.1 and 5.2.

Richard Guillot, U.S. Environmental Protection Agency, assisted the Team by obtaining the particulate-matter monitoring results used in Chapter 3. We also acknowledge the guidance and information provided through the external review draft of *Air Quality Criteria for Particulate Matter* (U.S. Environmental Protection Agency 1995). Although this document has not been formally released and is not available for citation, the information provided by the authors was of considerable help in defining the issues and directing the search for answers in Chapter 3 of this assessment.

Finally, we are deeply thankful for Holly Selig's assistance in building some of the data bases and in teaching us how Geographic Information System software can be used to perform analyses.

Figure 1

SOUTHERN APPALACHIAN ASSESSMENT AREA



Executive Summary

The Southern Appalachian ecosystem is widely recognized as one of the most diverse in a temperate region. The headwaters of nine major rivers lie within the boundaries of the Southern Appalachians, making it a source of drinking water for much of the Southeast.

The Assessment area (fig.1) includes parts of the Appalachian Mountains and Shenandoah Valley extending southward from the Potomac River to northern Georgia and the northeastern corner of Alabama. It includes seven states, 135 counties, and covers approximately 37 million acres. The Southern Appalachians are one of the world's finest remaining ecological regions. Early in the 20th century, the Appalachian landscape and natural resources were being exploited; croplands, pastures, and hillsides were eroding; and timberlands were being cut with little thought for sustaining the resources. National forests and national parks were created to preserve and restore the natural resources in the region. The seven national forests in conjunction with three national parks, the Blue Ridge Parkway, and the Appalachian Trail form the largest contiguous block of public lands east of the Mississippi River.

This comprehensive, interagency assessment, began in the summer of 1994 and was completed in May 1996. It was designed to collect and analyze ecological, social, and economic data. The information provided will facilitate an ecosystem-based approach to management of the natural resources on public lands within the assessment area.

Public participation has been, and will continue to be, an important part of the assessment. One of the first actions of the assessment was to conduct a series of town hall meetings at which the public gave suggestions on the major themes and questions to be addressed. These questions, supplemented by additional concerns expressed by land managers and policy makers, form the structure for the assessment.

The questions helped to organize the Atmospheric Team's analysis and to focus the response. These questions are answered and all of the key findings are presented in Chapter 2 through Chapter 6 of this report. The following summary lists the questions and some of the key findings. Also presented are the current trends and future patterns anticipated for the Southern Appalachians.

Question 1:

What are the major air pollutants which could impact the Southern Appalachians, and what areas receive the greatest exposure?

Question 2:

What is the current concentration of particulate matter in the air of the Southern Appalachians?

Question 3:

How good is visibility in the Southern Appalachians, and how does air pollution affect visibility?

Question 4:

To what extent are aquatic resources in the Southern Appalachian Assessment area being affected by acid deposition?

Question 5:

What impact does ground-level ozone have on forests?

The major types of air pollution emissions addressed in this report are particulate matter, nitrogen oxides, volatile organic compounds, and sulfur dioxide. These pollutants are important because the secondary pollutants formed from these primary pollutants are suspected of

causing visibility reductions, ozone impacts to vegetation, and acid deposition impacts to terrestrial and aquatic environments in the Southern Appalachians. Particulate-matter concentrations in the region are fairly uniform and meet government air-quality standards. Visibility in the region has decreased since the 1940s as haziness has intensified. Sulfur dioxide emissions are believed to be primarily responsible for the regional haze throughout the region, although some other pollutants have a small contribution to regional haze. The Southeast has the poorest visibility in the eastern United States. Furthermore, visibility is poorest during the summer months when the greatest number of people are viewing scenery in the mountains. Acid deposition is being deposited in the SAA region, and headwater streams are most susceptible to acidification. However, sulfates, and base-cations (chemicals which can offset the effect of acidic deposition) are both decreasing in rainfall, and therefore pH has not improved over 13 years. Loadings of nitrate and ammonium in precipitation are also a concern to watersheds because these compounds also lead to acidification of headwater streams. Acidifying compounds which begin as nitrogen oxide emissions may have greater impacts after the year 2010 because nitrogen oxide emissions are expected to increase. Nitrogen oxides are also contributing factors to ground level ozone, which can cause growth reductions and physiological stress to trees. One area, Whitetop Mountain in Virginia, is classified as violating government air-quality standards for ozone. The areas with the greatest potential for growth loss due to ozone exposures are in the northern and southern tips of the Southern Appalachians and wherever sensitive hardwood trees are located at higher elevations.

Current Trends and Future Patterns

Sulfur Dioxide and Visibility Impairment

Sulfur dioxide emissions increased nationally between the 1940s and 1970s, but current national emissions have returned to about the same levels as in 1940. Despite the national trends, sulfur dioxide emissions in and near the Southern Appalachians increased slightly between 1985 and 1994. Therefore, visibility is not as good as it was 50 years ago. Visibility in the Southeast degraded between the 1950s and 1970s, improved between the 1970s and 1980s, and has not improved since the 1980s. Current visibility data show that the standard visual range (approximately 25 miles) is far below the estimated annual average natural

Figure 2 The photographs depict what a 3-deciview decrease in haziness (visibility improvement) would look like compared with the current median summer condition and natural background visibility. The view is James River Face Wilderness in Virginia.

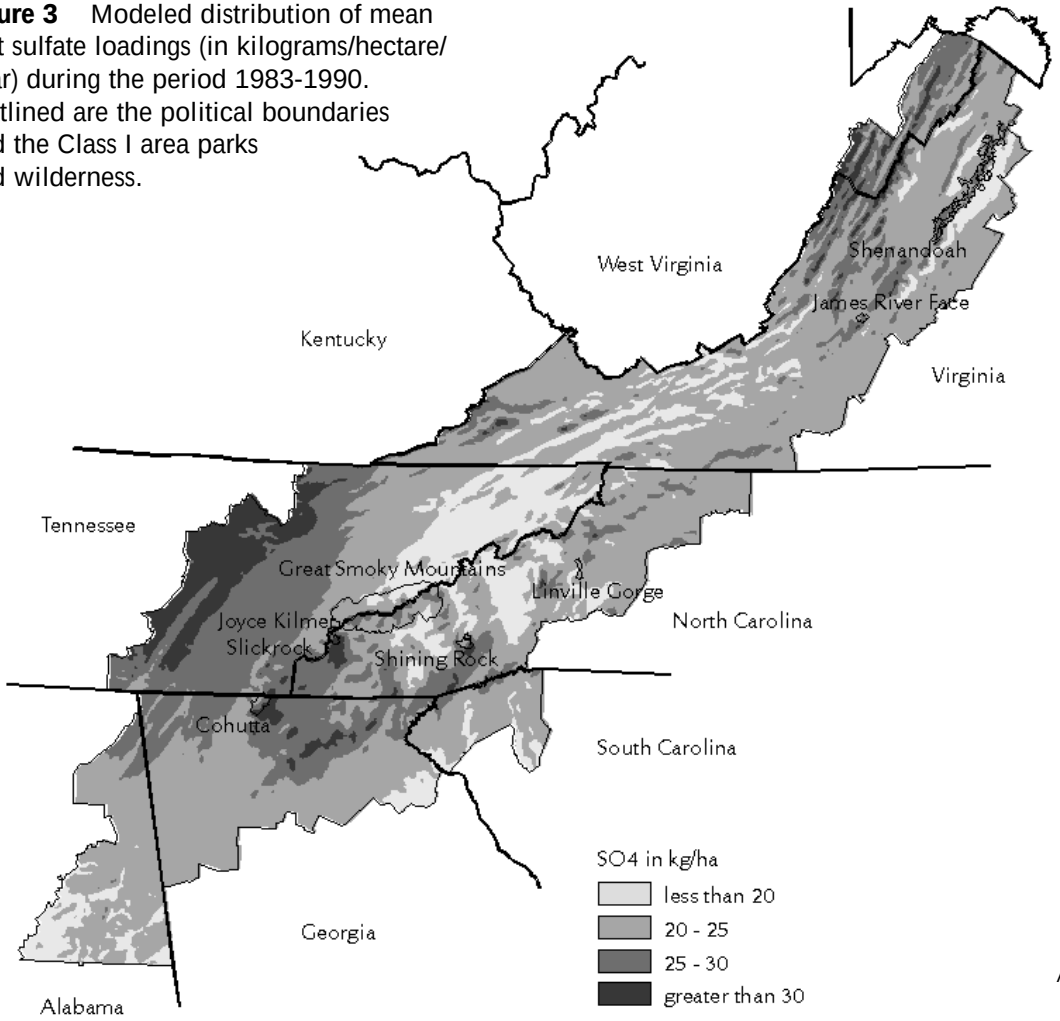
background of 93 ± 30 miles (fig. 2). Sulfur dioxide, a gas which is transformed in the atmosphere to form particles, is the largest contributor to reduced visibility. The primary sources of sulfur emissions are power plants both within and outside the SAA region. The poorest visibility occurs during the summer and spring months when relative humidity is the highest, and these seasons coincide with many outdoor recreation activities, especially the viewing of scenery. Photographic scenes of Class I wildernesses taken since the late 1980s show that the worst visibility conditions occur within the northern and southern portions of the SAA area. Since the late 1940s, haze in the southeastern United States has increased dramatically in all seasons of the year, but by far the most significant rise has been the summer haze which has about doubled. This increase in haziness leads to reduced visibility. The National Park Service has documented that reduced visibility negatively affects public enjoyment of scenic mountain vistas.

Visibility is expected to improve with a reduction of sulfur dioxide emissions that come with full implementation of the Clean Air Act (CAA) Amendments of 1990. Estimates predict a 2- to 3- deciview improvement in visibility (fig. 2). Will the predicted improvement in visibility as a result of CAA regulations be noticeable to the public and will the public be satisfied? Continued monitoring of visibility and public opinion on observed conditions will be needed in order to answer the question.

Acid Deposition and Aquatic Effects

Besides improvements in visibility, reductions in sulfur dioxide emissions are predicted to also reduce the amount of acid deposition within the Southern Appalachians. Sulfate deposition is greatest at the highest elevations and in the northern portion of the Southern Appalachians (fig. 3). The high-elevation sites typically have soils which are derived from materials that have a low buffering capacity. In

Figure 3 Modeled distribution of mean wet sulfate loadings (in kilograms/hectare/year) during the period 1983-1990. Outlined are the political boundaries and the Class I area parks and wilderness.



the mid-Appalachians, implementation of the Clean Air Act (CAA) Amendments should maintain the same proportion of chronically acidic streams as in 1985, unless nitrogen saturation occurs. Under current deposition levels, streams in the Southern Blue Ridge are susceptible to acidification (Fig. 5.7). Streams in the northern portion of Southern Appalachian and upper reaches of the southern portion of the assessment area, particularly in Class I areas, are more sensitive than those surveyed by the National Stream Survey. The Direct Delay Response Program estimated that a 30- to 50-percent reduction in sulfate deposition would prevent further acidification of streams in the Southern Blue Ridge. The 1990 CAA Amendments are predicted to accomplish a reduction of sulfate in that range. However, even under reduced sulfate deposition, streams in poorly buffered watersheds could remain acidified. In watersheds that are losing the capacity to buffer incoming sulfur, streams may continue to acidify, despite reduced sulfate input.

Nitrate loadings from rainfall are highest in the northern portion of the SAA and at some high elevation sites (fig. 4). Emissions of nitrogen oxides are expected to increase after the year 2010 if the population continues to grow. As mentioned previously, nitrate deposition can increase stream acidity and can increase the amount of aluminum released from the soils. Some high-elevation sites in the Southern Appalachians are saturated with nitrogen compounds, and this saturation will lead to further chronic and episodic acidifying events. The problems with nitrate acidification may also be exacerbated in watersheds that are defoliated by large populations of gypsy moths because the feeding by the gypsy moths leads to increased nitrogen being deposited on the soils.

Episodic or chronic acidification of streams can lead to elevated levels of aluminum which in turn could reduce survival and diversity of macroinvertebrate and fish populations in sensitive streams. The Southern Appalachians are a popular region for people to fish, and acid deposition will continue to reduce the number

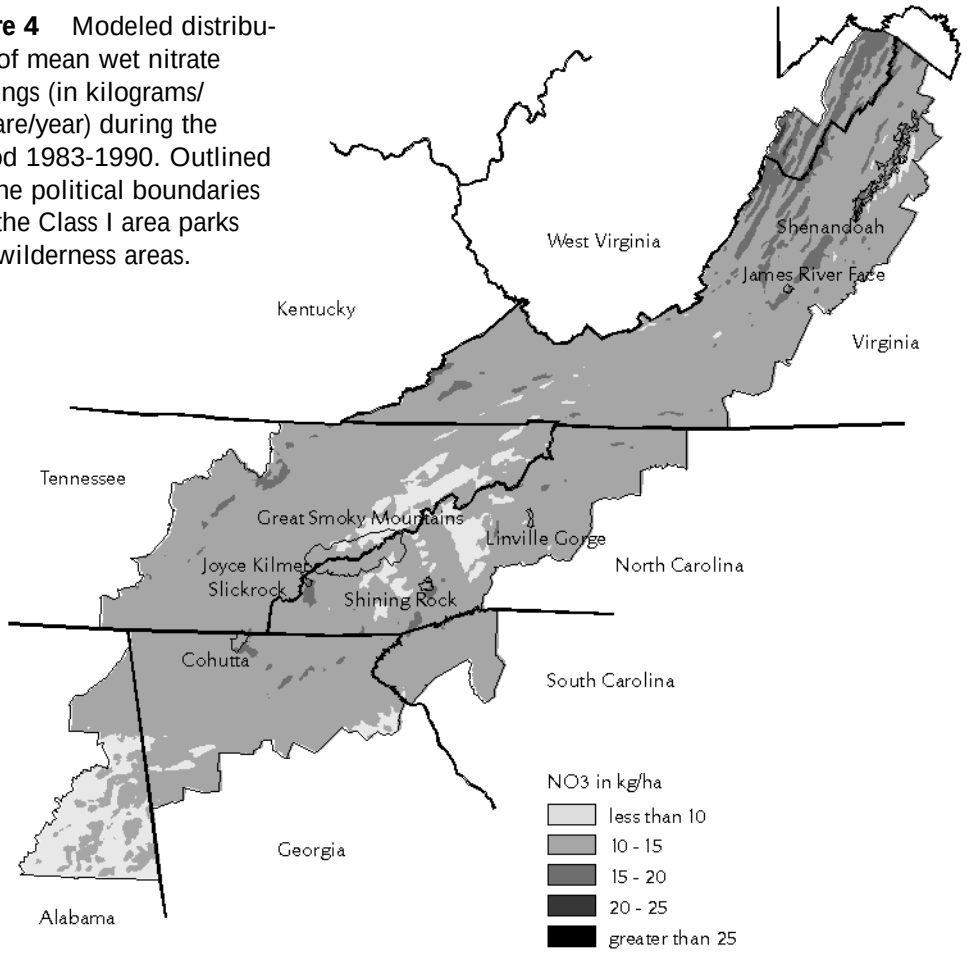


Figure 4 Modeled distribution of mean wet nitrate loadings (in kilograms/hectare/year) during the period 1983-1990. Outlined are the political boundaries and the Class I area parks and wilderness areas.

of streams suitable for fishing in some locations of the SAA region.

Ozone and Potential Vegetation Damage

Releases of nitrogen oxides and volatile organic compounds also contribute to increased ozone formation within the Southern Appalachians. As with other pollutants, some of the ozone in the mountains is formed locally, but most of the precursors are transported into the region from surrounding urban areas. Current ozone exposures are causing visible symptoms on the foliage of sensitive species, and this common injury can be found yearly in numerous locations. Current monitored concentrations of ozone frequently exceed concentrations found at pristine sites. Vegetation found at high-elevation sites below the spruce/fir ecosystem may have more favorable moisture conditions resulting in greater sensitivity to ozone exposures than at lower-elevation sites.

No published reports or data exist to document the amount of growth loss (damage) caused by ambient ozone exposures to trees throughout the Southern Appalachians. The approach used by the Atmospheric Team identified areas where ozone damage had the greatest potential to occur. These areas were identified by examining data on ozone exposures and soil moisture. The ozone exposures were divided into four levels which represented broad groupings of tree species. Throughout the SAA area, ozone exposures and soil moisture availability are sufficient to cause growth losses to the highly sensitive species for most years. Low moisture in the mid-1980s may have resulted in significant growth loss to vegetation, and ozone is believed to have only a minimal role in any growth loss between 1985 and 1988. Between 1983 and 1990, vegetation in the northern and southern portions of the SAA area may have experienced the greatest frequency of growth reduction from ozone exposures (fig. 5).

What are the implications of ozone exposures on the health of forests in the Southern Appalachians? The forest products industry may be concerned if reduced growth decreases the amount of available timber in the future. Ozone exposures could also be reducing the genetic diversity within a species, as seen with white

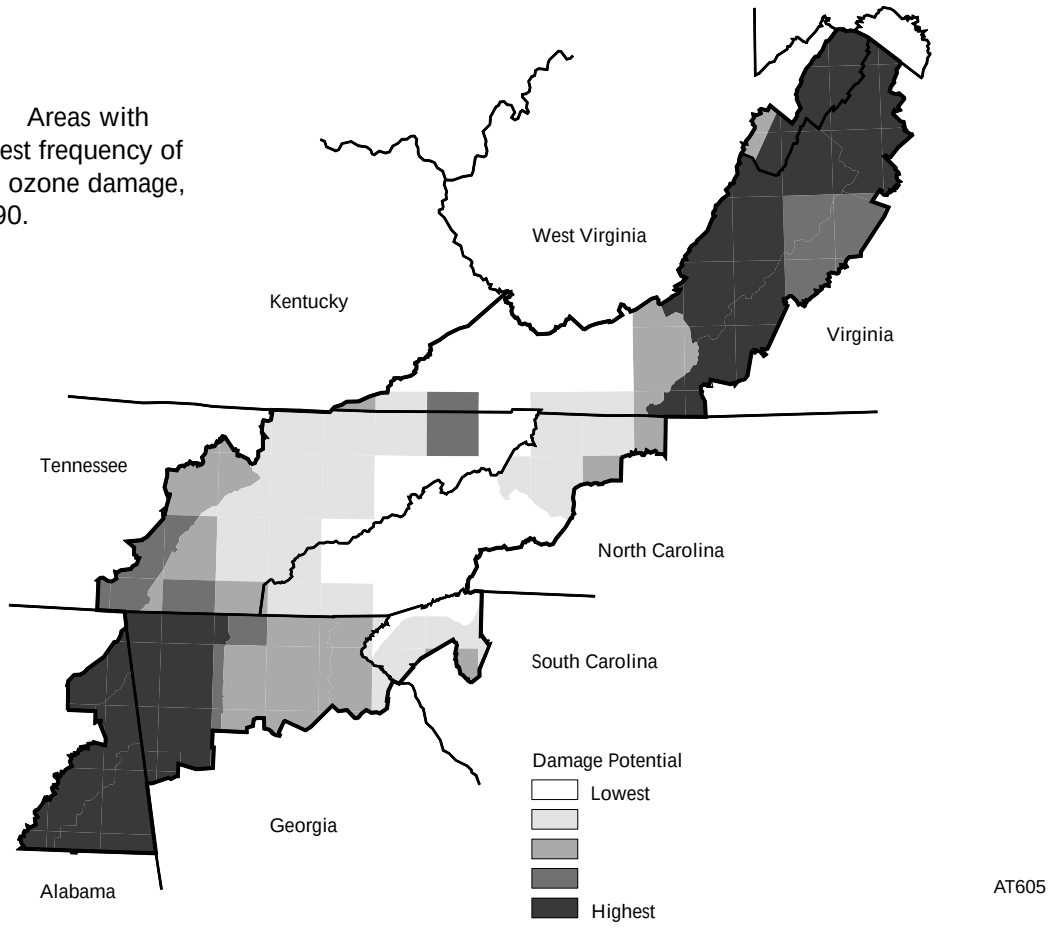


Figure 5 Areas with the greatest frequency of potential ozone damage, 1983-1990.

pines. Furthermore, little is known about what effect ozone exposures may have on rare and endangered plant species that are found in the Southern Appalachians.

Particulate Matter and Prescribed Burning

There is a growing interest among land managers to increase the amount of prescribed fires in the region for numerous purposes, such as habitat improvement for rare and endangered species. For urban areas within or adjacent to the Southern Appalachians, a small or moderate increase in prescribed fires should not cause a problem with the annual National Ambient Air Quality Standards (NAAQS) for particulate matter. For those rural areas where prescribed fire is common, there is a potential to violate the 24-hour air-quality standard within one mile of a prescribed fire. The U.S. Environmental Protection Agency (EPA) is examining the current NAAQS for particulate matter. A tighter standard may result in prescribed fire activities receiving greater attention from air regulatory agencies.

Many forest ecologists state that there is a need to return fire to its historical role in the ecosystem, reducing combustible fuel and enhancing wildlife and plant habitat, especially for fire-dependent, pine ecosystems. This policy would be accomplished through an increased level of prescribed burning. Is there an upper level of prescribed fire over a given time period that would exceed NAAQS for particulate matter? To answer this question, an increased level of particulate monitoring would be needed in rural areas; most particulate monitors are currently located in urban areas.

Regional Cooperation

There are several themes common to both this summary and the following chapters. Airborne emissions and the resulting impacts to forested ecosystems are a regional problem requiring regional solutions. Air pollution impacts to natural resources within the Southern Appalachians are caused by industrial or utility sources and mobile sources within and external to the SAA area. Federal land managers of Class I wildernesses and national parks and state and local air quality agencies within the SAA region have come to the same conclusion. To address this problem, the Southern Appalachian Mountain Initiative (SAMI) was formed. SAMI stakeholders include a wide array of federal, state, local, industrial and environmental representatives, and concerned citizens. SAMI may implement emission management options to help reduce airborne emissions, perhaps beyond what is mandated by the 1990 CAA Amendments. It is hoped that these further reductions will benefit the highly sensitive, high-elevation Class I areas and reduce pollution impacts throughout the Southern Appalachians.

General Conclusions

This study, as it applies to air quality issues and their impact to forest ecosystems, is a broad-scale assessment. As such, these findings stated should be used cautiously when applied to more localized areas such as a county or mountain. What holds true for the entire Southern Appalachians, or a portion of the Southern Appalachians, may not hold true for a specific site in the region.

The northern portion of the Southern Appalachians in West Virginia and in Virginia appears to be exposed to higher concentrations of pollutants which affect natural resources. Visibility is worse in these areas; the frequency of ozone damage is likely to be greater; acid deposition is higher; and the soils have low buffering capacity, so adverse effects are more likely. This pattern is also true for visibility and potential damage from ozone in the southern portion of the assessment area in northern Georgia and Alabama.

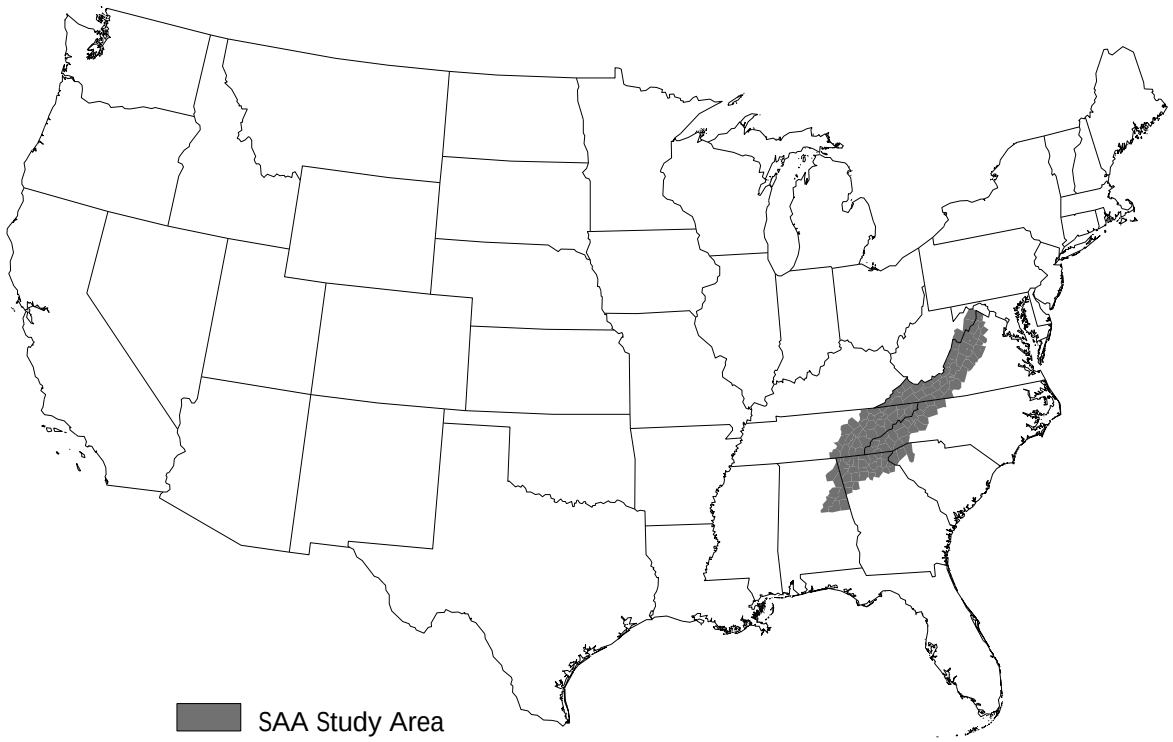
There are exceptions to these conclusions: it appears that the highest elevations throughout the Southern Appalachians are receiving the greatest amount of acid deposition, and plants at the highest elevations may be more sensitive to ozone exposures than similar vegetation growing at lower elevations because environmental conditions are favorable for the update of ozone. Finally, yearly variation in meteorology does have an influence on the amount of ozone formation, the amount of acid deposition in the rainfall, and the degree of visibility impairment; therefore, effects to natural resources will vary between years.

Introduction

The words "air pollution" call up images of smog hanging over a city, smoke coming from a stack at a factory, or a dark cloud from a vehicle's tailpipe. But, modern society is dependent on the combustion of fossil fuels for transportation, electricity, industrial processes, and heating of homes and businesses. The combustion of fossil fuels generates energy, and along with it toxic gases and particulates. These pollutants are transformed in the atmosphere and transported throughout the region, affecting people and resources in the Southern Appalachian Assessment (SAA) area (fig. 1.1).

Rarely can air pollution impacts to resources in the Southern Appalachian area be traced back to a single source. The environmental damage in the Copper Hill area in eastern Tennessee is probably an exception and can be attributed to specific sources. The Copper Hill area experienced a century of severe environmental abuse from crude copper-smelting operations and practices. Uncontrolled emissions of sulfur dioxide were so large that they were toxic to vegetation. Approximately 32,000 acres of the basin were severely affected by copper smelting. Fuelwood procurement for the smelter and grazing by livestock also had an impact on the basin. The impact to the Copper Hill region was so extensive that damage could still be seen 50 years later when the Tennessee Valley Authority began reclamation work in the area (Muncy 1986).

Figure 1.1 Location of the Southern Appalachian Assessment study area.



The air pollution impacts that are likely to be seen today in the Southern Appalachian area cannot be traced back to one, or even a few sources of pollution. Instead, pollutants are generated both within and outside of the SAA area at distances hundreds of miles away. Air pollution is produced in several ways: stationary or point sources such as power-generating plants and industrial facilities; area sources such as dust from roads, open burning, and smoke from fires; or mobile sources such as automobiles, trucks, and aircraft. Furthermore, many pollutants emitted directly from these sources are transformed in the atmosphere into secondary pollutants, such as ozone and sulfate and nitrate deposition. Secondary pollutants discussed in this report are those that are most likely affecting the forest environment.

Chapters 2 through 6 of this report answer specific questions developed at the beginning of the assessment process by public discussion. The Atmospheric Team added other questions which were important for natural resource planning. A question begins each chapter, and an introduction explains why the question is important. Next, the chapter presents data sources and methods used to answer the question. Finally, findings are presented, when available, on the current status, trends, impacts, and the predicted future to the year 2010 for the pollutants that each question addresses. Chapter 7 identifies data gaps where additional information would have improved interpretations.

The information presented is for a broad-scale assessment which focuses on air quality issues and the potential impact to forest ecosystems. Results may be viewed like an impressionistic painting where a viewer needs to stand back some distance in order to see the larger pattern more clearly. Therefore, the information and data presented should be used cautiously and may not apply for local planning; that is, a statement that holds true for the whole Southern Appalachians may not hold true for a specific site in the assessment area.

Major Air Pollutants

Question 1:

What are the major air pollutants which could impact the Southern Appalachians, and what areas receive the greatest exposure?

Pollutants are released into the atmosphere from both natural sources and human activity. Our analysis considered the types of air pollutants and selected the most important pollutants released from human activities that eventually affect the Southern Appalachian area. They are: particulate matter, nitrogen oxides, volatile organic compounds, and sulfur dioxide. The Team selected these primary pollutants because secondary pollutants formed from these primary pollutants are suspected of causing visibility reductions, ozone impacts to vegetation, and acid deposition impacts to terrestrial and aquatic environments. Information presented on these four categories of pollutants includes the location of emissions, any concentrations in the assessment area where the emissions are the greatest, and likely future trends in emissions. Another source of data presented is the toxicity indexing profile (TIP) that shows where toxic pollutants are released that could negatively impact human health or the environment. The TIP is not discussed in subsequent chapters, but the data are presented to show where in the SAA toxic pollutants are being released. Global climate change, resulting from emissions of carbon dioxide and other greenhouse gases, is another topic which is not discussed in this report. It is recognized that resources in the Southern Appalachians, for example, the spruce/fir forests occurring at high elevations, could be particularly susceptible to climatic influences. However, uncertainty associated with future regional climatic changes and the global nature of emission sources led the Team to conclude that a comprehensive analysis of this issue was beyond the scope of the assessment.

The second portion of the question for this chapter asks, "what areas receive the greatest exposure?" Atmospheric dispersion models are traditionally used to simulate pollution exposures across the landscape, or to map the potential downwind impact of a pollution source. The most accepted regional models which are very expensive to use were beyond the financial resources of the SAA. Instead, the Atmospheric Team considered using a simplified approach called statistical modeling. Although initial results were encouraging, agreement could not be reached among the federal agencies to include the results in this assessment. Thus the report does not present atmospheric dispersion data to answer the second portion of the question. The reader is referred to the sulfate and nitrate wet deposition map in Chapter 5 and the frequency of potential ozone damage map in Chapter 6 to find places where pollution exposures are the greatest.

Emissions Assessment Technique

Data were gathered on the location and the amount of pollutants emitted from large stationary sources within the Southern Appalachians and within 155 miles (250 kilometers) of the assessment boundary (fig. 2.1). This source area was selected to illustrate the types and magnitudes of sources that could contribute to pollutant loadings in the Southern Appalachians. It is difficult to define a specific boundary area for contributing sources because the atmospheric processes that control pollutant formation and transport vary by pollutant and as a function of meteorological conditions. Sources both within the designated 155-mile area and more distant sources could contribute to pollutant levels in the Southern Appalachians. The database used for the location of stationary pollution sources was the U.S. Environmental Protection Agency (EPA) Air Facilities Subsystem called the Aerometric Information Retrieval System (AIRS). The point sources included in the database emitted 40 or more tons/year of particulate matter, nitrogen oxides, volatile organic compounds, and sulfur dioxide. Data were retrieved in February 1995

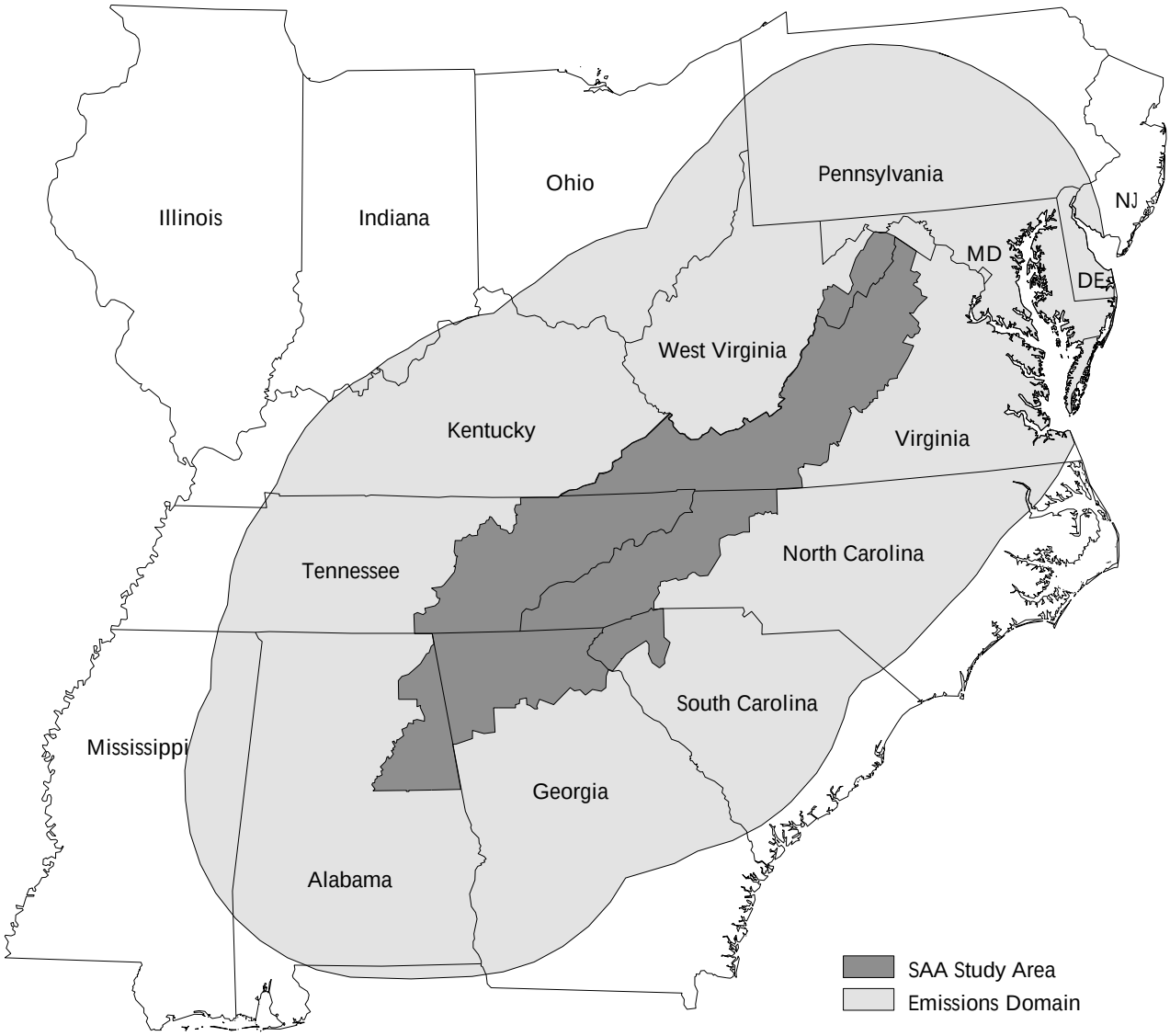


Figure 2.1 Emissions domain used for the Southern Appalachian Assessment.

and may not contain all of the sources that were emitting air pollution in 1995. For example, there were no listings of volatile organic compound sources for the state of Alabama. The data for AIRS are supplied and maintained by each of the respective state and local air pollution control agencies.

Point source emissions account for almost all of the sulfur dioxide emissions in the region, but other types of emission sources are important for nitrogen oxide, volatile organic compounds, and particulate matter emissions. These other important air pollution sources, for which detailed data were not obtained, include smaller point sources such as home heating systems and gas stations; mobile sources such as cars; and natural sources such as trees and soil. The primary source of information used to document these area-source and mobile-source emissions which could affect the assessment area was a document produced by the EPA called *National Air Pollutant Emissions Trends, 1900-1994* (EPA 1995a).

The EPA has hypothesized that exposure to a large number of toxic chemicals cumulatively endangers human health and ecosystem function. To estimate the areas with the greatest amounts of toxic release, we followed a toxicity indexing profile (TIP) methodology that aggregates toxic releases by county. The TIP index system is based on a toxicity rating used by the EPA Office of Pollution Prevention, Pesticides, and Toxic Substances and has been refined by Stockwell and others (1993). Essentially, each chemical within the toxic release inventory database is assigned a TIP score from 1 to 10 based on whether it exhibits toxicity in 10 categories. The categories are: carcinogenicity, heritable genetic and chromosomal mutation, developmental toxicity, reproduction toxicity, acute toxicity, chronic toxicity, neurotoxicity, environmental toxicity, persistence, and bioaccumulation. The TIP score is multiplied by the emission volume and indexed as to relative toxicity and then summed by county.

Emissions – Past, Current, and Future

Particulate Matter

Particulate matter in the atmosphere includes wind-blown soil, soot, smoke, and liquid droplets. Furthermore, sulfur dioxide, nitrogen oxides, and volatile organic compound gases are transformed, or condensed, in the atmosphere to form fine particles which are less than 2.5 microns in size (PM2.5). Particles are emitted into the air by sources such as factories, power plants, cars, construction activities, fires, and agricultural activities. Nationally, the major area sources of particulate matter 10 microns or less in size (PM10) are fugitive dust emissions from unpaved roads, construction, agriculture crops, and from paved roads (fig. 2.2) (EPA 1995a). Emissions of particulate matter are

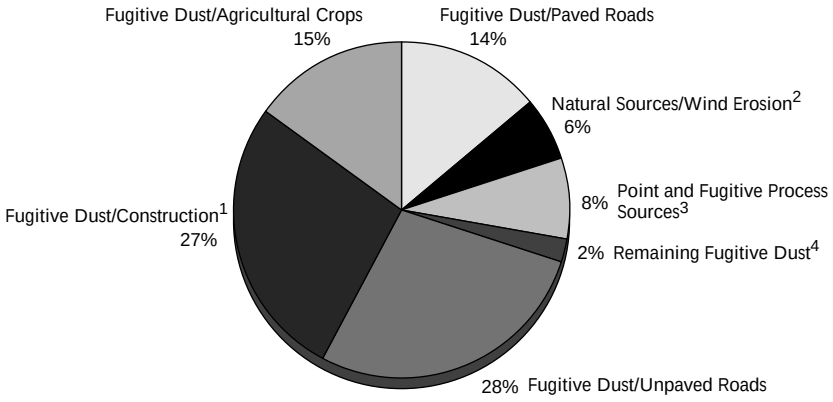


Figure 2.2 National particulate matter (PM10) emissions by principal source categories, 1994. (Source: EPA 1995a)

[1]Construction emissions represent the majority of the miscellaneous-fugitive dust-other category.
[2]Natural sources/wind erosion emissions are discussed as fugitive dust sources throughout this report.
[3]Point and fugitive process sources are all sources except the fugitive dust sources.
[4]Includes miscellaneous-agriculture and forestry-agricultural livestock and miscellaneous-fugitive dust-other excluding construction.

estimated or measured either as total suspended particulates (TSP) or particulate matter 10 microns or less in size (PM10). Figure 2.3 shows the location of major stationary sources of either TSP or PM10 emissions within and near the Southern Appalachian region, but these emissions comprise only 8 percent of the total PM10 emissions nationwide (fig. 2.2) (EPA 1995a). Nationally, between 1940 and 1994, particulate matter emissions from stationary sources have decreased significantly (fig. 2.4) (EPA 1995a). Particulate matter emissions (that is, PM10) from all sources are predicted to remain constant until the year 2010. The pattern could change if the number of acres burned from wildfires or prescribed fires increases significantly. Chapter 3 will take a closer look at the current amount of particulate matter measured in the atmosphere.

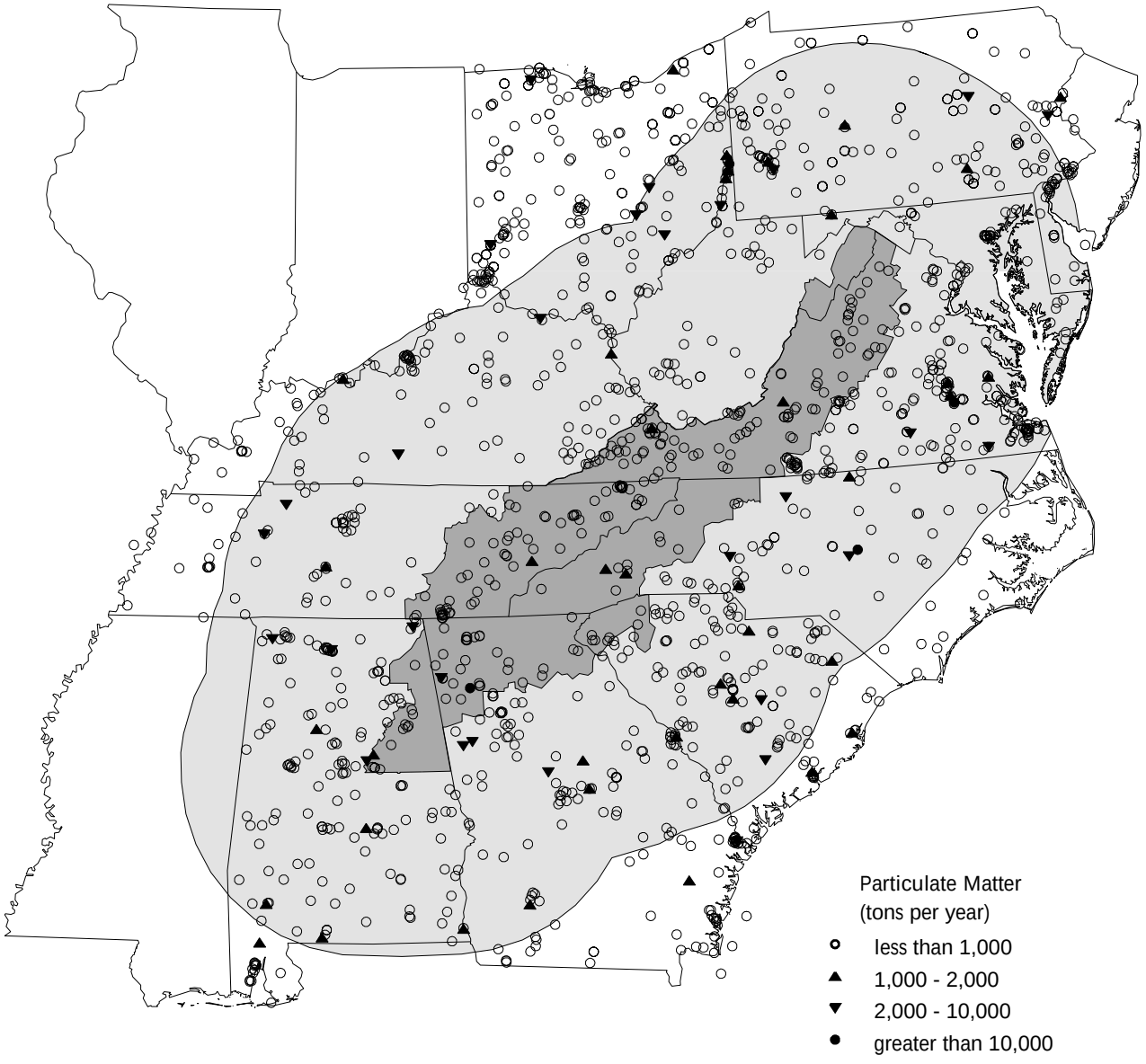


Figure 2.3 Location of point sources of particulate matter – 1995. Nationally, point sources comprise 8 percent of the total particulate matter emissions (see fig. 2.2).

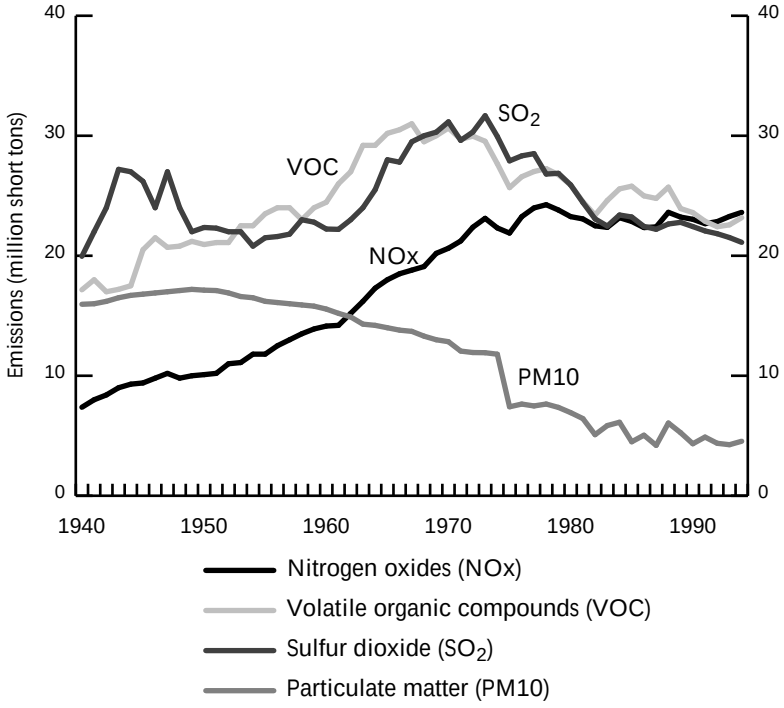


Figure 2.4 Trend in national emissions of nitrogen oxides, volatile organic compounds, sulfur dioxide, and particulate matter (PM10: nonfugitive dust sources) for 1940 to 1994. (Source: EPA 1995a)

Nitrogen Oxides

The primary (greater than 95 percent) form of nitrogen oxide emissions is nitric oxide. This gas is rapidly converted in the atmosphere, in the presence of volatile organic compounds and sunlight, to nitrogen dioxide which can subsequently be decomposed by sunlight to produce ozone. Available evidence suggests that nitrogen oxides are a controlling factor in the formation of ground-level ozone in rural areas of the southeastern United States (Chameides and Cowling 1995). Nitrogen dioxide, when trapped in sufficient quantities, can be seen as a brownish haze. Secondary pollutants formed from nitrogen oxides also reduce visibility and contribute to acid deposition. The largest contributors of nitrogen oxides are electrical power plants within and near the assessment area (fig. 2.5) and vehicles traveling the extensive road network (fig. 2.6). Nationally these two sources have equal annual emissions

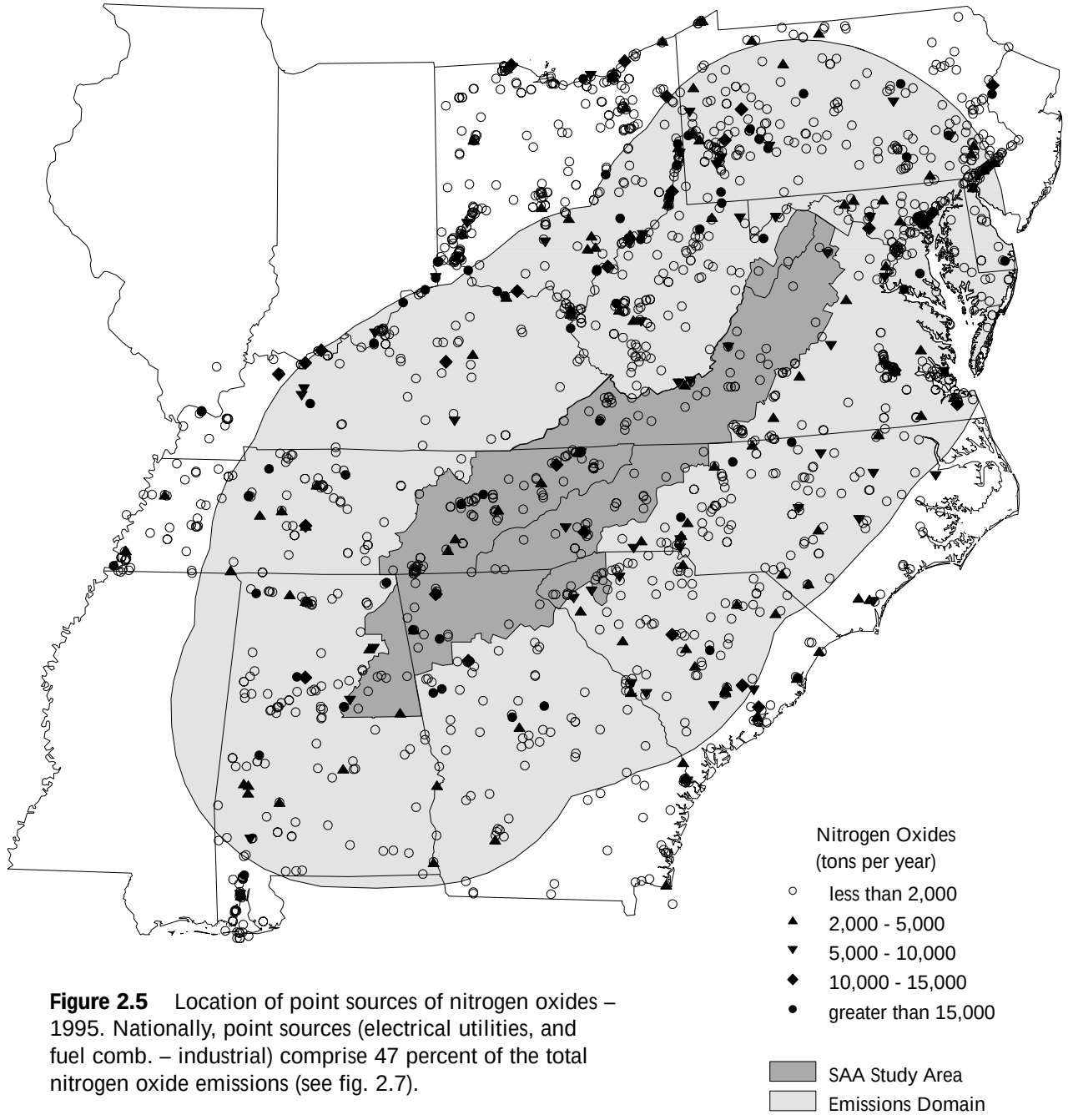


Figure 2.5 Location of point sources of nitrogen oxides – 1995. Nationally, point sources (electrical utilities, and fuel comb. – industrial) comprise 47 percent of the total nitrogen oxide emissions (see fig. 2.7).

AT203

(fig. 2.7) (EPA 1995a). Emissions of nitrogen oxides nationally have risen between 1940 and 1994 (fig. 2.4). Most of this growth is attributed to an increase in the number of vehicle miles traveled annually and to increases from electrical utilities (EPA 1995a). Title IV of the 1990 Clean Air Act (CAA) Amendments will reduce nitrogen oxide emissions from utility boilers by 2 million tons from the 1980 level, but there is no federal law to keep nitrogen oxide emissions at or below levels in 1980. Therefore, emissions in the Southern Appalachians are projected to increase by 2010 as vehicle miles traveled increase and as electrical demand rises with an increasing population (SAMAB 1996d). The potential effects of nitrogen oxide emissions are discussed further in subsequent chapters on visibility (Chapter 4), acid deposition (Chapter 5), and ground-level ozone (Chapter 6).

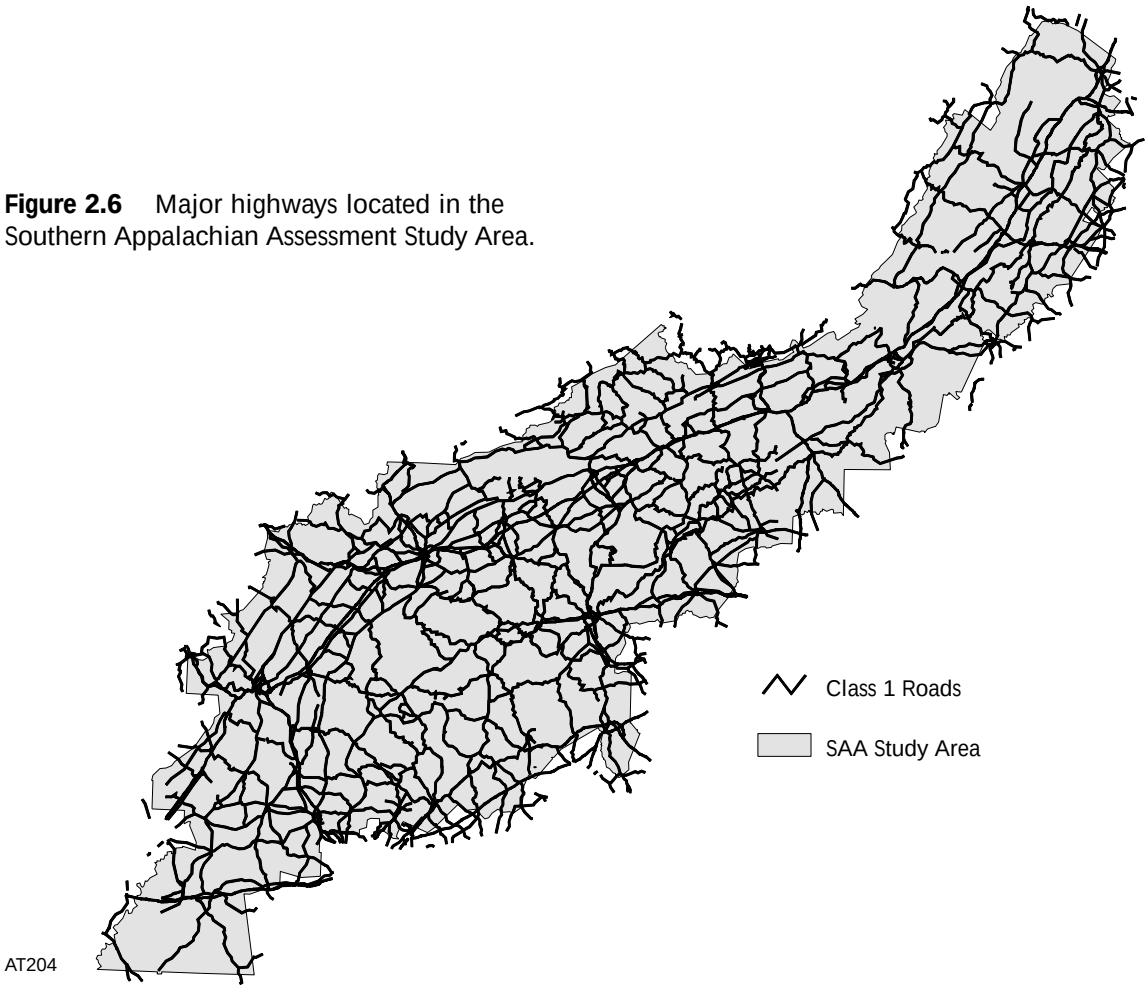


Figure 2.6 Major highways located in the Southern Appalachian Assessment Study Area.

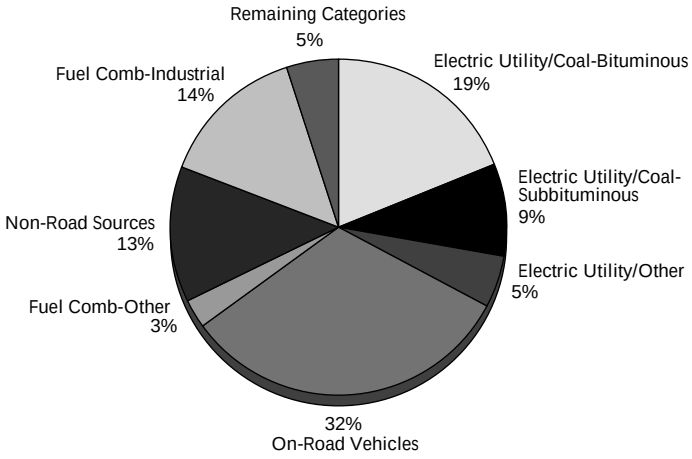


Figure 2.7 National nitrogen oxide emissions by principal source categories, 1994. (Source: EPA 1995a)

Volatile Organic Compounds

Volatile organic compounds represent a wide range of organic chemicals which are emitted into the atmosphere. Combined with nitrogen dioxide, these chemicals contribute to the formation of ground-level ozone (see Chapter 6). Stationary sources (fig. 2.8) release only a small portion of the total volatile organic compounds in the Southern Appalachian region. Trees are the primary source of volatile organic compounds with vehicle emissions second in importance in the assessment area (Placet and others 1991). Nationally, the main source of volatile organic compounds from human activity is associated with those released from highway vehicles (fig. 2.9). Emissions of volatile organic compounds have increased nationally between 1940 and 1970 and have decreased since 1970 (fig. 2.4) (EPA

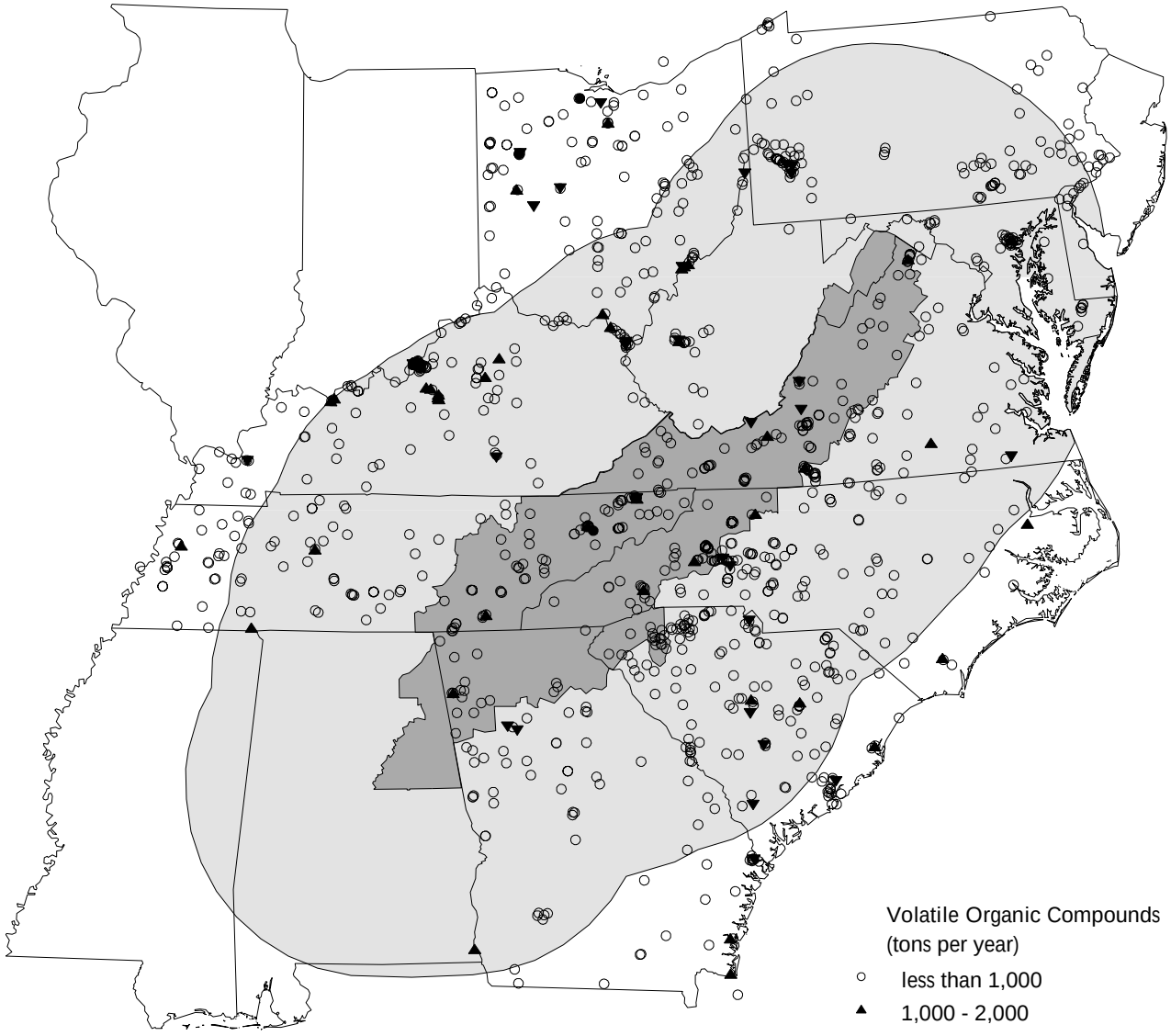


Figure 2.8 Location of point sources of volatile organic compounds – 1995. Nationally, point sources (storage and transport, and solvent utilization) comprise 35 percent of the total volatile organic compound emissions. The primary source of volatile organic compounds is from vegetation in the Southern Appalachians.

AT206

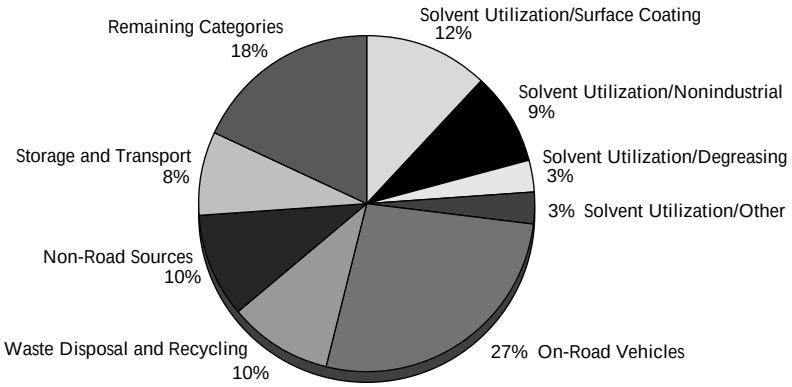


Figure 2.9 National volatile organic compound emissions estimates by source category, 1994. (Source: EPA 1995a)

1995a). Overall, future emission levels of volatile organic compounds in the Southern Appalachians are projected to increase by 2010 as vehicle miles traveled increase with an increasing population (SAMAB 1996d).

Sulfur Dioxide

Sulfur dioxide is a gas transformed in the atmosphere into secondary pollutants called sulfates which are the main contributors in the assessment area to visibility reduction (see Chapter 4) and acid deposition (see Chapter 5). The primary source of sulfur dioxide is from electrical utilities (fig. 2.10) (EPA 1995a). Numerous large point sources of sulfur dioxide, mainly coal-fired utilities, are located in northern Alabama, northern Georgia, and eastern Tennessee. There are also large sources in the

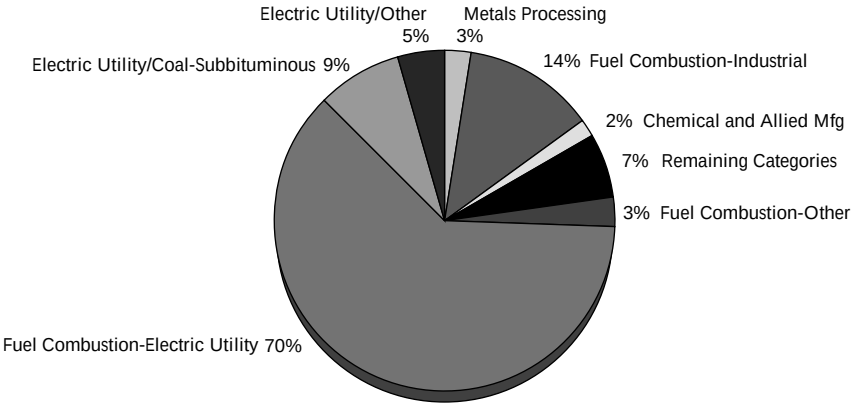


Figure 2.10 National sulfur dioxide emissions by principal source categories, 1994. (Source: EPA 1995a)

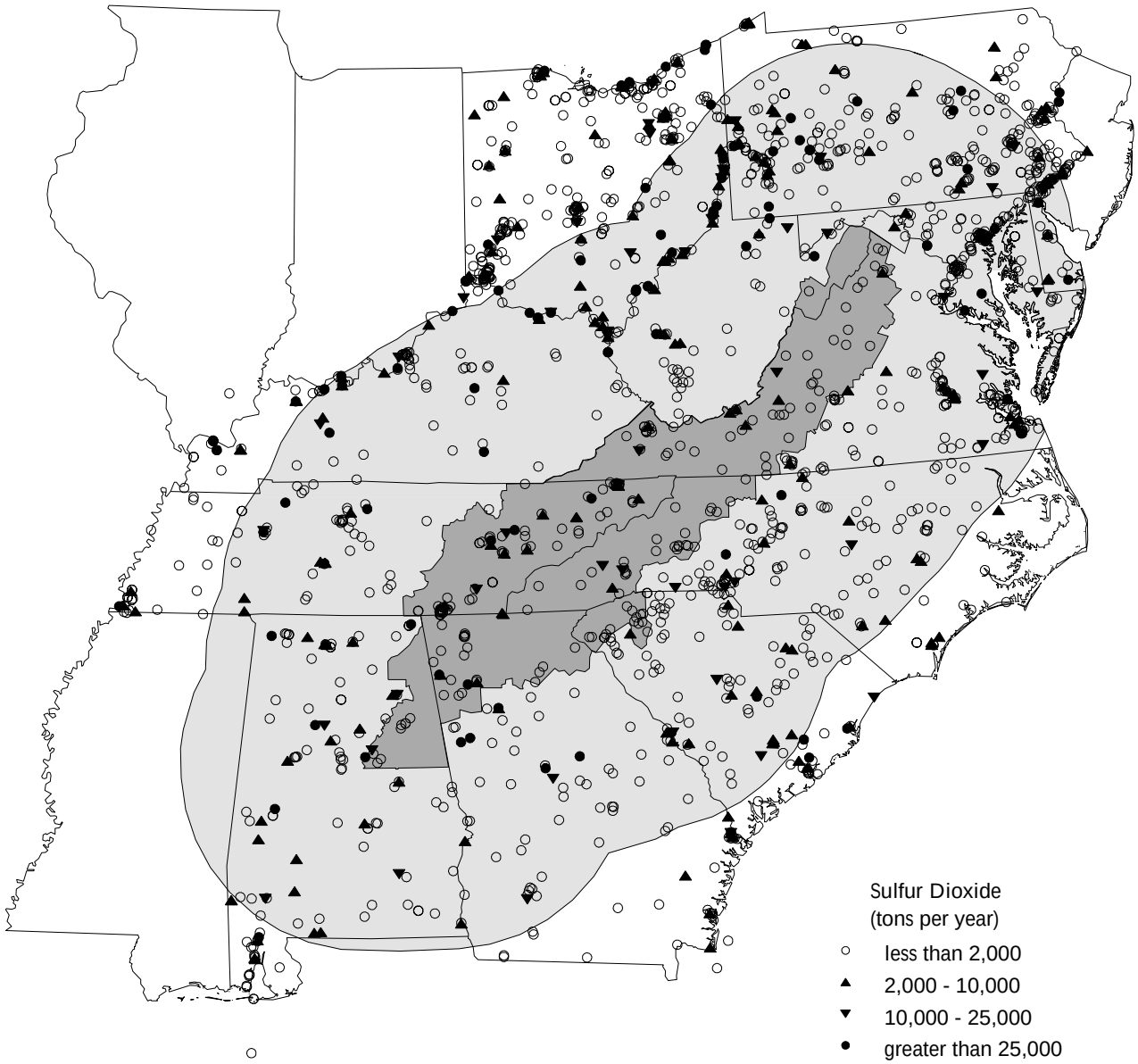


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Figure 2.11 Location of point sources of sulfur dioxide – 1995. Nationally, point sources release the majority of sulfur dioxide (see fig. 2.10).

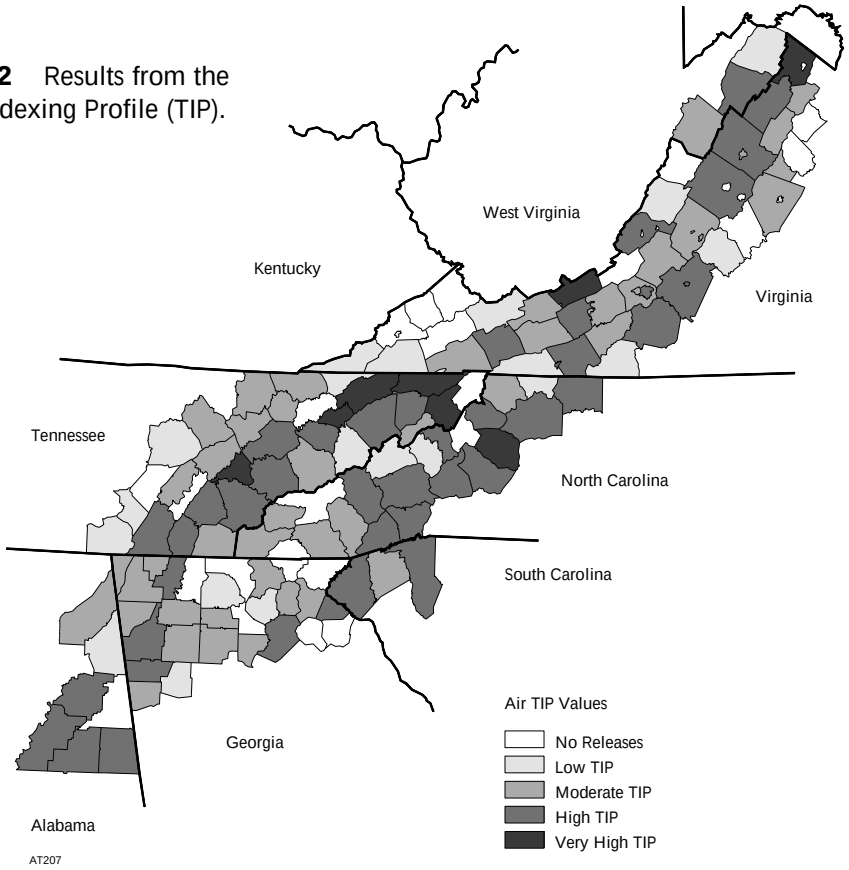
Piedmont region of North Carolina, the Ohio Valley, and the Allegheny Plateau sections of West Virginia and Pennsylvania (fig. 2.11). These large sulfur dioxide sources contribute to impacts in portions of the Southern Appalachians because the emissions are transported and changed to sulfates downwind of the facilities.

Sulfur dioxide emissions increased nationally between 1940 and 1970 and since then have steadily decreased nationally to approximately 1940 levels (fig. 2.4) (EPA 1995a). Despite this national decrease, the EPA has reported sulfur dioxide emissions in EPA Regions III and IV, which include the SAA, have increased slightly between 1985 and 1994 (EPA 1995a). The 1990 CAA Amendments will reduce sulfur dioxide emissions by 10 million tons below the 1980 level, and there will be a cap on emissions from utility and industrial sources. Emissions are expected to decrease in the Southern Appalachians, but the full extent of pro-rated reductions are not guaranteed, because sulfur dioxide sources within and near the assessment area can achieve these emission reductions by purchasing credits from sources in other regions of the United States.

Toxicity Indexing Profile

Some compounds produced by human activities are classified as toxic air pollutants. Examples of SAA area sources include chemical-manufacturing and paint-spraying operations. Toxic compounds are important because they can have severe human health impacts, or impact natural resources because of their persistence or biological accumulation in the environment. Figure 2.12 shows that the largest releases of hazardous air pollutants are in industrialized areas in urban corridors such as those found in eastern Tennessee and portions of western North Carolina. Releases of toxic air pollutants have declined in the Southern Appalachian states between 1988 and 1992. Full implementation of Title III of the 1990 CAA Amendments are expected to decrease hazardous air pollutants in the future.

Figure 2.12 Results from the Toxicity Indexing Profile (TIP).



Key Findings

1. **The major types of air pollution emissions which eventually lead to impacts on the natural resources of the Southern Appalachians are: sulfur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds.**

2. **Emissions of particulate matter in the Southern Appalachians have decreased since the 1970s and are expected to remain constant in the future.**

3. **Emissions of nitrogen oxides and volatile organic compounds have increased in the past and are expected to increase in the future as the population of the Southern Appalachians continues to grow.**

4. **Emissions of sulfur dioxide are expected to decrease in the future.**

5. **Release of toxic air pollutants are greatest in industrial corridors.**

Particulate Matter in the Air

Question 2:

What is the current concentration of particulate matter in the air of the Southern Appalachians?

Violations of the particulate matter National Ambient Air Quality Standard (NAAQS) have not occurred at any monitoring site in the Southern Appalachians. Within the rural environment, regional planners need to know existing particulate matter concentrations for two possible reasons: first, if emissions of particulate matter increase in localized areas, they may violate the existing NAAQS; and secondly, if NAAQS for particulate matter is lowered to protect human health, current monitored levels may violate the standard. Some natural resource managers want to know current particulate matter levels because they want to increase prescribed burning, which can be an important localized short duration source of particulate matter.

This chapter addresses current levels of particulate matter within the Southern Appalachians in order that others may be able to assess whether an increase in particulate matter sources, such as large stationary sources (for example, power plants) or unpaved roads, would exceed regulated limits. The chapter also considers whether particulate matter emissions from prescribed fires are likely to cause a violation of NAAQS.

The Clean Air Act (CAA), along with its Amendments of 1977 and 1990, addresses both a large variety of air pollution sources and a number of specific pollutants. The U.S. Environmental Protection Agency (EPA) maintains NAAQS for six common air pollutants: particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and lead. NAAQS is a two-part standard, with a primary standard that protects public health and a secondary standard for public welfare. The NAAQS primary standard for particulate matter is: no more than 50 microns per cubic meter (ug/m^3) on a yearly average basis and a maximum of 150 ug/m^3 for a 24-hour average. The secondary NAAQS protects public welfare, which means: forest and agricultural productivity, stability of ecosystems, transportation safety, maintenance of man-made improvements, and enjoyment of recreational opportunities. The secondary standard for particulate matter is identical to the primary standard. In both parts, "particulate matter" refers only to those airborne particles and aerosols that are less than or equal to 10 microns in size (PM10).

Particulate matter is a leading pollutant responsible for declines in visibility throughout the United States. Also, forest fire smoke can cause dangerous situations for brief periods of time when a portion of the visible plume drifts across a highway or other sensitive site. Along with the NAAQS for sulfur dioxide and nitrogen dioxide, the CAA provides specific programs to deal with visibility and acid deposition problems. These two issues are discussed in Chapters 4 and 5 of this report.

Particulate Matter Assessment Techniques

The information presented in this assessment can also be found in greater detail in a report by Wergowske (1995). The data used in this assessment are taken from particulate matter summaries in the EPA Aerometric Information Retrieval System (AIRS) database for 1985-1994, for the following states – Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, and Virginia. Information is also presented on particulate-matter-monitoring data collected near prescribed fires.

The 1985 through 1994 data sets contain several peculiarities because the focus of particulate-matter monitoring underwent a shift from total suspended particulate (TSP) to PM10. The advancement of medical science has, and continues to, increase the detail of the knowledge regarding the public health impacts of airborne particles; this progress in turn requires monitoring of smaller particles. The change in

NAAQS from TSP to PM10 initiated a gradual replacement of TSP-monitoring equipment by PM10 equipment. The number of TSP monitors decreased while the number of PM10 monitors increased during the period of interest for this report. Both data sets are presented. Wergowske (1995) examined monitoring data from urban areas and rural (called background-proxy sites) areas. The analysis indicated that particulate-matter concentrations appear to be similar for both areas. Therefore, the following analysis will present particulate-matter information using all available particulate-matter-monitoring data within the assessment area, and 40 to 80 miles beyond the assessment boundary.

To determine how close current monitored levels of particulate matter are to the NAAQS for particulate matter, this study examined the records, by year, for trends or extremes in the means and maxima of those two statistics that gage compliance with both particulate matter exposure standards. For PM10, the standards for average annual exposure and maximum 24-hour exposure are 50 and 150 ug/m3, respectively. For TSP, using accepted conversions, those figures would be 79 and 300 ug/m3, respectively.

Wergowske also noted by year the number of stations where observations showed exceedence of, or encroachment on (within 90 percent), the particulate matter standards. For PM10, 90 percent of the annual and 24-hour standards are 45 and 135 ug/m^3, respectively. Converting to TSP, those figures would be 71 and 270 ug/m^3, respectively (Wergowske 1995).

Current Particulate Matter Concentrations

Annual Average Particulate-Matter Concentrations versus the Annual Average NAAQS for Particulate Matter

One of the summary statistics available for each station-year of record is the arithmetic average of the 24-hour measurements made throughout the year. This annual average statistic shows how well air quality at the station measures against the annual NAAQS for particulate matter. Table 3.1 shows a summary, by year, of all stations in the Southern Appalachian

Table 3.1 A summary of annual average particulate matter measurements at all air-quality monitoring stations in the Southern Appalachians.

	PM10				TSP			
Year	Count	Mean (ug/m^3)	Maximum (ug/m^3)	#Obs. GT.45	Count	Mean (ug/m^3)	Maximum (ug/m^3)	#Obs. GT.71
1985	8	44	53	4	197	47	94	2
1986	17	44	57	8	205	52	92	12
1987	35	38	52	8	189	50	101	5
1988	37	35	47	2	166	52	91	7
1989	58	33	61	1	100	45	89	2
1990	78	30	50	2	85	46	94	2
1991	85	30	42	0	67	45	85	5
1992	92	26	39	0	53	39	79	1
1993	102	25	40	0	46	38	57	0
1994	106	24	40	0	37	39	58	0

Count = The number of station-years of record available for analysis.
Mean = The mean of all the station annual averages.
Maximum = The maximum station annual average out of all the station annual averages.
#Obs. GT. xx = The number of station annual averages which are greater than a value equivalent to 90 percent of the National Ambient Air Quality Standard for particulate matter.

delimited data set. This information shows:

1. During the period 1985-1994, the average annual particulate matter concentrations for the region appear to be declining when measured by both the mean of station PM10 averages and the mean of station TSP averages. The rate of decline is very steep (44 to 24 ug/m^3) for PM10.

2. The particulate matter trend is also declining when measured by the maximum of station PM10 and TSP averages (53 to 40 ug/m3, and 94 to 57 ug/m^3). Although it is not nearly as steep as is indicated by the mean of station PM10 averages.

3. In recent years there have been few occurrences when the average annual PM10 and TSP statistic exceeded the 90 percent of the annual NAAQS for PM10 or its TSP equivalent.

When station annual average particulate matter statistics are sorted and summarized by state, there do not appear to be substantial differences by state in average particulate-matter concentrations. Another summary of the seasonal station averages shows that spring and summer tend to have higher particulate-matter measurements, averaging about 12 percent above the overall mean. The spring and summer averages are higher since soils are usually dryer and more dust and soils are present in the atmosphere.

Maximum Annual Particulate Matter Values versus the 24-Hour NAAQS for Particulate Matter

Summary statistics for each station-year of record contain the highest of the individual 24-hour values recorded throughout the year. These values show how well air quality at the station measures against the 24-hour NAAQS for particulate matter. Table 3.2 shows a summary of these statistics, by year, for all stations in the Southern Appalachian data set.

1. The maximum yearly particulate-matter concentrations for the area are declining when measured by both the mean of station-year PM10 maximum and the mean of station-year TSP maximum (98 to 58 ug/m^3, and 110 to 84 ug/m^3).

2. Maximum particulate-matter concentrations are declining rapidly during the

Table 3.2 A summary, by year, of maximum 24-hour particulate matter measurements at all air-quality monitoring stations in the Southern Appalachians.

	PM10				TSP			
Year	Count	Mean (ug/m^3)	Maximum (ug/m^3)	#Obs. GT. 135	Count	Mean (ug/m^3)	Maximum (ug/m^3)	#Obs. GT. 270
1985	8	98	130	0	197	110	467	4
1986	17	92	163	2	204	120	460	2
1987	36	76	154	2	204	112	308	1
1988	38	80	147	1	182	117	298	2
1989	59	74	159	1	116	108	345	2
1990	79	72	148	2	103	99	369	3
1991	86	73	134	0	82	114	214	0
1992	92	55	142	1	70	83	320	1
1993	95	65	101	0	62	88	238	0
1994	100	58	132	0	53	84	147	0

Count = The number of station-years of record available for analysis.
Mean = The average of the individual 24-hour maximum, from all stations, throughout the year.
Maximum = The highest of the individual 24-hour maximum, from all stations, throughout the year.
#Obs. GT. xx = The number of station annual averages which are greater than a value equivalent to 90 percent of the National Ambient Air Quality Standard for particulate matter.

period of interest when measured by the highest of station annual TSP maximum (467 to 147 ug/m^3). This trend is declining slowly, if not holding steady, when measured by the highest of station annual PM10 maximum (130 to 132). This disparity will be discussed in a later section.

3. During 1985-1994, there were few occurrences when the annual maximum PM10 and TSP statistic exceeded 90 percent of 24-hour NAAQS for PM10 or its TSP equivalent.

As with station-year average particulate matter values, the maximum values were examined for seasonal patterns and for patterns among the states. However, no clear patterns were discernible in these data.

Particulate-Matter Concentrations in the Immediate Vicinity of a Prescribed Fire

There are very few particulate-matter monitors located in forested areas of the Southern Appalachians. Furthermore, forest fires rarely occur in the immediate vicinity of a particulate-matter-monitoring station in the network. However, two studies have been reported in southern states where portable PM10 monitors were briefly (2-12 hours) set up adjacent to prescribed fires. One study was conducted by the Florida Department of Environmental Protection and the Apalachicola National Forest (Florida Department of Environmental Protection 1993), and the other was done by the Texas Forest Service and the USDA Forest Service on the National Forests in Texas (Hunt and others 1994). Not surprisingly, both projects showed that the likelihood of exceeding the 24-hour NAAQS for particulate matter of 150 ug/m^3 increased in close proximity to the fire.

In nine-tenths of the cases, particulate-matter concentrations were less than 150 ug/m^3 one mile from the control line. In two-thirds of the cases, the standard was maintained as close as one-half mile from the control line. In a few cases, PM10 concentrations did not exceed the 24-hour standard even at the control line. In both studies, prior to burning, the PM10 concentrations in the air mass were measured between 15 and 30 ug/m^3 – well below both the annual and 24-hour standards. It is clear that PM10 concentrations associated with prescribed burns are dependent on weather, fuel conditions, and the duration of burn.

Summary of Current Particulate-Matter Concentrations and Trends

1. In recent years, particulate-matter concentrations have seldom approached the 24-hour standard for PM10 or its TSP equivalent. Even less frequently have particulate-matter concentrations approached the annual standard.

2. A comparison of quarterly average particulate-matter values shows that spring and summer tend to have higher values than fall and winter. A review of the months in which the yearly first and second maxima occurred at each station, however, does not reveal any strong seasonal pattern.

3. A review of the average annual and yearly maxima data by state does not show any strong spatial patterns in PM concentrations across the SAA area.

   In as much as there are no strong spatial or seasonal patterns for peak PM concentrations, managers responsible for infrequent and exceptionally large PM emissions will have trouble finding a "safe" season or locality where such emissions can be released without consideration.

4. The PM10 and TSP data give the appearance of a declining trend in annual PM concentrations. As discussed in the following paragraph, caution is advised before relying heavily on this apparent trend.

The revision of the NAAQS for particulate matter in 1987 not only focused attention on PM10, but also lowered the standard to a limited degree. This lowering, as well as other CAA regulatory efforts, may have led to true reductions in particulate matter. However, information in Chapter 2 notes that particulate-matter emissions from all sources has remained level since the 1960s. There is a possibility that

because of differences in measuring equipment, monitored particulate-matter concentrations have not really been declining. The change-over from TSP equipment to PM10 was done over an extended period of time to reduce the financial burden on monitoring agencies. Areas with the greatest likelihood of exceeding the particulate matter standard switched from TSP to PM10 monitors first. This selective replacement of equipment, which put priority on those sites with high particulate matter concentrations, could have made a level trend in particulate matter appear as downward trends in both PM10 and TSP. Therefore, until the data are examined more closely, it is possible that PM10 trends may be level instead of declining.

Particulate Matter Concentrations – Future Regulations Regarding Prescribed Fires

Changing of the NAAQS to PM2.5

The EPA is considering a lowering of the NAAQS for particulate matter if new information shows stronger standards are needed to protect public health from small airborne particles. A revised standard might focus on particulate matter smaller than 2.5 microns in diameter (PM2.5). At a recent workshop on environmental regulation and prescribed fire, a representative of the American Lung Association presented evidence that the current PM10 standard does not adequately protect public health. He reported that "a significant number of recent epidemiological research studies have found a correlation between levels of PM10 well below the current standard with a broad spectrum of adverse health effects, including death" (White 1995).

Visibility is also affected by fine particulates. Most of the haze in the Southern Appalachians can be attributed to PM2.5 (see Chapter 4). Due to this, the EPA is developing regional haze regulations concurrently with the particulate-matter standard review.

The EPA's ongoing review of NAAQS may result in regulating particulate matter to a level well below the current PM10 24-hour standard of 150 ug/m^3.

With changes on the horizon, it is clear that future land management decisions can no longer be made as in the past. Regional planners, and other people who conduct open burning or prescribed fires, must be prepared to accommodate these changes.

Particulate Matter Emissions from Prescribed Fires

Forests are usually seen as having a positive effect on air quality, but forest fires emit air pollutants. Prescribed fire is widely used by natural resources managers to benefit timber production, wildlife, rare and endangered species, and to reduce wildfires. Even before this century, inhabitants of the forested and rural southeast used controlled burning for a variety of purposes including: land clearing, game and domestic animal forage improvement, safety/protection, and forest fuel reduction. The Terrestrial Technical Report of the Southern Appalachian Assessment (SAMAB 1996c) discusses the prevalence of pre- and post-European settlement fires in the area. It is increasingly apparent that fire is an important process in many ecosystems, and that, in order to restore and manage terrestrial ecosystems, the use of prescribed fire may increase.

All forest fires emit air pollutants. The advantage of controlled prescribed burns over wildfire is that the timing, location, and intensity of the burns are moderated. This moderation reduces public health and safety hazards, limits property damage, and minimizes adverse effects on environmental resources such as air quality.

Emissions from prescribed fires could contribute to violations of several NAAQS-regulated substances: carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and particulate matter. As with most poorly controlled combustion processes, carbon monoxide is emitted in large amounts, approximately 140 lb/ton of fuel (EPA 1988). Carbon monoxide is not generally a threat in rural areas beyond the immediate vicinity of the fire. With the possible exception of "peat" and "muck soil" sites, forest fires emit only negligible amounts of sulfur (USDA Forest Service 1976). Nitrogen and volatile organic compounds are emitted at approximate rates of 4 and 24 lb/ton of fuel, respectively (EPA 1988). The amounts of nitrogen and volatile organic compounds emitted from prescribed fires in the

Southern Appalachians are insignificant in comparison with other natural and man-caused sources of these pollutants. However, both of these pollutants are precursors to the formation of ground-level ozone and may become significant where ozone problems already exist. Emissions of both nitrogen oxides and volatile organic compounds from open burning have been targeted for reduction in state plans to achieve the ozone standard in areas where ozone is persistently high (Georgia Environmental Protection Division 1994). Chapter 6 of this report discusses the current status of ground-level ozone and its potential effect on forest trees.

Particulate-matter emissions from forest fires vary widely depending on the type and amount of accumulated fuel, weather, fuel moisture, and the fire's rate of spread. The average emission rate for particulate matter is estimated at 17 lb/ton of fuel consumed. At an average consumed-fuel load of approximately 9 tons/acre, fires could yield as much as 153 lb/acre of particulate matter (EPA 1988). Forest managers will need to be cautious if either the size or number of acres burned in prescribed fires is increased. A large increase in particulate-matter emissions could lead to a violation of the particulate matter NAAQS. As mentioned previously, PM10 NAAQS have been exceeded downwind of prescribed fires.

Particulate matter formation in forest fire smoke is a complex process. Coagulation and condensation of solid and gaseous organic compounds form the bulk of particles in the smoke. These particles are almost always less than 5 microns in size. Larger particles of ash and unburned fuel are carried aloft, but they usually settle to the ground within a distance of 1/2 to 1 mile of the burn. Approximately 80 percent of the particulate matter mass carried aloft from forest fires is in particles less than 1 micron in size. Particles found by aircraft samplings of smoke plumes are rarely larger than 10 microns (USDA Forest Service 1976). Based on National Research Council (1993) information, Wergowske (1995) has estimated that current levels of forest fire smoke contribute about 1.5 percent to overall fine particle mass on an annual basis. It is important to note that prescribed fires could receive greater attention in the future if the NAAQS is lowered to PM2.5 and emissions from prescribed fire are increased.

Key Findings

1. Particulate-matter concentrations in the Southern Appalachian area are distributed uniformly, but have some seasonal variation. Spring and summer mean concentrations are approximately 12 percent above the annual mean.

2. At most monitoring stations, particulate-matter concentrations are well below current air-quality standards. New sources which emit small amounts, or even modest amounts, of particulate matter probably will not cause a violation of the annual standard.

3. If tighter particulate matter standards are implemented, prescribed fires may cause a violation of air-quality standards since the prescribed fire emissions of particulate matter are predominately less than 1 micron in size.

Visibility in the Southern Appalachians

Question 3:

How good is visibility in the Southern Appalachians, and how does air pollution affect visibility?

The Southern Appalachians can summon images of cool clear streams, forested mountains, birds and other wildlife, or perhaps a special place that has a spectacular view of distant ridges. Viewing scenery is one of the most often cited reasons for visiting national forests and parks. However, visibility in the Southern Appalachians has deteriorated over the past 40 years, and the degradation is linked to sulfur emissions from the combustion of fossil fuels, such as coal and oil. The same pollutants that lead to visibility impairment also contribute to human health effects and acidic deposition effects on streams, soils, and vegetation.

Many people think of visibility in terms of the distance between themselves and a clearly viewed object. But visibility is more closely associated with the conditions that allow appreciation of landscape features than with distance. The texture of different cloud formations, the color of fall foliage, and the form and clarity of a geologic outcropping are all important indicators of visibility and visual air quality.

In addition to being an important component of the recreational experience, visibility is protected by federal law. The Clean Air Act (CAA) Amendments of 1977 declared as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas where impairment results from manmade air pollution." Class I areas are those wildernesses larger than 5,000 acres and national parks exceeding 6,000 acres, which were in existence as of August 7, 1977. The majority of the available visibility data for the Southern Appalachian Assessment (SAA) area has been collected at the Class I areas to determine the amount of visibility impairment occurring from manmade pollutants. There are seven Class I areas in the Southern Appalachians: James River Face Wilderness and Shenandoah National Park in Virginia; Linville Gorge, Shining Rock, and Joyce Kilmer-Slickrock Wildernesses in North Carolina; Cohutta Wilderness in Georgia; and Great Smoky Mountains National Park in Tennessee and North Carolina. Sipsey Wilderness in Alabama and Dolly Sods Wilderness in West Virginia are Class I areas located just outside the assessment area boundary, but are included in this report to represent the northwest and southwest extremities of the assessment area. Figure 4.1 shows the locations of

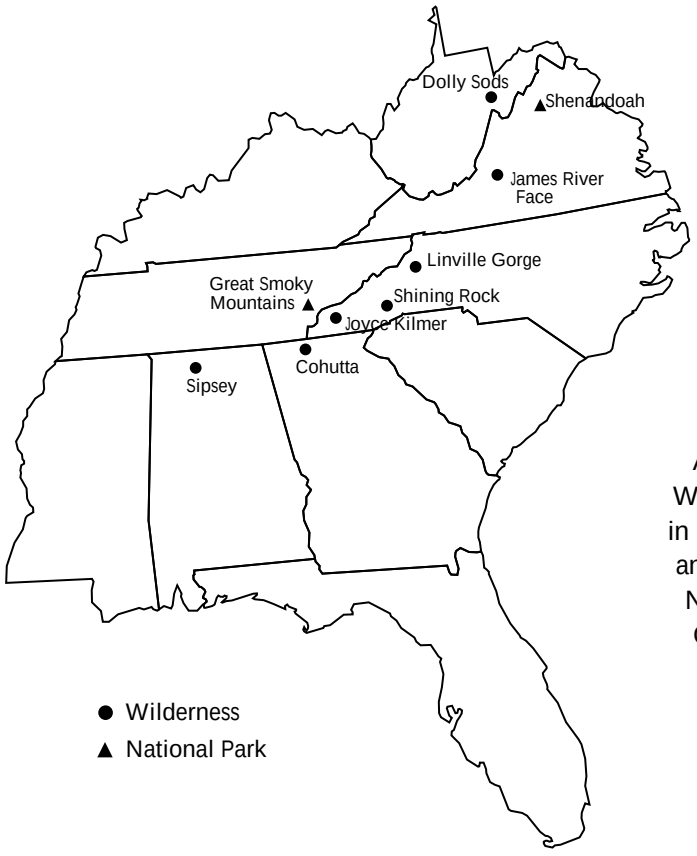


Figure 4.1 Location of southeastern Class I areas where visibility monitoring has been conducted.

these Class I areas. The purpose of this chapter is to present information on historical visibility conditions, compare those with current conditions, and predict future trends. However, before launching into discussion of visibility conditions and trends, this next section will provide background information which explains the causes of visibility impairment and methods of measuring visibility.

Background Information to Understand Visibility

Causes of Visibility Impairment

Visibility impairment is most simply described as the haze which obscures clarity, color, texture, and form. Several components interact to determine visibility conditions: the object being viewed, the atmospheric conditions influencing the sight path, the lighting conditions, and the viewer. Visibility impairment is caused by aerosols (solid or liquid particles dispersed in the air) or gases in the atmosphere that scatter or absorb light, thereby reducing visibility. Knowledge of the chemistry and physical properties of the aerosols responsible for visibility impairment can provide insight into the causes of visibility problems. Scattering efficiency for visible light is greatest for particles and aerosols with diameters in the 0.1-1.0 micron range. Fine particles, with diameters less than 2.5 microns (PM2.5), contribute greatly to the scattering and absorption of light, the sum of which is called light extinction. The significant chemical components in fine aerosols are sulfates, nitrates, organic carbon, soot (light-absorbing carbon), and soil dust.

A wide variety of pollutants may result from daily activities that include driving cars to work, generating electricity to light homes and businesses, and producing consumer goods. Depending on the location, time of the year, and atmospheric conditions, these human-caused pollutants can significantly reduce visibility. Table 4.1 illustrates the principal types of sources responsible for emissions of pollutants which lead to regional haze.

Once emitted into the atmosphere, the fate of these pollutants will be largely determined by meteorological conditions, especially winds, relative humidity, and solar radiation. According to an EPA report (EPA 1995a), most visibility impairment results from the transport by winds of emissions and secondary particles, often over great distances (typically hundreds of miles). Consequently, visibility impairment is usually a regional problem, rather than a local one. Regional haze is caused by the combined effects of emissions from many sources distributed over a large area, rather than of individual plumes caused by a few sources at specific sites. Stable atmosphere conditions known as stagnation areas also inhibit movement of pollutants, sometimes leading to severe haze episodes in the Southeast (Holzworth and Fisher 1979).

Relative humidity is another weather parameter that affects visibility. Certain kinds of

Table 4.1 Percentage contribution by source category to pollutants which affect visibility in the eastern United States.

Source Category	SO_x	Organic Particles	VOC	Elemental Carbon	Suspended Dust	NH_3	NO_x
Electric utilities	78	—	—	—	—	—	39
Diesel-fueled mobile sources	1.5	—	—	47	—	—	16
Gasoline vehicles	1	34	31	29	—	—	26
Petroleum and chemical industries	4.5	—	11	—	—	—	—
Industrial coal combustion	7	—	—	—	—	—	—
Residental wood burning	—	20	13	15	—	—	—
Fugitive dust (on/off-road traffic)	—	—	—	—	100	—	—
Feedlots and livestock waste management	—	—	—	—	—	66	—
Miscellaneous	8	46	45	9	—	34	19

SO_x - sulfur oxides
VOC - volatile organic compounds
NH_3 - ammonia
NO_x - nitrogen oxides
(Source: National Research Council 1993)

particles, especially sulfates, are hygroscopic, which means they attract water. In a humid atmosphere, sulfate particles combine with water and grow to a size that makes them more efficient light scatterers. For a given level of pollution, an atmosphere with higher relative humidity will have more haze than if relative humidity was lower (Sisler and others 1993).

Visibility Measurements

Scientists and resource managers use several different types of equipment to measure visibility conditions, each of which differs in terms of cost, siting restrictions, ease of operation, and usefulness of data. The most common types of optical visibility-monitoring equipment include the transmissometer and nephelometer. These tools directly measure the light-extinction coefficient and scattering coefficient, respectively. Scenic monitoring utilizes interpretation of 35-mm photographic slides. Aerosol monitors measure the particles in the atmosphere that affect visibility. Combinations of these types of equipment are used to describe and define visibility.

Several different parameters are used to express visibility. Standard visual range (SVR), derived from photographs, has been the most commonly used measure of visibility by the Forest Service. SVR, usually expressed in kilometers, is the greatest distance at which an observer can barely see a black object viewed against the horizon sky. The higher the SVR value, the better the visibility conditions.

Another common measure of visibility is the light-extinction coefficient or B_{ext}. The light-extinction coefficient represents the ability of the atmosphere to absorb and scatter light. As the light-extinction coefficient increases, visibility decreases. Direct relationships exist between concentrations of particles in the air and their contribution to the extinction coefficient. These relationships are often presented in an annual extinction-budget plot showing the percentage of light extinction attributed to each particle type. The extinction budget, as discussed in a later section, is an important method for assessing the causes of visibility impairment.

Neither SVR nor extinction coefficient has a consistent direct relationship to perceived visual changes caused by uniform haze. Depending on baseline visibility conditions, a specific change in SVR or extinction coefficient can result in a visual change which is either obvious or imperceptible relative to the total SVR. For example, an improvement of 10 miles in SVR may be quite perceptible at an eastern location with an annual average visibility of 40 miles, but a 10-mile change in SVR may not be perceptible at a western location with an annual average visibility of 150 miles. The deciview (dv), a visibility index designed to describe changes in visibility perception across locations with all types of baseline conditions, is another commonly used measure of visibility (Pitchford and Malm 1994). It is designed to be perceptually linear (similar to the decibel scale for sound), meaning that a change of any given dv should appear to have approximately the same magnitude of visual change on any scene regardless of baseline visibility conditions. A 1-dv change is about a 10 percent change in the extinction coefficient – a small but perceptible scenic change. The dv value increases as haze increases, so it is known as a haziness index.

Visibility Assessment Techniques

Visibility data collected at airports since the 1950s were used in this assessment to examine historic conditions and trends over the past 40 years. Current conditions are described from data collected through the Interagency Monitoring of Protected Visual Environments (IMPROVE) network (Sisler and others 1993), and data obtained from pictures taken at many of the wildernesses beginning in 1987. Predictions of future visibility trends were made by the EPA based on estimated changes in pollutant concentrations resulting from implementation of the 1990 CAA Amendments.

Visibility – Past, Present, and Future

In the eastern United States, annual average natural background visibility is considered to be 93 ± 30 miles (150 ± 45 kilometers) (Trijonis and others 1991), which corresponds to an average range of 7 to 13 dv. Natural background visibility is defined as the visibility condition without the addition of anthropogenic (human-caused) pollution. Currently, the annual average visibility in the Southern

Appalachians is 20 miles (32 kilometers) (Sisler and others 1993), which corresponds to 24 dv. With the implementation of the CAA Amendments of 1990, which call for sulfur dioxide reductions, visibility in the Southern Appalachians is predicted to improve by 2 to 3 dv (3 to 7 miles) (EPA 1993a). This section describes past and present visibility conditions and expectations for the future.

Historical Visibility in the Southeastern United States

Visibility data collected at airports for more than 40 years give an idea of the direction of long-term trends in visibility. Daylight observations of pre-selected visibility markers, large dark objects at known distances from the observation point, are used to determine the most distant visible marker. The shortcoming of this technique is a lack of targets far from the observer. Visual range is estimated as the distance to the farthest identifiable marker, when, in fact, visual range could be greater with a more distant target. The reported visual range is always an underestimate of the actual visual range. For example, an observation reported as 10 miles means that visual range is greater than 10 miles. In spite of this problem, visual range estimates from airport data do allow us to look at relative change over time.

The work of Husar, Elkins, and Wilson (1994), based on airport visual range data, shows that haze has intensified over a large contiguous region east of the Mississippi River during the past 40 years. In the 1960s, the poorest visibility conditions in the eastern United States were recorded for the cold season in the area surrounding Lake Erie and the New York-Washington megalopolis. By the 1980s the haziest conditions were found in Tennessee and the Carolinas in the summer. The haze situation has not changed significantly in the 1990s. The poorest visibility in the Southeast still occurs in the summer months.

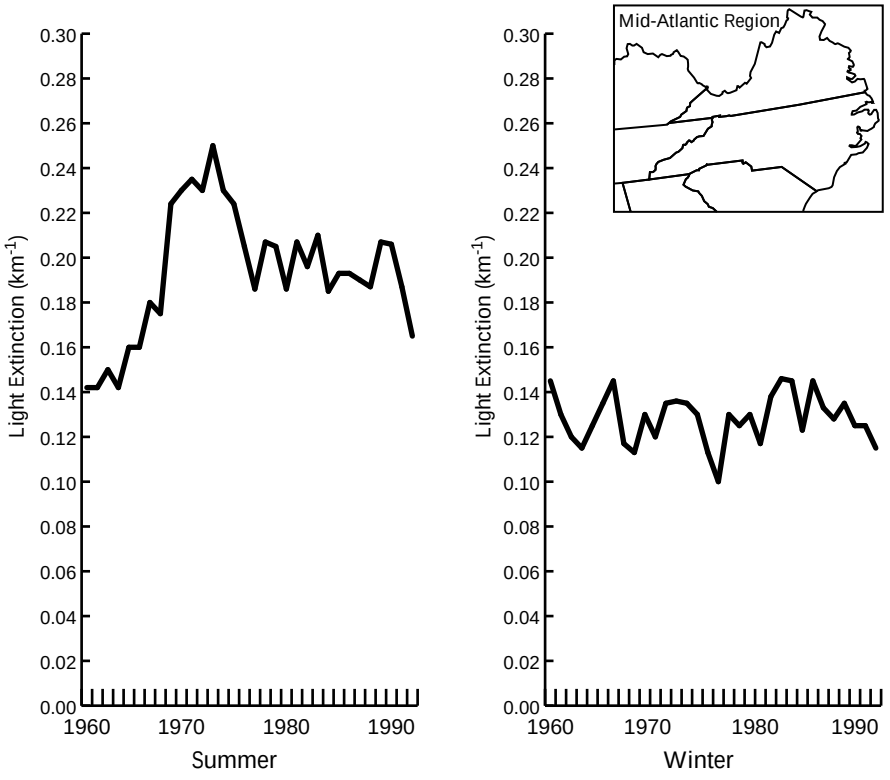


Figure 4.2 Historical trends in winter and summer haze (light extinction) from airport data for the mid-Atlantic region, including the southern Appalachian area (1960-1992). As light extinction increases, haze increases and visibility deteriorates. Visibility deteriorated slightly between 1960 and 1992 in the winter months. Summertime visibility worsened between 1960 and the early 1970s, then improved somewhat by 1980. Since then summertime visibility conditions have remained fairly stable. (Source: Husar and others 1994)

Figure 4.2 shows the historical trends in winter and summer haze for the southeastern area as reported by Husar and others (1994). During the 1960s visibility deteriorated slightly in winter and substantially in summer. In 1961 the haze pattern was fairly constant throughout the year. By 1970, a strong summertime peak had emerged that was roughly twice the magnitude of the winter haze. Summertime visibility then improved somewhat in the late 1970s and has remained fairly stable since then. Husar and others (1994) suggest that the "changes from a winter maximum in haze in the 1960s to summer maximum in the 1980s can be attributed in part to increased sulfate from increased sulfur dioxide emissions due to increased combustion of coal to produce electrical power for air conditioning or to increased photochemical smog which leads to more complete conversion of precursors (nitrogen oxides, sulfur dioxides and organics) to particulate matter during the summer. Other changes in trends and patterns are due to the complex interplay between emissions and meteorology." Causes of visibility impairment will be further discussed following the description of current visibility conditions.

Current Visibility Conditions in the Southern Appalachians

Visibility conditions in many Class I areas across the nation are currently monitored using IMPROVE protocols. Cameras and/or special samplers for particulate matter (aerosol samplers) are present near these Class I areas to characterize, describe, and define visibility over time. Many sites also directly monitor the optical characteristics of the atmosphere using nephelometers.

Shenandoah National Park and Great Smoky Mountains National Park are fully equipped IMPROVE sites which collect optical and aerosol data as well as scene data using cameras. These sites have been in operation since the early 1980s. Visibility monitoring of Forest Service Class I areas began in the late 1980s with the installation of a camera-monitoring network to "affirmatively protect visibility conditions" under the CAA Amendments. The first sites were installed in 1987 near the James River Face Wilderness in Virginia and Dolly Sods Wilderness in West Virginia. In 1989, cameras were installed for four other Forest Service Class I Wildernesses in the assessment region – Linville Gorge, Shining Rock, and Joyce Kilmer-Slickrock in North Carolina; and Cohutta in Georgia.

The collection of camera data provides a valuable first step towards characterizing visibility conditions in the Southern Appalachians. These data were summarized for each Forest Service Class I area in reports by Air Resource Specialists, Inc. (ARS 1995). Results of the camera-based monitoring (table 4.2) reflect the same seasonal patterns seen in the historical data. For a recent 6-year period (1987-1993), median winter SVR has been roughly four times greater than median summer SVR. The median SVR is similar for all sites during the months of

Table 4.2 Median camera-based standard visual range (SVR) estimates, in miles (mi) and kilometers (km), and haziness values in deciview (dv), for the summer and winter seasons (for the combined years 1987–1993). These seasons represent the worst and best visibility conditions in the Southern Appalachians. The National Forest Class I Wildernesses are arranged by summer visual range, beginning with the areas having the poorest visibility.

	Summer (July/Aug)			Winter (Dec/Jan)		
	SVR		Haze	SVR		Haze
Class I Wildernesses	mi	km	dv	mi	km	dv
James River Face, VA	15	25	27.5	66	106	13.1
Cohutta, GA	15	25	27.5	76	122	11.7
Dolly Sods, WV	17	27	NA	NA	NA	NA
Joyce Kilmer–Slickrock, NC	17	28	26.4	151	244	4.7
Linville Gorge, NC	19	30	25.7	87	140	10.3
Shining Rock, NC	19	30	25.7	138	220	5.8

NA = not available
(Source: Air Resource Specialists, Inc. 1995)

Table 4.3 Annual camera-based standard visual range (SVR) estimates in miles (mi) and kilometers (km), and haziness values in deciview (dv), for the combined years 1987–1993. Class I areas are arranged with the haziest site first and progressively clearer sites following.

	Median[1]			Best[2]			Worst[3]		
	SVR		Haze	SVR		Haze	SVR		Haze
Class I Wildernesses	mi	km	dv	mi	km	dv	mi	km	dv
Dolly Sods, WV	26	42	22.3	87	140	10.3	9	15	32.6
James River Face, VA	36	58	19.1	117	189	7.3	11	18	30.8
Cohutta, GA	40	65	17.9	125	201	6.7	14	22	28.8
Linville Gorge, NC	42	68	17.5	132	212	6.1	16	26	27.1
Shining Rock, NC	48	78	16.1	171	276	3.5	14	23	28.3
Joyce Kilmer–Slickrock, NC	55	89	14.8	206	331	1.7	<14	<22	28.8

[1]Median SVR represents the visual range estimate for the conditions defined as the median, where 50 percent of the observations were better, 50 percent were worse.

[2]Best SVR represents the visual range estimate for the best visibility conditions. Of all the observations, only 10 percent were better than this, 90 percent were worse.

[3]Worst SVR represents the visual range estimate for the worst visibility conditions. Of all the observations, 90 percent were better than this figure, only 10 percent were worse.

(Source: Air Resource Specialists, Inc. 1995)

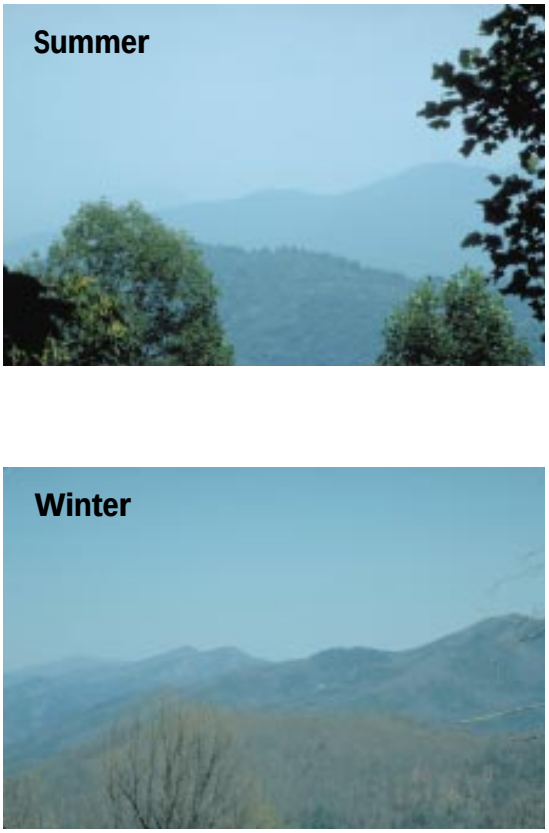


Figure 4.3 Photographs of James River Face Wilderness depicting seasonal variation in visibility conditions. The photograph on top shows annual median visibility for the summer months. The photograph on the bottom shows annual median visibility for the winter months. There is a difference of 14 deciview (81 miles standard visual range.)

July and August: 15 to 19 miles. Poor summertime visibility is a function of weather as well as air pollution. In the summer, stagnant air masses remain over much of the southeastern United States, trapping pollution and allowing concentrations to increase. High pollution concentrations, high temperatures, and high relative humidity lead to haziness and poor visibility. Pictures of James River Face Wilderness in figure 4.3 show this dramatic difference between winter and summer visibility.

All camera data collected at each of the southeastern Forest Service Class I areas were combined and analyzed to determine the annual median, worst, and best visibility (table 4.3). Median, worst, and best visibility conditions are defined as:

Median - The visibility value occuring at the midpoint of all observations.

Best - Only 10 percent of the observations were better and 90 percent were worse.

Worst - Only 10 percent of the observations were worse and 90 percent were better.

The camera data documents that current annual median SVR is between 26 and 55 miles (42 and 89 kilometers). Visibility appears to be better farther south in the assessment area. The West Virginia and Virginia Class I areas have the poorest visibility. For these two areas, the best SVR is less than 124 miles (200 kilometers), the median is between 26 and 36 miles (42 and 58 kilometers), and the worst is less

than 12 miles (20 kilometers) (fig. 4.4). Class I areas in North Carolina and Georgia have slightly better visibility. The best SVR for these sites is greater than 125 miles (201 kilometers), the median is between 40 and 55 miles (65 and 90 kilometers), and the worst is around 15 miles (23 kilometers).

Visibility in the other Class I areas – Sipsey and Dolly Sods Wildernesses, Shenandoah National Park and Great Smoky Mountains National Park – can be described using results of aerosol monitoring. Aerosol measurements and current understanding of light-extinction efficiencies of aerosol components are used to derive a reconstructed light-extinction coefficient. The sum of the extinction coefficients is then converted to SVR. SVR estimates for sites with aerosol-monitoring data are shown in table 4.4.

Because aerosol data are collected differently than scene data, the definitions of median, best, and worst visibility are slightly different. Aerosol samples are collected for a 24-hour period of time, twice a week, resulting in approximately 100 samples per year. Median visibility is described using the middle 20 observations; best visibility conditions are explained using the 20 best observations; and the worst visibility conditions by using the dirtiest 20 observations. Because of the differences in data collection, analysis, and interpretation, SVR estimates generated by camera and aerosol data should be compared with caution. With this in mind, it appears that visibility at Sipsey and Dolly Sods Wildernesses, and at Shenandoah and Great Smoky Mountains National Parks is poorer than any other Class I area in the Southern Appalachians.

Figure 4.4 Photographs of James River Face Wilderness in southwest Virginia depict the measured range of visibility.

Table 4.4 Annual standard visual range (SVR) estimates in miles (mi) and kilometers (km) for combined years of sampling. These SVR estimates are derived from light extinction coefficients, reconstructed from measured aerosol mass and composition.

		Median[1] SVR		Best[2] SVR		Worst[3] SVR	
Class I Area	Years of Data	mi	km	mi	km	mi	km
Sipsey Wilderness, AL	1992-1994	19	30	32	52	13	21
Dolly Sods Wilderness, WV	1991-1994	20	33	42	67	9	15
Shenandoah National Park, VA	1988-1994	24	37	47	75	11	18
Great Smoky Mountains National Park, NC/TN	1988-1994	24	38	46	74	12	19

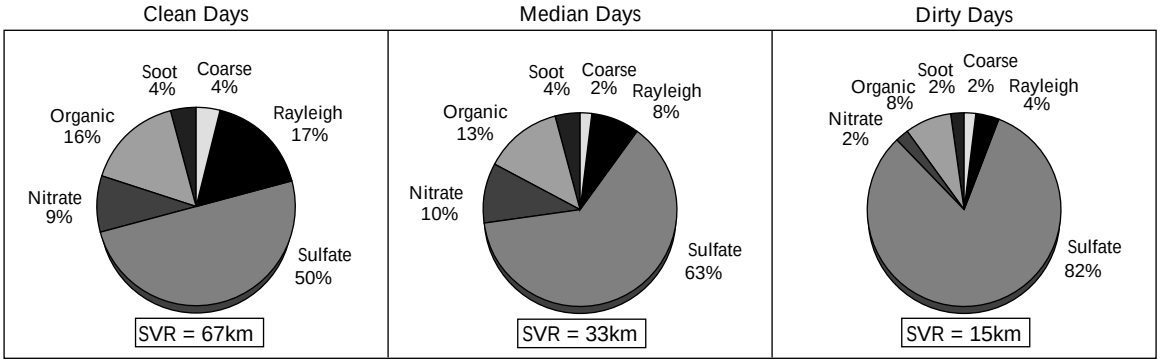
[1]Median SVR represents the visual range estimate from the median 20 observations.

[2]Best SVR represents the visual range estimate from the cleanest 20 observations.

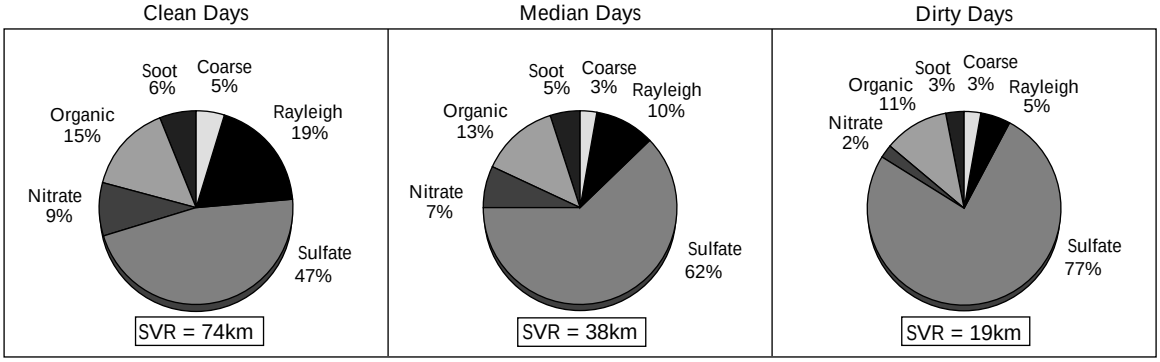
[3]Worst SVR represents the visual range estimate from the dirtiest 20 observations.

(Source: IMPROVE data)

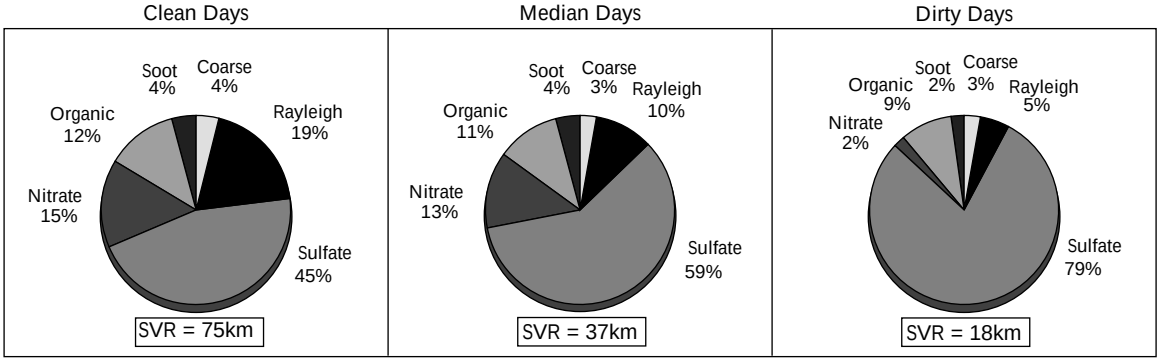
Dolly Sods Wilderness 9/91-8/94



Great Smoky Mountains National Park 3/88-2/94



Shenandoah National Park 3/88-2/94



Sipsey Wilderness 3/92-2/94

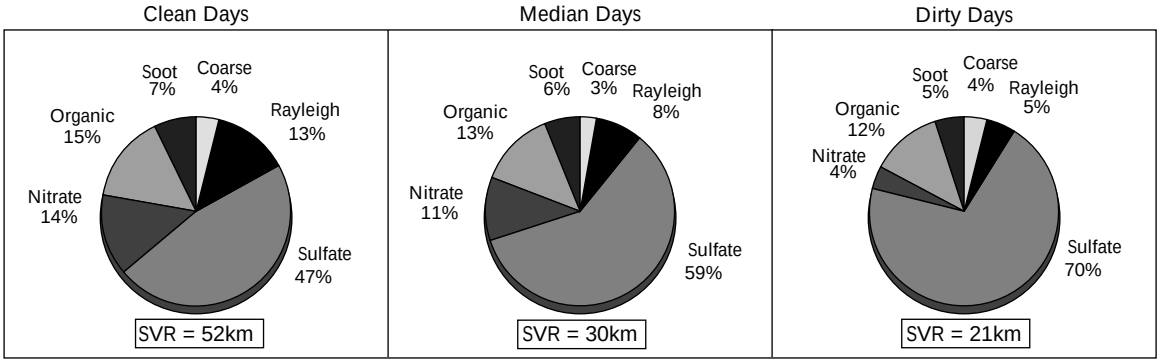


Figure 4.5 Annual visibility extinction budgets derived from aerosol measurements for Class I areas in the southeastern United States. The charts clearly show the predominant role of sulfate in visibility reduction. (Source: IMPROVE data)

Causes of Visibility Impairment in the Southern Appalachians

Aerosol samples collected twice a week for several years through IMPROVE provide information on particles in the atmosphere which can be correlated with optical camera measurements of visibility. Extinction budget plots (fig. 4.5) for four southeastern sites show the relative contribution to atmospheric extinction of each aerosol species plus natural light scattering. The extinction budget shows that aerosols account for about 90 percent of the light extinction (aerosols being comprised of sulfate, nitrate, organics, coarse dust, and soot). Sulfate accounts for approximately 60 percent of the extinction on days with median visibility, making it the primary cause of haziness. On days with the worst visibility, sulfate accounts for closer to 80 percent of the extinction. Sulfate is recognized as the primary cause of light extinction in the Southern Appalachians (National Research Council 1993, Sisler and others 1993), and as sulfate increases so does haziness. A detailed description of how each species of aerosol contributes to atmospheric extinction can be found in the IMPROVE publication, "Spatial and Temporal Patterns and the Chemical Composition of the Haze in the United States" (Sisler and others 1993).

The historic trends in visibility follow closely the changes in sulfur dioxide emissions within the region. Figure 4.6 compares summer sulfur dioxide emissions and visibility in the Southeast for the years from 1940 to 1985. Both sulfur dioxide and light extinction increase from the late 1940s through the early 1970s and then slightly decrease or level off in the late 1970s and early 1980s. The trend in sulfur dioxide emissions for the Southeast has remained stable or increased slightly between 1985 and 1994 (EPA 1995a). This pattern deviates somewhat from the national trends in sulfur dioxide emissions, which show a sharp decline in emissions during the 1970s followed by a slightly decreasing trend since the early 1980s (fig. 2.4) (EPA 1995a). The trend in sulfur dioxide emissions for the Southeast is probably due in part to dramatic population growth in the region accompanied by increased energy demands.

There is a strong correlation between sulfur dioxide emissions and haziness for a very good reason. Sulfur dioxide is a precursor of sulfates, and sulfates are known to be the main anthropogenic or human-caused factor contributing to light scattering in the Southern Appalachians. This fact has been documented in many sources including the National Acid Precipitation Assessment Program (NAPAP) (Trijonis and others 1991); National Research Council, (1993); EPA (1994, 1995c); Sisler and others (1993); and IMPROVE (1994).

Analysis of fine particulate data from Shenandoah and Great Smoky Mountains National Parks by Eldred and Cahill (1994) shows an annual increase in sulfate of 2 to 3 percent each year between 1982 and 1992. This increasing trend was even more

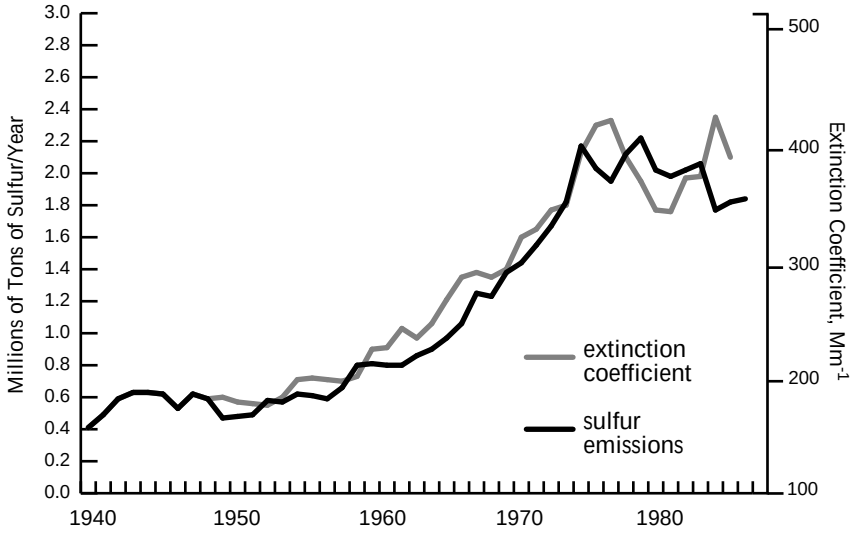


Figure 4.6 Relationship between sulfur dioxide emissions and haziness in the southeastern United States during the summer months. (Source: Trijonis and others 1991)

pronounced in the summer months when sulfate concentration increased 4 percent each year. Based on this information, the apparent lack of improvement in visibility conditions since the early 1980s is understandable. What is more elusive is why sulfate would be increasing at such a steady rate when sulfur dioxide emissions are stable or only increasing slightly. Changes in visibility patterns and trends are caused by changes in the concentration of fine particles in the lower atmosphere, primarily sulfates in the southeastern United States. It has been reported that these changes can be attributed to either 1) changes in emissions of sulfates or precursors of sulfates (such as sulfur dioxide or nitrogen oxides), 2) changes in photochemical smog (ozone) which influences the rate of formation of sulfate, or 3) changes in meteorological conditions which influence sulfate formation (Husar and others 1994).

Weather conditions such as high relative humidity and precipitation in the form of snow, rain, and fog also contribute to visibility impairment. In general, the higher the relative humidity, the greater the scattering of light by sulfate aerosols, which intensifies regional haze. The combination of high relative humidity and sulfate concentrations found in the Southern Appalachians, especially in the summer months, results in poor visibility (Sisler and others 1993). Data from Shenandoah National Park illustrate this interaction. Between 1988 and 1994, the relative humidity at Shenandoah averaged 69 percent, and the median SVR was 25 miles (40 kilometers) (23 dv). Using conversion factors developed from IMPROVE data, a reduction in mean relative humidity to 50 percent would have resulted in a median SVR of roughly 37 miles (60 kilometers) (19 dv), an improvement of 4 dv. Removing all of the sulfate from the atmosphere during that time period would have resulted in a median SVR of approximately 62 miles (100 kilometers).

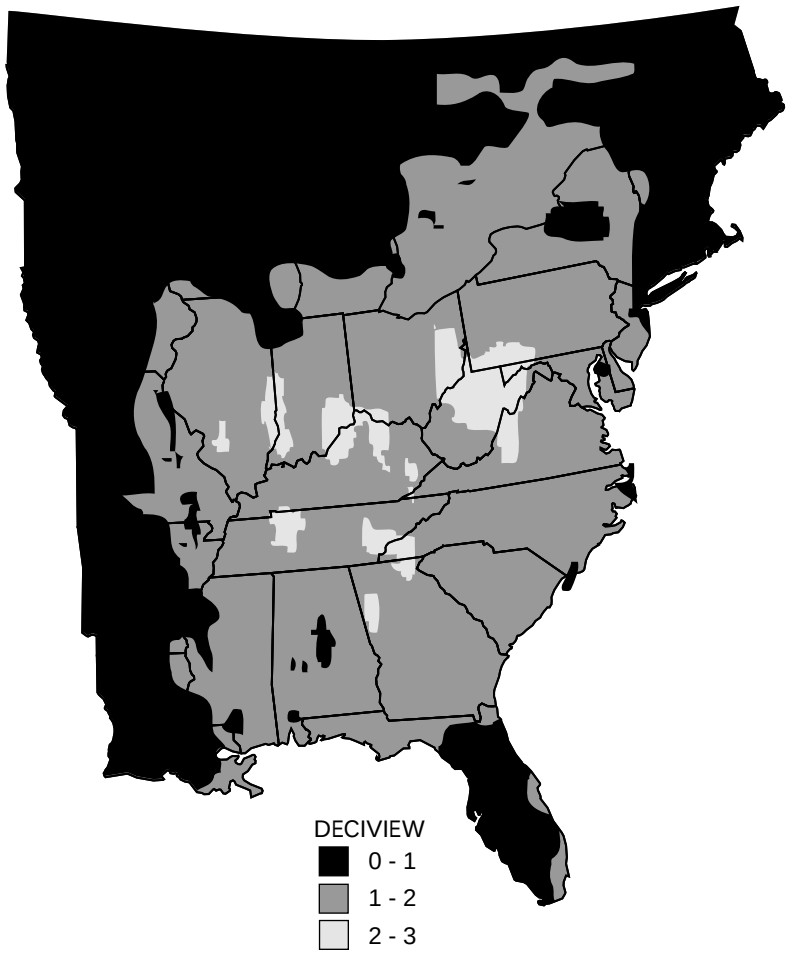


Figure 4.7 The Regional Acid Deposition Model (RADM) predicts decreases in annual median haziness (visibility improvement) due to implementation of the Clean Air Act Amendments of 1990. (Source: EPA 1993a)

Clearly, the SAA area is exposed to high levels of sulfate derived from sulfur dioxide emissions. The worst visibility conditions are the result of high sulfate concentrations and high relative humidity occurring coincidentally.

Future Trends in Southern Appalachian Visibility

The EPA conducted an assessment of the progress and improvements in visibility in Class I areas and reported the results to Congress in October 1993 in a report entitled "Effects of the 1990 Clean Air Act Amendments on Visibility in Class I Areas." The following information is taken from that report, which should be consulted for further detail on methodology.

To predict future visibility conditions in the southeastern United States, the EPA used the Regional Acid Deposition Model (RADM) and the RADM Engineering Model post-processor (EM-VIS). The estimated emission changes resulting from implementation of the 1990 CAA Amendments were used as inputs. The EPA predicts an improvement of 1 to 2 dv in annual median visibility throughout the Southern Appalachians by the year 2010, when full implementation of the 1990 CAA Amendments is expected to reduce sulfur dioxide by 50 percent (fig. 4.7). For example, annual average visibility at Sipsey Wilderness is predicted to increase from 19 to 21 miles. Certain areas will see slightly greater improvements. Haziness is expected to decrease by 2 to 3 dv in Dolly Sods Wilderness in West Virginia, Shenandoah National Park in Virginia, and Great Smoky Mountains National Park in eastern Tennessee and western North Carolina. At Shenandoah National Park a 3-dv improvement will increase visibility from 25 to 32 miles.

The EPA's assessment also predicts that the greatest improvements will be seen in summer when sulfates dominate light extinction. Figure 4.8 shows a predicted 2- to 3-dv improvement

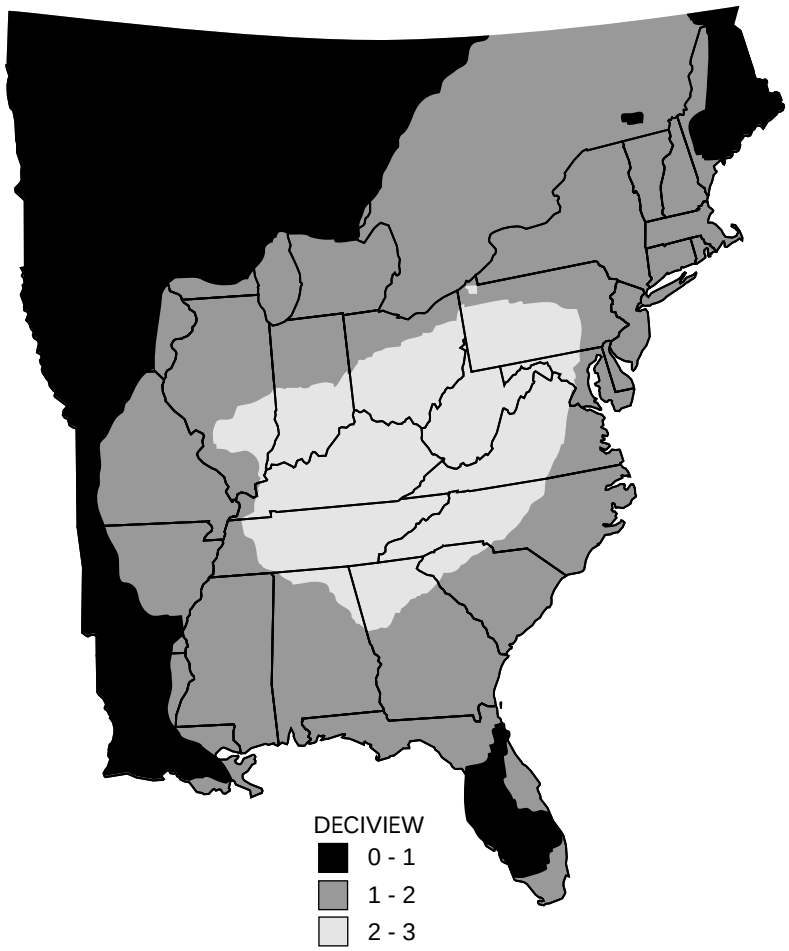


Figure 4.8 The Regional Acid Deposition Model (RADM) predicts visibility improvements, due to implementation of the Clean Air Act Amendments of 1990 to be greatest during the summer months. (Source: EPA 1993a)

in visibility in the summer across the whole SAA region. Photographs of James River Face Wilderness in figure 4.9 show what a 3-dv (roughly 4 miles) improvement in annual average summer visibility would look like. Predicted winter improvements will be less significant; only 1 dv.

These improvements directly relate to provisions of the CAA Amendments that address control of sulfur dioxide emissions in the eastern United States. Figure 4.10 illustrates projected reduction of sulfur dioxide emissions between 1985 and 2010 in this region (EPA 1993a). The largest decreases will come from the utility industry, which accounts for the greatest portion of sulfur dioxide emissions in the East.

It is significant to note, however, while a 1993 EPA report predicts improvements in regional visibility for the Southern Appalachians, the final statement in the executive summary issues the caution, "Although visibility will improve in many eastern Class I areas..., there will still be perceptible man-made regional visibility impairment in all Class I areas nationwide" (EPA 1993a). Efforts are underway which may further reduce sulfur emissions affecting the SAA region. The Southern Appalachian Mountain Initiative (SAMI) is considering additional ways to reduce the impacts of air pollution on Class I areas of the SAA region. Reports by NAPAP and EPA on visibility (Trijonis and others 1991, EPA 1993a) indicate that visibility can be improved with reductions in sulfur emissions, predictions which inspire SAMI to develop strategies to achieve improvements.

Figure 4.9 The photographs depict what a 3-deciview decrease in haziness (visibility improvement) would look like compared with the current median summer condition and natural background visibility. The view is James River Face Wilderness in Virginia.

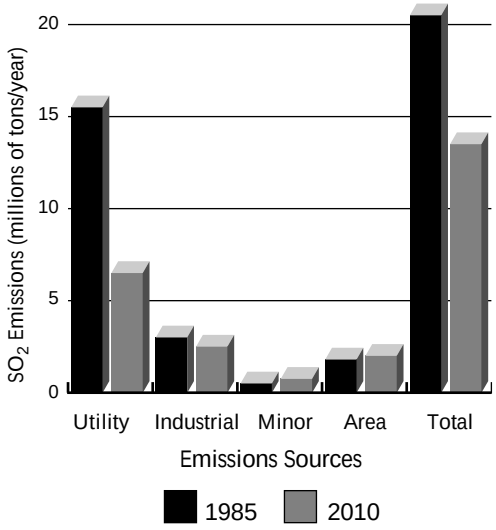


Figure 4.10 Projected sulfur dioxide emissions in the eastern United States after the Clean Air Act Amendments of 1990 are implemented. (Source: EPA 1993a)

Key Findings

1. **Visibility in the Southern Appalachians has deteriorated considerably since the 1950s.**

2. **The poorest visibility conditions occur in the summer months.**

3. **Sulfates which result from sulfur dioxide transformation in the atmosphere are the largest single human-caused contributor to haziness in the Southern Appalachians.**

4. **Sulfate concentrations increased 2 to 3 percent each year between 1982 and 1992.**

5. **Visibility can be improved by reducing sulfur dioxide emissions from human-caused sources.**

6. **The Clean Air Act Amendments of 1990, once implemented, should lead to improvements in summertime visibility in the Southern Appalachians. Estimated improvements may be up to 3 deciview (about 4 miles SVR).**

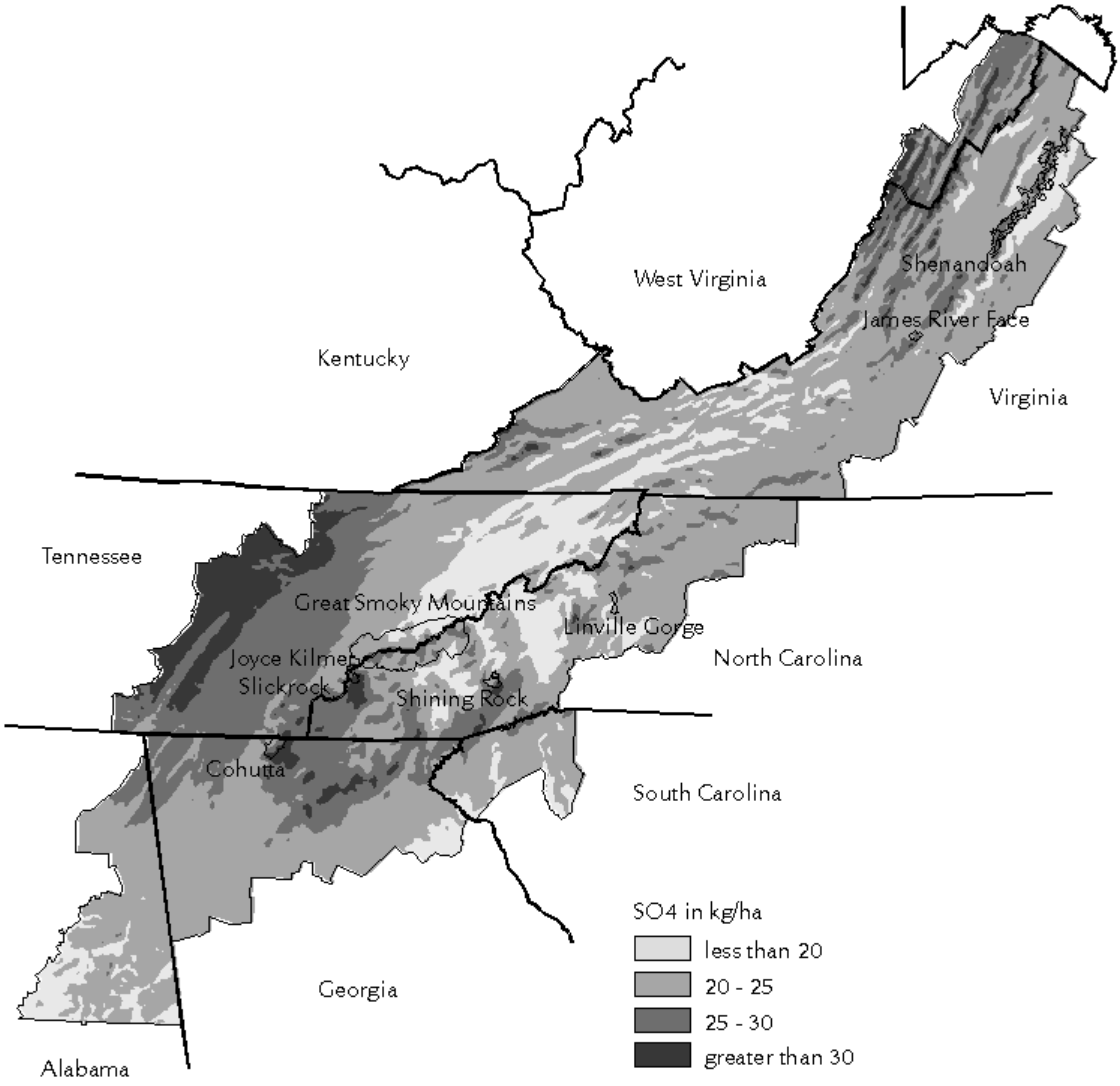


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Figure 5.1 Modeled distribution of mean wet sulfate loadings (in kilograms/hectare/year) during the period 1983-1990. Outlined are the political boundaries and the Class I area parks and wildernesses.

Acid Deposition

Question 4:

To what extent are aquatic resources in the Southern Appalachian Assessment area being affected by acid deposition?

Media reports loudly proclaim that "acid rain is killing lakes and streams." Is that statement accurate and what does that really mean in terms of headwater streams and their biological communities found within the Southern Appalachian Assessment (SAA) area? During the 1980s researchers worked to define the amount of acid deposition, also known as acid rain or acid precipitation, that was falling in the Southeast.

As part of the National Acid Precipitation Assessment Program (NAPAP), researchers designed and carried out the National Stream Survey (NSS) to estimate the extent of stream resources affected by acid deposition. This SAA chapter makes use of databases and model results generated under the NAPAP program (1980-1990), along with site-specific investigations of watershed and aquatic processes at locations such as Shenandoah National Park, Great Smoky Mountains National Park, and Coweeta Hydrologic Laboratory watershed to describe the acid-deposition threats to aquatic resources. This assessment also reviews the findings made by the U.S. Environmental Protection Agency (EPA) as part of their NSS and the Direct-Delayed Response Program (DDRP) (Church and others 1989) to come up with an estimate of the stream reaches sensitive to acid deposition.

Assessment Methods

This chapter summarizes what is reported in existing peer-reviewed literature and agency reports about deposition chemistry and aquatic effects in the SAA area. To describe the status of deposition in the SAA, this study relies on the National Atmospheric Deposition Program data (NADP 1994), along with information from the Integrated Forest Study (IFS) (Johnson and Lindberg 1992). Information on trends in acid deposition is taken from a recent paper by Lynch and others (1995).

Furthermore, this chapter uses NADP chemical data (1983-1990) from locations in the eastern United States, along with U.S. Geological Survey Digital Elevation data sets and National Oceanic and Atmospheric Administration rainfall measurements to model deposition chemistry spatially throughout the eastern United States, with a focus on the SAA region. In this analysis, weighted least-squares regression techniques were used to take into account the influence of regional topography (such as mountain ranges) on deposition. The products generated include maps showing contours of mean loadings in kilograms/hectare (kg/ha) of sulfate (fig. 5.1) and of nitrate (fig. 5.2) averaged for the years 1983-1990. Kilograms/hectare is equivalent to pounds/acre. The maps of the modeled distribution of wet deposition chemistry are products produced specifically for the SAA effort and have not yet been published in the peer-reviewed literature.

The status of stream chemistry and biology is summarized from the NAPAP State-of-Science documents (L. Baker and others 1991; J. Baker and others 1991; Thornton and others 1991; Turner and others 1991; Wigington and others 1991) and from other syntheses of the NSS data and special watershed and biological effects studies summarized in Kaufmann and others (1991), Charles (1991), Herlihy and others (1991, 1993), as well as other literature cited in the reference list. This SAA chapter does not attempt to further synthesize information generated since the NAPAP reports, but rather relies on a number of "case studies" of stream resources that have been intensively studied to determine the effects of acid deposition on aquatic resources. These case studies illustrate the types of responses to loadings of acids, sulfate, and nitrate that can be expected in sensitive stream reaches in the SAA area.

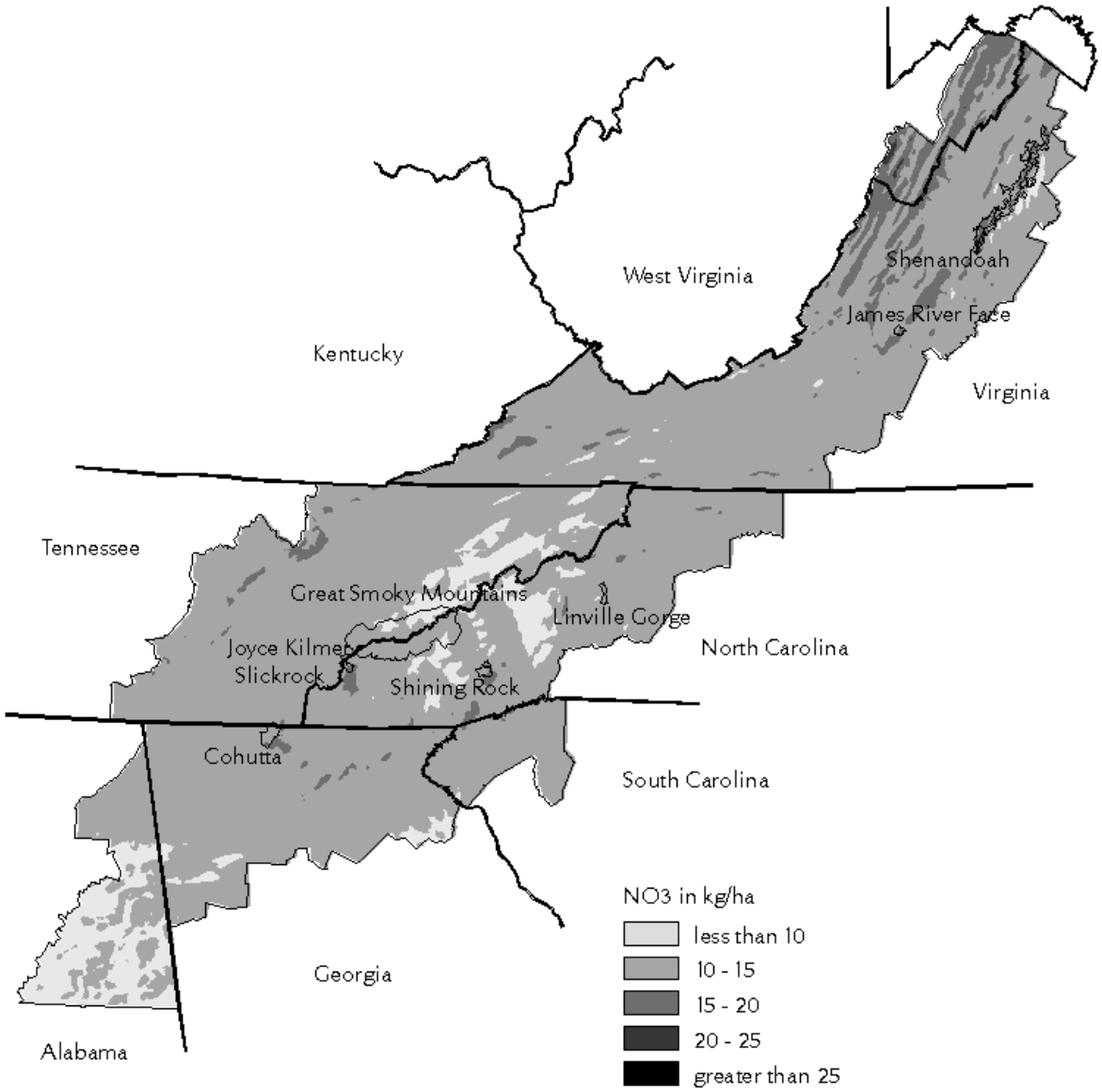

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Figure 5.2 Modeled distribution of mean wet nitrate loadings (in kilograms/hectare/year) during the period 1983-1990. Outlined are the political boundaries and the Class I area parks and wilderness areas.

Status of Deposition in the SAA Region

Background

A thorough discussion of regional wet and dry deposition and the effects on watersheds and surface waters sensitive to acid deposition is found in *Acidic Deposition and Aquatic Ecosystems* (Charles 1991), with chapters on areas containing sensitive streams in the mountains of western Virginia (Cosby and others 1991) and the southern Blue Ridge province (Elwood and others 1991).

Wet deposition includes rain, snow, sleet, and hail, along with "occult" deposition such as fog and cloudwater. Another component of total deposition is dry deposition, which is the amount of acidic particulate matter and gases that are deposited to surfaces. Chemical substances of interest in determining the "dose" to

aquatic ecosystems are: hydrogen ion (pH), sulfate, nitrate, and ammonium. Wet deposition estimates reflect both the concentrations of chemicals in precipitation and the total amount of wet deposition that falls during the year. Wet, dry, and occult deposition can be combined to estimate total loading of pollutants to ecosystems. Since dry and occult deposition are usually not measured at monitoring sites, most of this discussion centers on estimates of wet deposition. The values for total pollutant loading to sensitive, high-elevation watersheds would be considerably greater than is now estimated by the NADP if dry deposition and cloudwater deposition were included (Johnson and Lindberg 1992).

Wet deposition is measured in the United States by a national network of about 200 sites coordinated by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Samples of wet deposition are collected weekly and sent to the Central Analytical Laboratory in Illinois for chemical analysis. Other wet deposition networks operating in the United States to verify the effects of emission reductions on sulfate and nitrate deposition chemistry are Clean Air Status and Trends Network (CASTNET) and Atmospheric Integrated Research Monitoring Network (AIRMoN) (NAPAP 1995). Currently, wet deposition network sites operating in the SAA region include the following NADP sites:

Site Name	Elevation
Shenandoah National Park, VA	3,544 feet (1,074 meters)
Horton's Station, VA	3,178 feet (963 meters)
Coweeta Hydrologic Laboratory, NC	2,264 feet (686 meters)
Mt. Mitchell, NC	6,557 feet (1,987 meters)
Great Smoky Mountains National Park, TN	2,112 feet (640 meters)
Walker Branch, TN	1,125 feet (341 meters)

Current Deposition Chemistry

The most recently published NADP data (1993) for the United States, with the contours for sulfate and nitrate loading and for pH are found in figures 5.3-5.5. These maps compare wet deposition chemistry in the SAA region with that found in the rest of the United States for this most recent measurement year. An examination of the individual station data contained in the annual report (NADP 1994) shows sulfate loading ranging from 17 to 26 kg/ha for 1993, compared with the highest measured 1993 loading of 34 kg/ha at a station in Ohio (fig. 5.3; NADP 1994). A similar pattern is seen for nitrate loading measured in 1993 (fig. 5.4; NADP 1994). The range of values for the NADP sites within the SAA is 9 to 16 kg/ha, with the highest values in the United States located in Ohio (28 kg/ha). The northeastern and north central regions of the United States have the highest regional deposition of sulfate and nitrate.

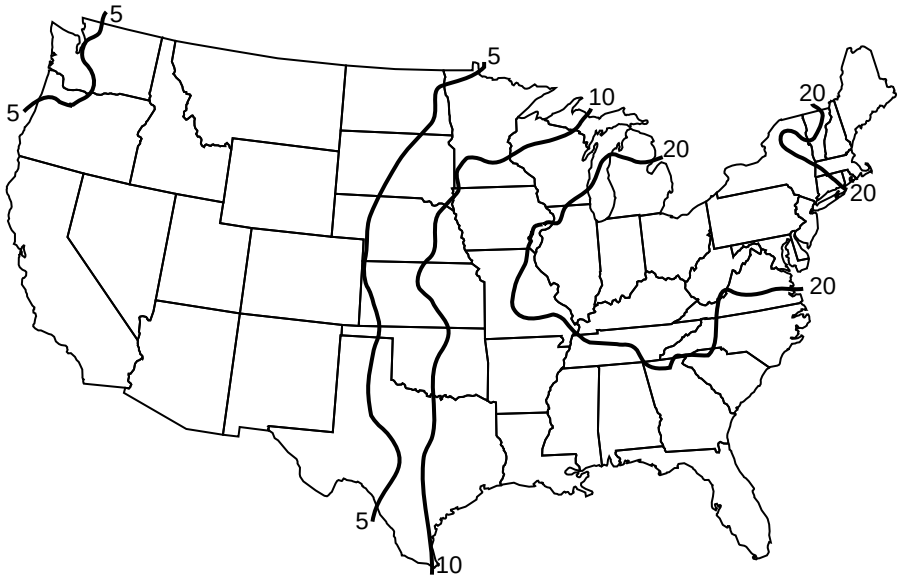


Figure 5.3 National Atmospheric Deposition Program (NADP) map of contours of sulfate loading (kg/ha) for 1993. (Source: NADP 1994)

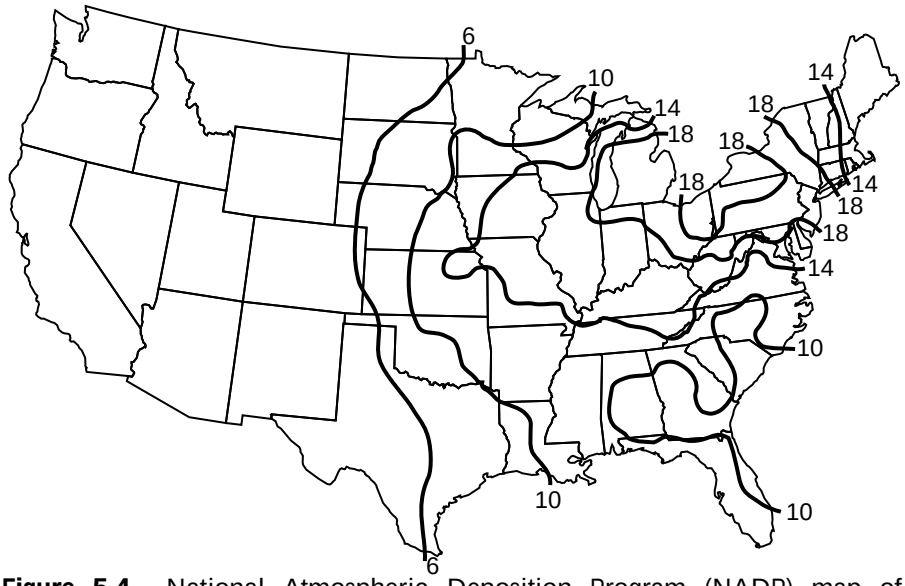


Figure 5.4 National Atmospheric Deposition Program (NADP) map of contours of nitrate loading (kg/ha) for 1993. (Source: NADP 1994)

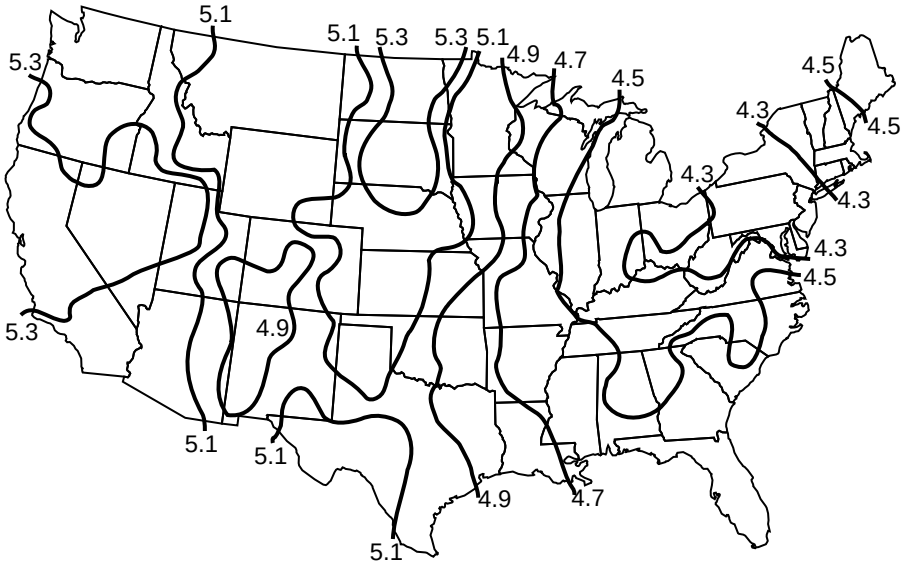


Figure 5.5 National Atmospheric Deposition Program (NADP) map of contours of pH for 1993. (Source: NADP 1994)

In the Southeast, deposition of sulfate and nitrate peaks in the region of the Southern Appalachians, coincident with one of the subpopulations of sensitive streams. The NADP station at Great Smoky Mountains National Park recorded the highest sulfate and nitrate loadings in the region during 1993. Deposition data from even higher-elevation sites in the park show that deposition is greater in the spruce-fir zone because of greater inputs of pollutants through rain, snow, cloudwater, and dry inputs (Johnson and Lindberg 1992).

The volume-weighted pH of wet deposition in the SAA region ranged from 4.3 to 4.5 compared with the 1993 minimum value of 4.2, recorded at a number of stations in the northeastern United States (fig. 5.5; NADP 1994). The assessment region received some of the most acidic rainfall recorded in the United States.

Figures 5.1 and 5.2 indicate a longer-term estimate of wet deposition loading of sulfate and nitrate. The maps show spatial distribution of annual average loadings in kg/ha/yr for data collected during 1983-1990. These loading estimates represent precipitation and topography-weighted interpolation of wet deposition between the NADP monitoring sites. In general, the SAA region has a background sulfate loading of 20-25 kg/ha/yr. Higher sulfate loadings (25-30 kg/ha/yr) are mapped on the following Class I areas: Shenandoah National Park, Great Smoky Mountains National Park, James River Face Wilderness, Joyce Kilmer-Slickrock Wilderness, Shining Rock Wilderness, and Cohutta Wilderness (fig. 5.1). The map of sulfate deposition shows a maximum loading in the range of 35-40 kg/ha/yr in a few isolated pockets in northeast West Virginia and near the southern edge of Joyce Kilmer-Slickrock Wilderness in North Carolina. The values shown on this sulfate contour map are considerably higher than those estimated from the 1993 NADP data (17-26 kg/ha/yr). This lack of agreement between the measured (1993) and modeled (1983-1990) loadings is due to two factors: (1) there is a longer data record for the modeled estimates, with higher values measured during the 1980s, and (2) higher modeled sulfate values occur when actual precipitation amounts at higher elevations are combined with chemical concentration values obtained from lower elevation NADP stations.

The modeling results for wet deposition nitrate loadings (fig. 5.2) are generally in the 5-10 kg/ha/yr range throughout the SAA area. There are some pockets of higher loading (10-15 kg/ha/yr) in northern Virginia and northeastern West Virginia and scattered through the midsection of the SAA region. These higher nitrate loadings overlap with five of the seven Class I areas (Shenandoah National Park and James River Face Wilderness in Virginia; Shining Rock and Joyce Kilmer-Slickrock Wilderness in North Carolina; and Cohutta Wilderness in Georgia). This outcome is not surprising given that the wildernesses are generally found in upland terrain characterized by greater precipitation amounts than the surrounding areas. Figure 5.2 does not show high loadings of nitrate in Great Smoky Mountains National Park, a site that receives orographically-enhanced deposition of both nitrate and sulfate (Nodvin and others, 1995). This discrepancy may be because data used to compile figure 5.2 were not collected at high-elevation monitoring sites.

Deposition to high elevation watersheds is still underestimated by the interpolation technique used to produce figures 5.1 and 5.2 because these estimates do not include dry and cloudwater deposition. These hard-to-measure forms of deposition can contribute significantly to the total load of chemicals that falls on sensitive watersheds. Figure 5.6 compares sulfate inputs in dry, wet, and cloudwater deposition at

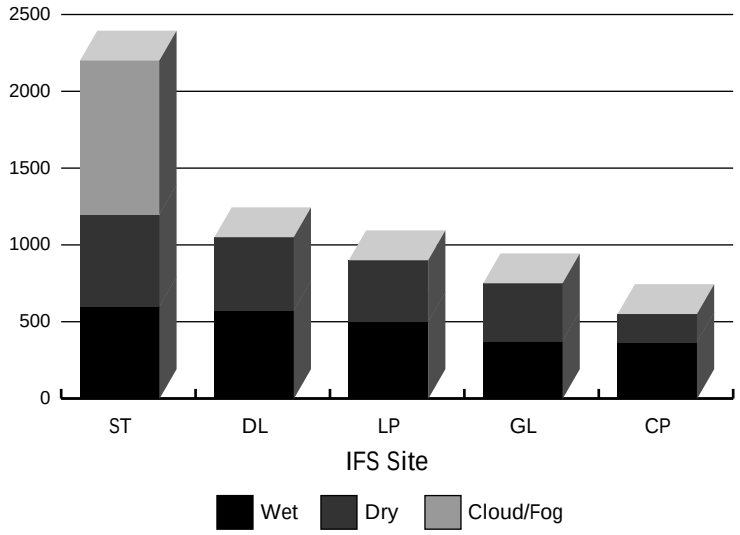


Figure 5.6 Total loading of sulfate (eq $ha^{-1}y^{-1}$) to Integrated Forest Study (IFS) sites (during 1986-1989), at Great Smoky Mountains National Park (ST), Duke Forest (DL), Oak Ridge (LP), B. F. Grant Forest, Georgia (GL) and Coweeta Hydrologic Laboratory (CP). (Source: Johnson and Lindberg 1992)

an IFS site in Great Smoky Mountains National Park (Johnson and Lindberg 1992). This site was located in the high-elevation, spruce-fir forest in Great Smoky Mountains National Park at an elevation of 5,742 feet (1740 meters). This site was equipped with a tower so that rain, dry deposition, and cloudwater could be collected above the forest canopy. The sulfur deposition estimates showed wetfall and dryfall to be approximately equal contributors to chemical load, with cloudwater contributing most of the sulfate in an average year during the study period (1986-1989). Converting the values from equivalents per hectare (used in fig. 5.6) to units of kg/ha, this yearly IFS estimate of 48 kg sulfate in all forms of deposition is considerably greater than the 1993 NADP wet deposition estimate (fig. 5.3) of 26 kg at Great Smoky Mountains National Park.

Trends in Wet Deposition Chemistry

An analysis of wet chemistry data (1980-1992) for selected NADP sites throughout the United States was performed by Lynch and others (1995) to look for statistically significant trends in average concentrations of major chemicals in rain and snow. Four sites in the SAA region were included in this analysis: Horton's Station, Virginia; Coweeta Hydrologic Laboratory, North Carolina; Great Smoky Mountains National Park, Tennessee; and Walker Branch, Tennessee. During this 13-year period, sulfate and base cations such as calcium, magnesium, and sodium significantly decreased (probability less than 0.05) at all four sites, with Coweeta showing a significant decrease in both nitrate and hydrogen-ion (pH) concentrations. What is interesting to note is that while the sulfate concentration in wetfall appears to be decreasing over time in the southeastern United States, the pH of the rain has stayed constant. This trend may be explained by the decrease in base cations concentrations in the rain at the four locations cited above. This decrease in base cations in rainfall, also seen in other parts of the United States and in Europe (Hedin and others 1994), indicates that there is less buffering material in the atmosphere. There is no single explanation why this change in rain chemistry through time is so widespread. Two possible explanations for this decrease in base cations in rain include changes in agricultural tillage practices and the addition of particulate control devices on power plant and industrial stacks.

Summary of Acid Deposition

Acid deposition is being deposited in the SAA region. The annual average pH of wet precipitation in 1993 for this region was second only to areas of the northeastern and north central United States. The loading of sulfate and nitrate in wet deposition over the period of 1983-1990 is highest in upland areas, including many Class I areas of the SAA. Precipitation pH over a 13-year period has been static, reflecting a general decline in both the sulfate and the base cation loadings in the few NADP sites used in this trend analysis. Although it is difficult to quantify the contribution of dry deposition and cloudwater deposition to total loading in the mountainous areas of the SAA, it is reasonable to expect that the NADP loading estimates could be doubled in these sensitive areas.

Chemistry and Biology of Streams in the SAA Region

Much has been written about the sensitivity to acidification of streams in the SAA region,

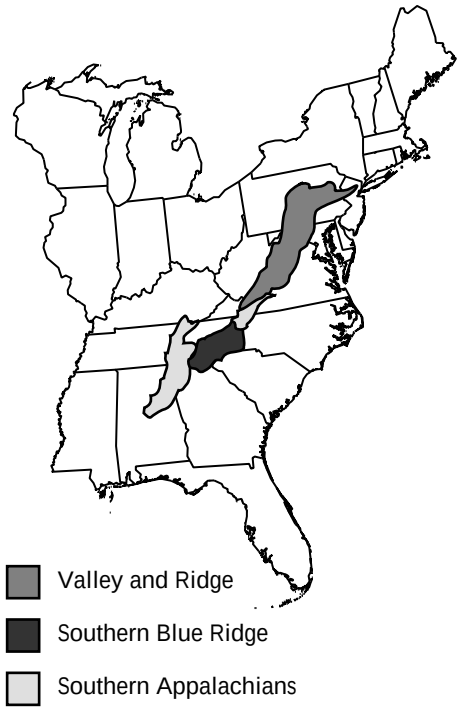


Figure 5.7 Subregions of the National Stream Survey - Phase I. (Source: Kaufmann and others 1988)

especially those in the Valley and Ridge Province, the Southern Appalachians, and the Southern Blue Ridge (fig. 5.7). There are two types of acidification of streams in the SAA region: chronic and episodic. Long-term information on chronic acidification is available for streams in Shenandoah National Park (Cosby and others 1991), Great Smoky Mountains National Park (Elwood and others 1991), and St. Mary's River watershed on the George Washington and Jefferson National Forests (Webb and others 1989; Mohn and others 1988). More data are now being generated on the frequency, severity, and extent of episodic acidification in southeastern streams. These studies require intensive, site-specific investigation. A good overview of the status of streams in the SAA region and the processes that cause chronic and episodic acidification in headwater streams is provided in the Aquatics Technical Report of the SAA (SAMAB 1996a). A more detailed analysis of data collected and analyzed since the NADP assessment for sensitive Class I areas of the SAA can be found in the report "Effects of Acidic Deposition on Aquatic Resources in the Southern Appalachians with a Special Focus on Class I Wilderness Areas" (Herlihy and others, in review).

A simple measure of the "sensitivity" of stream water to chemical change is acid-neutralizing capacity (ANC), or the ability of the stream water to buffer incoming acids. When acid deposition falls on stream watersheds located on bedrock that is resistant to weathering, the result can be a decrease in the ANC in the stream water, along with a decrease in pH. Depending on the chemistry of the deposition as well as the chemistry of watershed soils, there may also be increases in sulfate, nitrate, and aluminum (leached by acids from soils and sediments). All of these chemical changes can adversely affect aquatic biological populations. The organisms most likely to respond to changes in the chemistry of stream water include native fish species, such as trout, dace, and minnows; and aquatic insects. In stream reaches that have become "acidic," the ANC is less than or equal to zero.

Chronic Acidification

During the early years of the NAPAP program, researchers working in the southeastern United States were primarily interested in the process of chronic acidification of streams caused by added sulfate from wet and dry deposition. This surface water acidification process is summarized in Turner and others (1991):

"The magnitude of change in water chemistry parameters in response to acidic deposition and changes in watershed drainage chemistry may range from an equivalent increase in base cation concentrations to a reduction of 50 or more ueq/1 ANC, to a shift from a low ANC or acidic, organic-dominated system, or to a sulfate-dominated system with little change in ANC or pH. The first response is probably most common. In the latter two cases, the net effect of atmospheric deposition of S on lake and stream chemistry is a shift toward systems that are dominated by mineral acidity and that have high concentrations of inorganic aluminum which is toxic to aquatic organisms."

An example of chronic acidification of a low-ANC stream is Deep Run in Shenandoah National Park, where the sulfate concentrations in the stream increased about 2 micro-equivalents per liter per year (ueq/l/yr) for the 1980-1987 period, while the pH declined from 5.6 to 5.3 and the stream lost about 0.75 ueq/l/yr of ANC (Cosby and others 1991).

Deposition of sulfate and acids to sensitive watersheds results in (1) soil acidification, (2) leaching of base cations from soils, and (3) surface water acidification. In some watershed soils, sulfate in rain is absorbed by the soils until the soils are saturated. Then the sulfate begins to leach out into the stream waters, resulting in "delayed" acidification of streams (Church and others 1989, 1992). Even if sulfate in deposition is significantly reduced, stream recovery from acidification may not be immediate.

Episodic Acidification and Nitrogen Saturation

In the mid-1980s, researchers in the eastern United States began to investigate the temporary acidification of streams due to large rain events, known as episodic acidification (Wigington and others 1991). The National Park Service sponsored episodic acidification studies in Shenandoah National Park and Great Smoky Mountains National Park. These studies focused on short-term changes in ANC, pH, and aluminum in stream water and attempted

to relate the chemical changes to fish responses. These studies also began to focus attention on a phenomenon known as "nitrogen saturation."

In this situation, large rain storms are accompanied by large increases in nitrate in stream water. This process seems to be the result of both atmospheric deposition of nitrate and loss of nitrate from the watershed vegetation and soils due to forest maturation and insect infestations, such as gypsy moth and balsam woolly adelgid (Webb and others, 1995; Nodvin and others, 1995).

Evidence for episodic acidification by "nitrogen saturation" (or excess supply of nitrogen that cannot be used by biota) comes from work in the Northeast (Aber and others 1991) and in the Southeast (Jones and others 1983). One of the early instances of fish kills resulting from episodic acidification comes from the study of the Raven Fork Creek drainage located in the Great Smoky Mountains National Park and on the Cherokee Indian Reservation, where base flow pHs of about 6.0 dropped to pHs in the range of 4.3 to 4.7 during stormflow, accompanied by increases of both nitrate and sulfate. In streams monitored in the northeastern United States and in the mid-Appalachian Highlands, nitrate is now observed at high concentrations during hydrologic episodes and during baseflow periods, indicating that the supply of nitrogen has exceeded the capacity of the soils and vegetation to absorb it (Stoddard 1994). There are a number of explanations for this nitrogen "leakage," including the maturation of forests, effects of insect infestation, and excess nitrogen supply in deposition. One particular, severe case of nitrogen saturation is being studied in the Noland Divide watershed in Great Smoky Mountains National Park (Nodvin and others, 1995). At this high elevation, spruce-fir-forested watershed located at 5,531-6,336 feet (1676-1920 meters), both sulfur and nitrogen depositions are high, and the streams draining the watershed have nitrate concentrations greater than sulfate. The nitrogen saturation in this watershed contributes to both chronic and episodic acidification of streams.

Estimates of Stream Sensitivity to Acidification in the SAA

The NSS, carried out in spring 1986, was a project designed to estimate the portion of streams which had acidified or were highly sensitive to acidification in the southeastern and mid-Atlantic regions of the United States. Based on this survey, EPA researchers concluded that the following percentage of combined lengths of streams were acidic: 0.8 percent in the Valley and Ridge Province, 0.5 percent in the Southern Appalachians, and none in the Southern Blue Ridge (fig. 5.7). These acidic streams were generally located in forested watersheds less than 30 square kilometers (11.6 square miles), in the upland areas of the SAA region (Herlihy and others 1991). Percentages of stream reaches with a spring baseflow ANC of less than 50 ueq/l (a common definition of a highly sensitive stream) were: 6.5 percent in the Valley and Ridge Province, 3.5 percent in the Southern Appalachians, and 7.8 percent in the Southern Blue Ridge. Regional variation in streamwater ANC was associated with concentrations of base cations, indicating that local geology is the primary factor controlling the sensitivity of streams to acid inputs. Stream reaches most likely to be acidic or to have low ANC values are located in forested upland areas (Kaufmann and others 1988). Within the mid-Atlantic region (including the mountains of western Virginia), 70 percent of the acidic streams had aluminum in excess of 100 micrograms per liter (ug/l), a concentration often associated with biological effects (Kaufmann and others 1991).

It is important to note that these estimates of acidic and low-ANC streams included in the NSS analysis are for broad regions that include insensitive areas like the valleys of the Valley and Ridge Provinces. The percentages of affected streams are higher when only the subpopulation of streams found in the highest elevations of the SAA are examined.

Regional stream surveys in Virginia have included 344 native brook trout streams in the mountains of western Virginia, most of which are located on public lands. This Virginia Trout Stream Sensitivity Survey (VTSSS) was initiated to better describe the water chemistry and watershed geology in an area identified by the NSS as being particularly susceptible to acidification. The survey showed that 49 percent of these streams had a ANC less than 50 ueq/l. Ten percent of the surveyed streams were acidic. Sulfate was the major anion in those streams, with all watersheds showing sulfate retention in soils (Webb and others 1989).

Stoddard (1994) used the NSS data set to estimate the potential for chronic acidification due to nitrate deposition. He concluded that streams in the Valley and Ridge Province and the Southern Appalachians (fig. 5.7) show some potential for chronic acidification due to nitrate. However, in all of the NSS regions, chronic acidification is more closely tied to sulfate than to nitrate. It is important to note one outstanding exception among stream chemistries in the SAA area. In Great Smoky Mountains National Park, many of the streams have higher concentrations of baseflow nitrate than sulfate; in fact, streams in Great Smoky Mountains National Park have the highest recorded nitrate concentrations of any streams draining undisturbed watersheds in the United States. Silsbee and Larson (1982) report nitrate concentrations in Great Smoky Mountains National Park streams ranging from 0.2 to 90 ueq/l, often higher concentrations than are found in deposition. This finding suggests that watersheds in this part of the SAA area are net sources of nitrogen to streams. Old growth forests, such as those in Great Smoky Mountains National Park, may no longer be acting as nitrate sinks, and nitrate may be leaching out of these old growth watersheds.

Biological Effects

Sensitive fish species in streams of the SAA region include rainbow and native brook trout, along with non-sport fish, such as dace, sculpin, and minnows. Studies of aquatic insect species diversity indicate a loss of sensitive species (such as mayfly larva) from streams that have experienced either chronic or episodic acidification. A thorough discussion of sensitive aquatic species and their responses to acidification are included in the NAPAP Report No. 13 (J. Baker and others 1991). A quantitative assessment of the loss of fisheries in the southeastern United States is not possible because of the lack of databases on both the extent of sensitive fish populations and on the number of stream reaches that have been acidified. However, intensive site studies indicate that both aquatic insects and fish species common to streams of the SAA region are sensitive to changes in pH, calcium, and aluminum concentrations in stream waters. Some examples of these biological effects studies are summarized below.

In Shenandoah National Park, researchers have studied three stream systems intensively (Paine Run, Staunton River, and Piney River) gathering information on acidic episodes and fish response to those changes in acidity. Both chronic and episodic exposures to acidity in these streams have resulted in lethal and sublethal effects on fish, particularly brook trout and blacknose dace (Bulger and others 1994).

In St. Mary's River, located on the George Washington and Jefferson National Forests in Virginia, there is a report of declines in fish populations and changes in benthic fauna with an historical change in pH from 6.8 to 5.2. Comparison of a 1988 biological survey with results obtained in the 1930s indicated declines in most kinds of benthic invertebrate and acid-sensitive fish that Mohn and others (1988) suggested were the result of acidification.

At Fridley Run, also found on the George Washington and Jefferson National Forests, liming has been successfully used to increase stream pH from 4.7 to 6.4 and to reduce aluminum concentrations to the point that brook trout can now reproduce in the treated stream reach (Hudy and others 1995). Such site remediation has been practiced in other parts of the United States and Europe where acid deposition and other stresses (e.g. acid mine drainage) have affected water chemistry and fish survival. These treatments are expensive and difficult to maintain. In general, we expect changes in aquatic community structure at chronic pH levels of between 6.0 and 6.5 (J. Baker and others 1991). Because some of the streams in the SAA do have such low pHs and high aluminum concentrations, effects on aquatic biota are expected. However, direct quantification of biological effects is not possible given the scarcity of regional and site-specific data sets.

Future Estimates of Aquatic Impacts in the SAA Area

Under the CAA Amendments of 1990, the EPA was required to prepare an assessment of the information available to set a deposition standard to protect sensitive ecosystems from damage due to deposition of acidity, sulfur, and nitrogen compounds. The conclusion of the report *Acid Deposition Standard Feasibility Study, Report to Congress* (EPA 1995b) is that the regions of the United States most at risk from continued acid deposition are located in

the eastern part of the country, with the target systems being lakes and streams of the Appalachian Mountain chain, stretching from the Adirondacks in New York to the southern Blue Ridge in Georgia. In this report, the EPA presents modeling analyses for three case studies in the Northeast, the mid-Appalachian region, and the southern Blue Ridge province.

Models developed during the DDRP and the Nitrogen Bounding Study were used in predicting future acidification of streams in the mid-Appalachian and the Southern Blue Ridge regions. In the mid-Appalachians implementation of the CAA Amendments should "maintain [the year] 1985 proportions of chronically acidic target streams in the year 2040 if the time to nitrogen saturation is 250 years or longer; more rapid nitrogen saturation (in the range of 100 years) may require reductions in anthropogenic sulfur and nitrogen deposition by 25 percent below levels achieved by the CAAA" (EPA 1995b). In the Southern Blue Ridge region "with implementation of the CAA, no chronically acidic streams are expected within the target population [of streams] in the year 2040" (EPA 1995b).

Models were also used to estimate the impact of sulfur dioxide and nitrogen oxide emission reductions on the number of episodes of stream acidification. The current estimate in the mid-Appalachian region is that about 30 percent of target stream reaches are likely to become acidic during the worst rainfall episodes; this estimate is about seven times the number of stream reaches that are now chronically acidic.

A study of the input-output budgets for sulfate in a Southern Appalachian forested watershed continues at Coweeta Hydrologic Laboratory in southwestern North Carolina (Swank and Waide 1988). At this location, under moderate loadings of sulfate, stream water pH has stayed fairly constant while the sulfate in stream water has increased about 0.7 ueq/l/yr. This site was used to test a sulfur-cycling model developed during the IFS (Johnson and others 1993). The Nutrient Cycling model was run with data from the Coweeta watersheds to determine watershed and stream response to different sulfate loadings. These simulations suggest that increased sulfate deposition would cause substantial increases in sulfate and base cation leaching from the soils over the 30-year simulation period. The long-term data on stream sulfate concentrations at Coweeta confirm the Nutrient Cycling model's predictions of increasing soil sulfate saturation.

Key Findings

1. Some of the highest deposition loadings of sulfur, nitrogen, and acidity in the United States have been measured at high elevations in the Southeast. Modelled deposition rates of nitrogen and sulfur are even higher than those actually measured at NADP sites.

2. In the SAA, the highest loadings of sulfur and nitrogen in deposition are found in upland regions and high-elevation watersheds, coincident with a number of Class I parks and wilderness areas. Streams in these upland areas are least able to buffer the incoming acidity, especially during storm-generated episodes. In some of these sensitive streams, aquatic biota (fish and invertebrates) are being affected by both chronic and episodic acidification.

3. We are significantly underestimating the total loading of chemicals to sensitive headwater systems due to technical problems associated with measurement of cloudwater and dry deposition.

4. Sulfate concentrations in precipitation are decreasing in the SAA region, and concentrations of base cations are also decreasing, resulting in precipitation pH that has not changed over 13 years.

5. Nitrogen saturation of watersheds will play a larger role in acidification of some streams in the future. Increases in nitrate and ammonium concentrations in streams due to deposition loading, forest maturation, and insect defoliation contribute to episodic and chronic acidification.

6. With the implementation of the CAA Amendments of 1990, it is unlikely that sulfur deposition will cause additional streams to become chronically acidified in the SAA region. However, the models are not now able to account for the influence of nitrogen deposition in increasing the number of streams subject to both chronic and episodic acidification.

Ground-Level Ozone

Question 5:

What impact does ground-level ozone have on forests?

Ozone is a naturally occurring chemical in both the upper atmosphere and at ground level. Although they can be higher, the majority of hourly average concentration levels of ozone near the ground are usually less than 0.04 parts per million (ppm) at pristine sites in the world (Lefohn and others 1990). Hourly average concentrations above 0.05 ppm are frequently recorded at monitoring stations in the eastern United States (Lefohn and Jones 1986). Ozone exposures above 0.05 ppm are of greatest concern to scientists, resource managers, and the public. Ozone is potentially the most significant pollutant affecting forests in North America (Barnard and others 1991).

Numerous surveys have been conducted within the Southern Appalachian mountains where symptoms found on the leaves of known sensitive species resemble the pattern of ozone injury found under controlled experiments. Renfro (1989) reported ozone symptoms on 21 trees, 15 herbs, 9 shrubs, 3 vines, 1 fern, and 1 grass species in Great Smoky Mountains National Park. Ozone symptoms have also been reported consistently for several species for numerous years at wildernesses designated as Class I areas under the Clean Air Act (CAA) Amendments of 1977 (Brantley and Tweed 1994). Surveys in Shenandoah and Great Smoky Mountains National Parks found a relationship between the amount of injury to foliage and elevational trends in monthly average ozone exposures (Winner and others 1989, Chappelka and others 1992). Other researchers, such as those noted by Dowsett and others (1992), have also reported ozone injury within the Southern Appalachians, and symptoms of ozone injury can be found in many areas in any year.

Several factors affect the uptake of ozone by a plant. Primarily, the genetic code of a plant influences how a plant will respond to ozone. Among plant species there are differences in sensitivity when exposed to the same ozone levels. Variation in sensitivity to ozone within a species can also occur. During field surveys it is possible to see one plant with severe ozone symptoms, while another individual of the same species, growing adjacent to and experiencing similar environmental conditions as the first individual, has no ozone symptoms. In another example, it appears that a portion of the most ozone-sensitive eastern white pines (*Pinus strobus* L.) have been removed from the population due to ozone exposures (U.S. Environmental Protection Agency 1986). Other factors, such as light, temperature, relative humidity, soil nutrients, and soil moisture also influence the uptake of ozone. The U.S. Environmental Protection Agency (EPA 1986) has presented evidence which indicates that drought stress may reduce the impact of ozone on plants, but the protective benefits may be masked by the growth and productivity losses which occur from the drought.

Monitored concentrations in the atmosphere recorded as hourly average values in ppm in the database represent exposure. The exposure is defined as the amount of ozone which contacts the outside of the leaf; whereas the dose is the amount of ozone which actually enters the leaf. Estimates of dose are difficult to predict without detailed modeling of the relationship between exposure and dose. Exposure is used as a surrogate for dose, and exposures are used by researchers and policy makers to assess the possible effects of ozone on vegetation.

Ozone enters a leaf through openings called stomata. Once inside the leaf the ozone is either destroyed by biochemical processes, or the ozone kills the cells found just below the upper leaf surface and between the veins of the leaf. Cells which are killed lose their green pigmentation and usually turn reddish or black, in a process called stippling. The symptoms of ozone injury cannot be observed until a large number of cells are dead. People who conduct field surveys have a checklist of characteristics

which identify plants with ozone symptoms. The symptoms indicate that the plant has had a physiological response to the ozone dose, resulting in injury. Damage results when the ozone dose was large enough to reduce the intended human use or the value of the plant or ecosystem (Tingey and others 1991). This report uses the term damage to mean a growth loss is predicted, even though forested lands in the Southern Appalachians are used for many purposes other than commercial timber production. Furthermore, it is believed that ozone symptoms, as indication of injury, can be found on sensitive species in the Southern Appalachians (Dowsett and others 1992). Thus, the remainder of this report will focus on the possible extent and frequency of damage from ozone to forest trees within the Southern Appalachians.

Ozone Assessment Techniques

Ozone formation is strongly influenced by meteorological conditions and the amount of ozone precursors present in the atmosphere (National Research Council 1992). For example, 1988 was a hot and dry year during which large sections of the eastern United States had high ozone exposures; by comparison, 1989 was cool and moist, and the ozone exposures were low. The range in yearly ozone exposures required that more than one year be examined to describe the current condition for the study area. The years selected for the analysis were 1983 through 1990.

Initially, many researchers used long-term average concentrations to describe ozone exposures when assessing vegetation effects (Heck and others 1992). The EPA (1989) examined the peer-reviewed literature and concluded that long-term averages are not adequate indicators for relating ozone exposure to plant response. Furthermore, EPA (1986 and 1992) concluded that greater effects to vegetation occur when the exposures include short-term, high concentrations rather than long-term, low concentrations. The W126 statistic is a mathematical index, which places emphasis on the high concentrations, but does not ignore the potential effects that can occur from the mid- and lower-level concentrations. Each hourly average ozone concentration is used in the calculation, and all of the W126 values are added together over the growing season. Although the W126 exposure index includes all hourly average concentrations, it focuses on concentrations from 0.04 ppm and higher; the inflection point of the sigmoidal weighting is near 0.066 ppm. At approximately 0.10 ppm and above, a maximum weighting of 1 is provided (Lefohn and Runeckles 1987). Results obtained from the W126 calculations or any other cumulative exposure index can result in high values, but high hourly average concentrations equal to or above 0.10 ppm may not occur. Consequently, the recommendation of Lefohn and Foley (1992) has been followed, and the number of hours greater than or equal to 0.10 ppm are also included in the analysis.

For this assessment, data in EPA's Aerometric Information Retrieval System (AIRS) database and from the National Dry Deposition Network program were used. The monitoring sites included those in the states of Alabama, Georgia, Indiana, Illinois, Mississippi, Missouri, Arkansas, South Carolina, North Carolina, Tennessee, Kentucky, Virginia, West Virginia, Maryland, Pennsylvania, and Ohio. The monitoring sites selected from these states had 75 percent or greater data capture for each particular year. Numerous statistics were calculated using the 24-hour period over the growing season, defined as the months of April through October. The statistics used for this assessment are the W126 (Lefohn and Runeckles 1987) and the number of hours with ozone concentrations greater than or equal to 0.10 for the months of April through October.

Ozone Sensitivity Levels

Numerous studies have been conducted to examine the relationship between ozone exposures and tree response. A listing of the studies considered for this assessment are found in table 6.1. These particular studies were selected because the hourly ozone values were available for each of the experimental treatments. Both pieces of information were necessary to determine levels at which ozone exposures are likely to cause damage to plants of varying ozone sensitivity. Ozone exposure data were used to calculate the W126 value and number of hours greater than or equal to 0.10 ppm for each study. These values, along with the information on associated growth loss to individual species, were used to identify four sensitivity

categories of forest-tree response to ozone exposure. The categories are described below and again in table 6.2. Note that as ozone exposure increases in intensity, more species can be affected.

Minimal - This ozone exposure is so low that little or no growth loss is predicted to occur for any species. Ozone symptoms may have been present even though the exposures were low.

Level 1 - The ozone exposure at this level is high enough to cause growth reductions in species considered highly sensitive to ozone, such as black cherry.

Level 2 - The ozone exposure at this level is high enough to cause growth reductions in species with moderate sensitivity to ozone, such as tulip poplar, in addition to those species which are included in Level 1.

Level 3 - The ozone exposure at this level is high enough to cause growth loss in many species, even those normally considered resistant to ozone exposures, such as red oak, in addition to these species in Level 1 and Level 2.

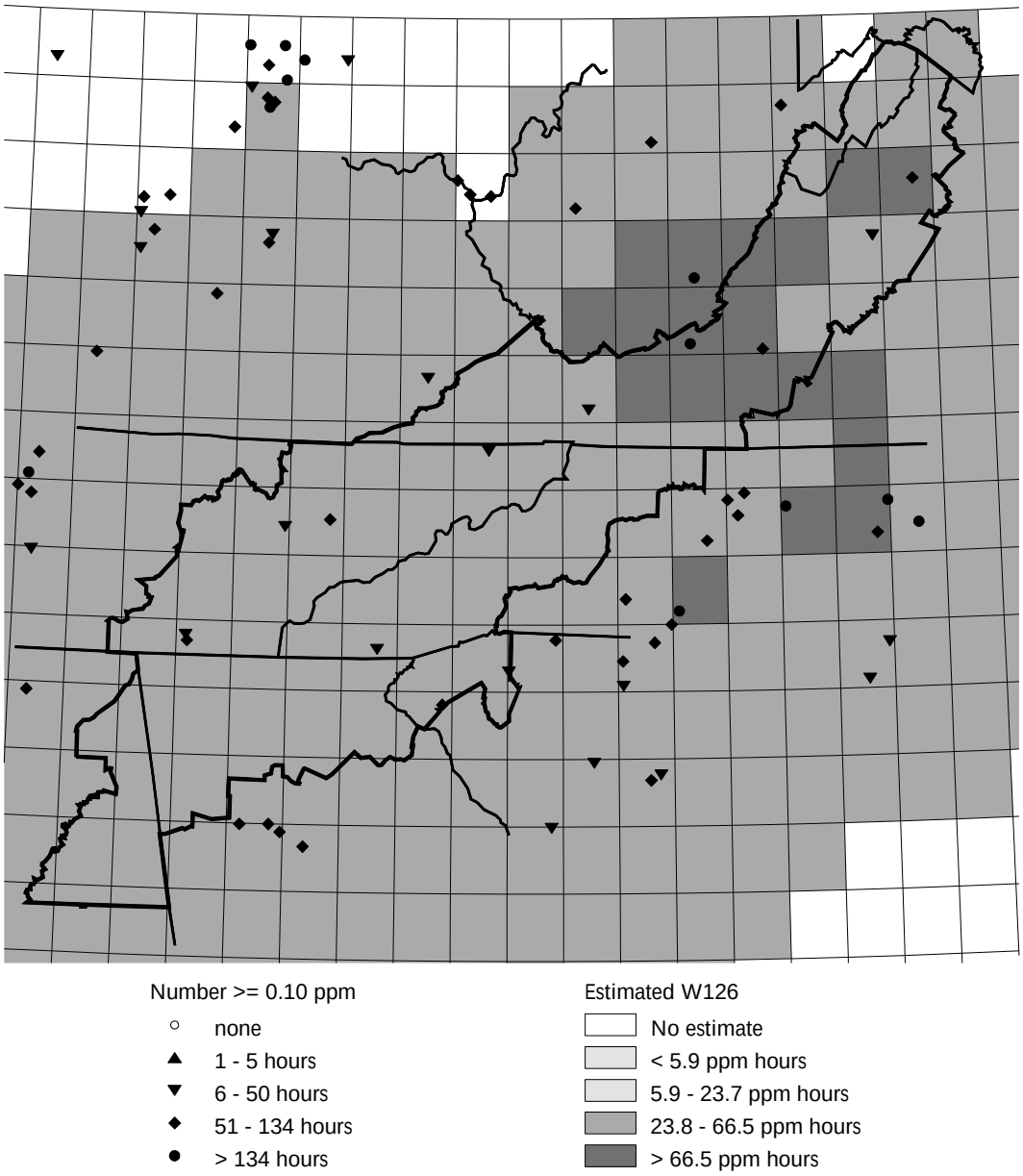
Ozone Impacts to Trees Across the SAA

The next step in the analysis was to stratify the landscape by these categories to show areas where ozone exposures may have been great enough to cause growth reductions to tree species of various ozone sensitivities. To accomplish this task, it was necessary to extrapolate the ozone-monitoring data beyond the monitoring sites. Extrapolations of the W126 values across the SAA were accomplished using a statistical technique described in a report by Lefohn and others (1995). The W126 estimates were made for grid cells of 0.5 degrees latitude by 0.5 degrees longitude across the Southern Appalachian region.

Table 6.1 Listing of ozone exposure studies considered to identify the exposure effects levels for selected Southern Appalachian trees.

Forest Tree Response Category[1]	Common Name	Genus and Species	Reference
Level 1	black cherry	*Prunus serotina*	Neufeld and others 1995
			Samuelson 1994
	slash pine	*Pinus elliotti*	Hogsett and others 1985
Level 2	green ash	*Fraxinus pennsylvanica*	Kress and Skelly 1982
	sycamore	*Plantus occidentalis*	Kress and Skelly 1982
	tulip poplar	*Liriodendron tulipifera*	Lee 1995
			Kress and Skelly 1982
			Chappelka and others 1988
			Cannon and others 1993
	white ash	*Fraxinus americana*	Kress and Skelly 1982
	white pine	*Pinus strobus*	Lee 1995
			Reich and others 1988
Level 3	American beech	*Fagus grandifolia*	Jensen and Dochinger 1982
	loblolly pine	*Pinus taeda*	Lefohn and others 1992
			Shafer and Heagle 1989
			Kress 1995
			Kress and Skelly 1982
	pitch pine	*Pinus rigida*	Kress and Skelly 1982
	red maple	*Acer rubrum*	Lee 1995
			Samuelson 1994
	red oak	*Quercus rubra*	Samuelson and Edwards 1993
			Edwards and others 1994
			Samuelson and others 1995
	shagbark hickory	*Carya ovata*	Jensen and Dochinger 1989
	Virginia Pine	*Pinus virginiana*	Lee 1995
			Kress and Skelly 1982
	white oak	*Quercus alba*	Jensen and Dochinger 1989

[1]Classification based upon listed research studies, and frequency and magnitude of ozone symptoms observed during field surveys.



AT601

Figure 6.1 Results for the W126, and the number of hours with ozone concentrations greater than or equal to 0.10 ppm at ozone monitoring sites – 1988.

For each grid cell, a W126 value was assigned to one of the W126 ranges listed in table 6.2. The criteria listed in table 6.2 required consistency with both the W126 and the number of hours with concentrations greater than or equal to 0.10 ppm. Because the number of hours greater than or equal to 0.10 ppm could not be statistically extrapolated across the study area, it was necessary to finish the classification by visually examining the monitored values for the number of hours greater than or equal to 0.10 ppm. Grids which had one or more ozone monitors present were classified using the results from the ozone monitors, but cells which did not have an ozone monitor were classified by examining the pattern from ozone monitors surrounding the cell to be classified (fig. 6.1). Cells which met the W126 criteria for a particular category and not the number of hours greater than or equal to 0.10 ppm for the same category were assigned the category which matched the number of occurrences greater than or equal to 0.10 ppm. For example, some cells in northern Virginia

Table 6.2 Ozone exposure levels associated with forest tree response.

Forest Tree Response Category[1]	Effects Range[2] W126	Hours > = 0.10 ppm
Minimal	< 5.9	< 6
Level 1 (only highly sensitive species affected, e.g. black cherry)	> = 5.9	> = 6
Level 2 (moderately sensitive species affected, e.g. tulip poplar)	> = 23.8	> = 51
Level 3 (all species affected, even those normally resistant, e.g. red oak)	> = 66.6	> = 135

[1]Level 2 includes Level 1 species and Level 3 includes species included within Levels 1 and 2.

[2]Ozone effects ranges were selected for four response categories based upon the studies listed in table 6.1 The levels are reached when the seasonal ozone exposure is equal to or greater than the number of hours under the 0.10 ppm column and when W126 value falls within the range listed in the column for a particular response category.

were rated as Level 3 in 1988 for the W126 value (fig. 6.1), but were reduced to Level 2 because the number of hours greater than or equal to 0.10 ppm was less than 135 hours and more than 50 hours during the growing season (fig. 6.2). Each cell was assigned a value in the database once the final category was decided. Cell classification of "minimal" received a zero; Level 1 received a one; Level 2 received a two; and Level 3 received a three.

The experimental studies listed in table 6.1 used plants which were grown under optimum conditions of adequate soil moisture and nutrients. The picture presented in figure 6.2 assumes that the environmental conditions were favorable for ozone to enter the leaf and that the cumulative exposure would result in a growth loss. However, it is necessary to consider environmental conditions that affect a plant's sensitivity to ozone, especially drought. Showman (1991) and Jackson and others (1992) have both observed fewer ozone symptoms on sensitive species during periods of drought than in seasons with adequate rainfall, even though ozone exposures were high in the drought. Soil moisture is considered to be an important variable which influences the uptake of ozone by a plant (EPA 1986). The Palmer Hydrologic Index was chosen as a surrogate measurement of soil moisture. The index, a monthly value computed for climatic division, indicates the severity of a wet or dry spell (fig. 6.3). A Palmer Hydrologic Index of less than a minus two was considered to indicate low soil moisture conditions (Briffa and others 1994), and it was hypothesized that ozone would not damage the plants. Values above a minus two indicated adequate soil moisture, when ozone therefore could potentially penetrate the leaves and damage the plants. The average Palmer Hydrologic Index for the months of April through July was calculated for each climatic division and used in the assessment.

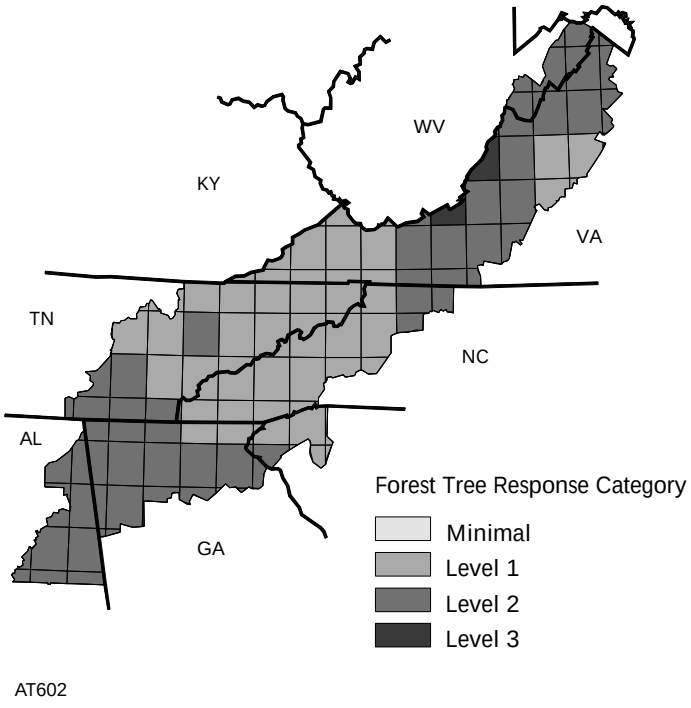


Figure 6.2 Results after combining the W126 and number of hours with ozone concentrations greater than or equal to 0.10 ppm – 1988.

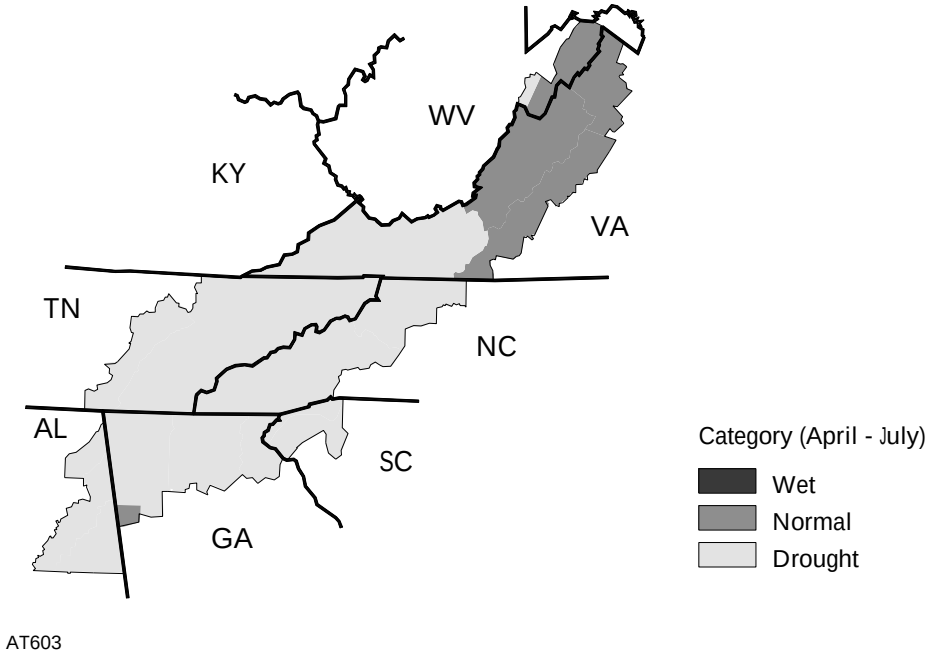


Figure 6.3 Palmer Hydrologic Drought Index result – 1988.

Combining the results from the Palmer Hydrologic Index (fig. 6.3) and ozone exposure (fig. 6.2) provides an indication of (1) soil moisture adequacy and (2) ozone exposures severe enough to cause growth losses. Areas which were classified as experiencing a drought were assigned the category as "minimal" effect from ozone; otherwise the sensitivity category value remained the same after applying the criteria in table 6.2 (fig. 6.4).

The final step in the analysis was to combine the results for all years to determine which areas had the greatest frequency of potential for growth loss. The values, zero through three, assigned to each of the forest-tree response categories were added together for the years 1983 through 1990.

Table 6.3 Number of acres where ozone exposures may have been large enough to cause growth reductions.

Year	Minimal	Level 1	Level 2	Level 3
1983		37,419,416		
1984	16,440,810	20,978,606		
1985	12,799,214	24,620,202		
1986	19,774,377	17,645,039		
1987	4,621,422	32,179,934	618,060	
1988		17,280,546	19,536,088	602,782
1989	36,179,580	1,239,836		
1990	24,151,128	13,268,288		

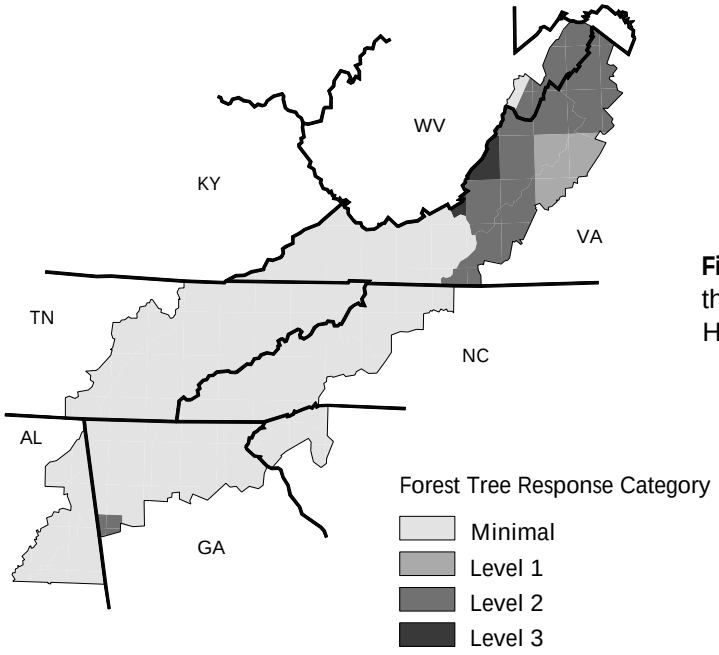


Figure 6.4 Results after combining the ozone exposure and the Palmer Hydrologic Drought Index – 1988.

AT604

Ozone – Current and Future

Current Ozone Impacts to the Southern Appalachian Forests

The results from statistical estimates placed almost all of the cells into W126 units of 23.8 - 66.5 ppm-hours for the years 1983 through 1990. In 1988, 11 of the 120 cells had W126 estimates of greater than 66.5 ppm-hours. Three cells in 1986 and 1989 and one cell in 1990 had a W126 estimate of 5.9 23.7 ppm-hours. No cells were classified as having less than 5.9 ppm-hours. These data indicate that Level 2 and Level 1 species may have had growth losses for the 8 years. However, because hourly average ozone concentrations were seldom greater than or equal to 0.10 ppm, such losses were not actually anticipated and the cells were reduced to a lower category. Southern Appalachian ozone monitors usually measured less than 40 hours when the hourly average ozone concentration was greater than or equal to 0.10 ppm. Only one year deviated from this pattern: in 1988, 5 of the 10 ozone monitors in the study area recorded greater than 50 hours in which the hourly average ozone concentration exceeded or equaled 0.10 ppm (fig. 6.1).

Considering only ozone exposures, table 6.3 lists the number of acres estimated in each of the sensitivity categories. Overall, the ozone exposures are such that somewhere in the Southern Appalachians, Level 1 species could have growth loss in almost every year. In 1989, there was a lack of ozone concentrations which equaled or exceeded 0.10 ppm, and there was a high probability that minimal growth loss was caused by ozone exposures. In 1988, on 52 percent of SAA acres, Level 2 species could be damaged, and on 2 percent, Level 3 species may have had sufficient ozone exposures for growth loss. It is important to note that the W126 exposure index value was accumulated over the April to October period. Most of the experimental data used in this assessment were collected over a 3- to 4-month period. Thus, using a 7-month period to accumulate the W126 value may overestimate the likelihood of experiencing growth losses.

Although ozone exposures may have been large enough to cause growth reductions, losses also require environmental conditions to be favorable for uptake of the pollutant by the vegetation. This assessment focused on soil moisture potential by examining the Palmer Hydrologic Index values for a climatic division. Portions of the Southern Appalachians were normal or wet in every year, but large areas

Table 6.4 Number of acres in each moisture index category.

	Average (April-July) Palmer Hydrologic Index		
Year	Drought	Normal	Wet
1983		29,679,142	7,740,274
1984		12,613,961	24,805,455
1985	27,631,889	9,787,527	
1986	36,177,782	1,241,634	
1987	11,572,194	21,059,223	4,787,999
1988	29,164,372	8,255,044	
1989		31,779,750	5,639,666
1990		11,461,453	25,957,963

experienced drought conditions in 1985 through 1988, with the largest amount (36,177,782 acres) being affected in 1986 (table 6.4). Consequently, the lack of soil moisture in portions of the region may have reduced uptake of ozone by vegetation, and ozone exposures had little effect on growth.

The combination of the Palmer Hydrologic Index results and the ozone exposure results are shown in table 6.5. The drought present in 1985 through 1988 significantly reduced the area that might have been adversely affected by ozone. Nevertheless, growth losses were probably occurring to the Level 1 (highly sensitive) species somewhere in the Southern Appalachians almost every year. In 1988, some areas may have had growth losses occurring to Level 2 and Level 3 species (see table 6.1). Figure 6.5 presents the areas with the greatest frequency of potential damage from ozone exposures. The range of possible values was between 0 and 24, but the results for this study show a range between 1 and 6 (table 6.6). Thus, ozone damage may have occurred to sensitive

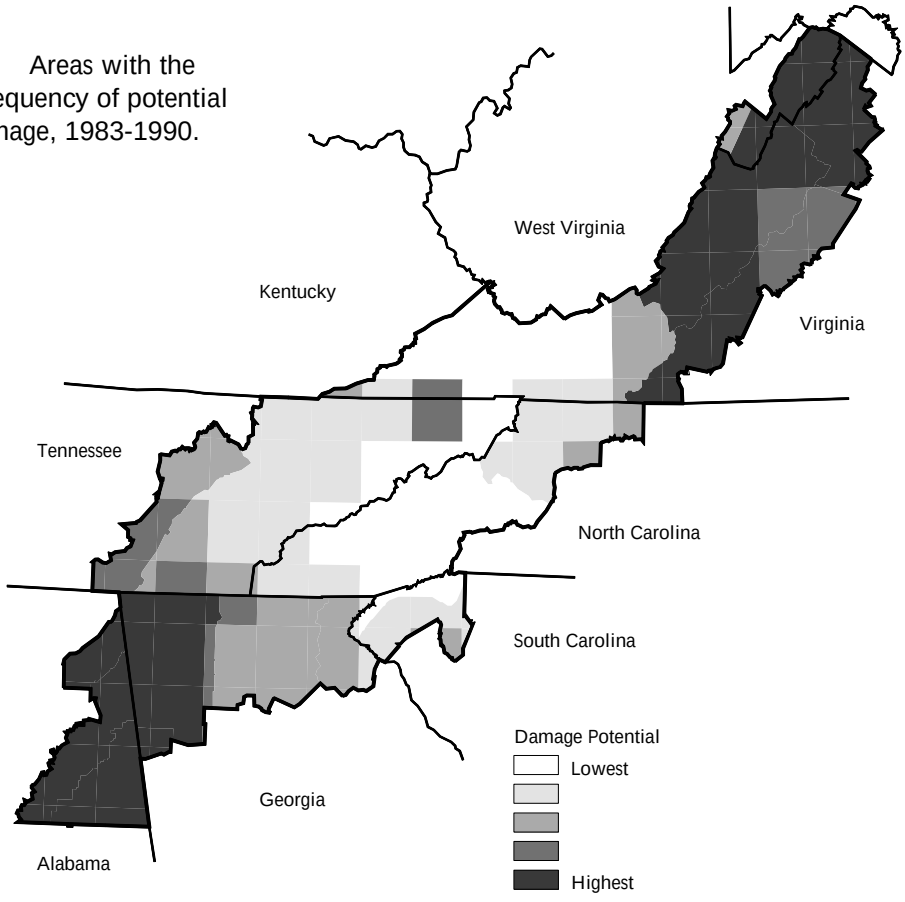


Figure 6.5 Areas with the greatest frequency of potential ozone damage, 1983-1990.

Table 6.5 Number of acres when ozone exposures and Palmer Hydrologic Index were favorable for growth loss.

Year	Minimal	Level 1	Level 2	Level 3
1983		37,419,416		
1984	16,440,810	20,978,606		
1985	32,124,860	5,294,556		
1986	37,419,416			
1987	14,954,963	22,464,453		
1988	29,164,372	1,420,764	6,417,044	417,236
1989	36,179,580	1,239,836		
1990	24,151,128	13,268,288		

species throughout the Southern Appalachians at least one year, but damage from ozone exposures did not occur at all locations every year. Northern Virginia and the SAA area in West Virginia, and the southern portion of the SAA located in Alabama and northern Georgia are the regions most frequently affected by ozone exposures (fig. 6.5).

Caution should be used in interpreting these findings since localized areas within the Southern Appalachians may have had adequate soil moisture, even though the climatic division was classified as drought. For example, it is known that high-elevation sites above 3,000 feet receive a significant amount of precipitation from cloud moisture. Furthermore, it has been reported that the western and central portions of the Appalachian mountains may receive more rainfall than the eastern portion (Hicks and others 1991). Thus, these areas may receive adequate moisture for the uptake of ozone through the stomates.

Lefohn and others (1990) have described another important aspect of the exposure question. Gaseous pollutant concentrations have been reported in ppm. This unit is a molecular fraction and is not affected by temperature and pressure. However, if exposures at low-elevation sites are compared with those experienced at high-elevation sites, where temperature and pressure are less, the variation of concentration (in units of micrograms per cubic meter [ug/m^3]) as a function of altitude is significant. Given the same ppm value experienced at both high- and low-elevation sites, the absolute concentrations (i.e., ug/m^3), at two elevations are different. Therefore, assuming that the sensitivity of a plant is nearly identical at both low and high elevations, some adjustment should be necessary when attempting to link experimental data obtained at low-elevation sites with air-quality data monitored at high-elevation stations. Lefohn and others (1990) have reported that pressure adjustments can be large for specific cumulative index values. There are some indications that vegetation sensitivity may not be similar as a function of elevation. Winner and others (1989) report that visible injury to foliage increased with elevation. However, the number of elevated hourly occurrences of high values did not increase, thus leading the authors to speculate that sensitivities may have differed as a function of elevation.

Future Trends in Southern Appalachian Ozone Exposures

Current efforts by state, local, and federal air pollution agencies provide evidence that ozone exposures in rural forests could possibly be reduced in the future. For example, there could be a lowering of ozone exposures in the Southern Appalachians as soon as ozone nonattainment areas outside the study area implement control strategies that bring the region back into compliance with federal law. Furthermore, a revision of the National Ambient Air Quality Secondary standard from the current form could also benefit the Southern Appalachian mountains. Currently, Whitetop Mountain in Virginia is the only area

Table 6.6 Number of acres for each damage category when all years are combined.

Damage Potential	Category	Acres
Lowest	1	8,078,321
	2	7,877,033
	3	6,040,146
	4	3,495,672
	5	11,026,331
Highest	6	901,910

designated as non-attainment for ozone because the 0.12 ppm standard was exceeded. A secondary standard, which included both cumulative ozone exposure, such as the W126, and peak concentration, such as the number of hours greater than or equal to 0.10 ppm, would assist in focusing efforts to reduce damage to vegetation in the Southern Appalachians.

Ozone exposures in the study area result from the chemical reaction of nitrogen oxides and volatile organic compounds. The volatile organic compounds are known to be abundant, and it appears that nitrogen oxides may be the limiting factor in ozone formation (Chameides and Cowling 1995). Regional strategies which reduce nitrogen oxides may result in lower ozone exposures for the Southern Appalachians. The current efforts of the Southern Appalachian Mountain Initiative (SAMI) could provide reasonable pollution control strategies that lead to reduced ozone exposures. Although SAMI is focusing on numerous Class I areas found in the Southern Appalachians, there should be benefits to all of the area if pollution control programs are implemented which reduce ozone exposures in the Class I areas.

Key Findings

1. Current ozone exposures are causing visible symptoms on the foliage of sensitive species. The injury can be found in numerous locations throughout the Southern Appalachians.

2. Ozone exposures, when soil moisture is adequate, may be sufficient to cause growth losses to the most sensitive species in the Southern Appalachians.

3. Low moisture availability occurred throughout the Southern Appalachians in 1985 through 1988. Growth losses to vegetation probably occurred, but the reductions should be attributed primarily to drought.

4. Between 1983 and 1990, conditions in the northern and southern portions of the Southern Appalachians were most conducive to growth reductions from ozone exposures.

Information and Research Needs for the Next Assessment

In the process of answering the questions posed at the beginning of this assessment, the Atmospheric Team noted voids where additional information would have improved the study process. Furthermore, many additional questions arose which dealt with areas for which scientists do not have ready answers. Therefore, the following information and research needs should be filled before another assessment on air quality is performed for the Southern Appalachians.

1. More air-quality monitoring is needed in rural and high-elevation areas for particulate matter, aerosol, acid deposition, and ozone. Also, more site-specific air-quality monitoring is needed to compare micro-climates versus area-wide conditions. For example, within a smaller scale geographic area, how does air quality differ on mountain top, mid-slope, and valley floor?

2. More work is needed to refine ozone exposures response for highly sensitive and moderately sensitive species. Growth losses may be occurring to moderately sensitive species, such as tulip poplar, at ozone exposures lower than what is reported in this assessment.

3. Research is needed to simulate more ambient-like exposures that reflect both the cumulative ozone exposure and number of hours greater than or equal to 0.10 ppm found in the Southern Appalachians.

4. The relationship of soil moisture and ozone exposure as it affects forest vegetation needs further investigation. What is the relationship between soil moisture and the opening of a leaf's stomate that allows ozone to penetrate?

5. Little is known about the effects, if any, ozone exposures are having on hard and soft nut production and on fruit production.

6. Future assessments might quantify the economic effects of forest growth attributable to air pollutants.

7. Correlation is needed to better understand the effects of regional meteorology on the dispersal of air pollutants within the region. For example, what effect do pollutants generated within the Atlanta metropolitan area have on the lower region of the Southern Appalachians?

8. The existing EPA-sponsored larger stationary point-source database is adequate; however, an area-source emissions database is needed to quantify the amount of pollutants from smaller point sources, fugitive sources, and mobile sources.

9. Development of a public participation process would assist with the definition of acceptable and unacceptable visibility conditions.

10. Further studies are needed to document the amount of PM10 and PM2.5 downwind, at various distances, from large prescribed fires.

11. Further research is needed on the role of nitrogen deposition to SAA ecosystems to determine to what extent nitrate deposition affects terrestrial and aquatic systems. Research in this area should continue to develop models to predict both short- and long-term impacts.

12. Further deposition monitoring is needed, specifically at high elevations, with an emphasis on estimation of cloudwater and dry deposition inputs.

13. Scientists need to better relate episodic acidification in streams with changes in biological populations using in situ observations and experiments. Models are needed to determine dose-response relationships for aquatic biota.

14. There is a need to evaluate the impact of continued sulfate deposition on the "delayed" acidification of streams as sulfate is released from soils once they become saturated.

Appendix A

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List of Figures

List of Tables

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Glossary

acid-neutralizing capacity (ANC):
A simple measure of stream water "sensitivity" is ANC or the ability to buffer incoming acids. When acid deposition falls on stream watersheds that are located on bedrock that is resistant to weathering, then we will see a decrease in the ANC in the stream water, along with a decrease in pH.

acidic deposition:
Also known as "acid rain" or "acid precipitation," wet and/or dry deposition of acidic materials to water or land surfaces. The pH of rain is considered acid when it is lower than about 5.2 on the pH scale. The chemicals found in acidic deposition include nitrate, sulfate, and ammonium.

acidic:
When we refer to stream reaches that have become "acidic," we mean that the ANC is less than or equal to zero.

aerosol:
An aerosol is a solid or liquid particle suspended in a gas. In this report the term "aerosol" is used interchangeably with "particulate."

AIRS:
The acronym for Aerometric Information Retrieval System, the national air quality and emissions database maintained by EPA and the air regulatory agencies of the individual states.

B_{abs}:
Absorption coefficient. A measure of light absorption in the atmosphere by particles and gases.

base cations:
Positively charged ions that may be leached into lakes and streams by acids. Examples of base cations are calcium, magnesium, potassium, and sodium.

B_{ext}:
Extinction coefficient. Measured directly by a transmissometer. Can be reconstructed from nephelometer and aerosol data. B_{ext} is equal to the sum of B_{scat} and B_{abs}.

B_{scat}:
Scattering coefficient. Measured directly by a nephelometer, the scattering coefficient includes scattering due to particles and atmospheric gases (Rayleigh scattering).

CAA:
The acronym for the federal Clean Air Act, including all of its amendments.

chronic acidification:
This means that the ANC of the streams is lost over the long term and the pH drops as a consequence of the addition of sulfuric acid and nitric acid to watersheds.

Class I areas:
National parks and wilderness areas managed by the National Park Service, U.S. Fish and Wildlife Service and the USDA Forest Service and defined by the Clean Air Act Amendments of 1977 as having "special protection" from effects of air pollution. These federal lands have been defined as having "air-quality related values" (AQRVs), such as water quality, native vegetation, ecosystem integrity, and visibility, that need protection from air pollution.

coarse particles:
Particles between 2.5 and 10 microns. Coarse particles are mostly composed of soils. The sum of the masses of coarse and fine particles (all particles smaller than 10 microns) is called PM10 (EPA "respirable particle mass").

deciview (dv):
A haziness index designed to be linear with respect to human perception of visibility. A 1 - 2 dv change in haziness corresponds to a small, visibly perceptible change in scene appearance. Higher deciview values indicate more extinction and a corresponding decrease in visual range.

dry deposition:
Also known as dryfall, includes the gases and particles deposited from the atmosphere to water and land surfaces. This dryfall can include acidifying compounds, such as nitric acid vapor, nitrate and sulfate particles, and acidic gases.

episodic acidification:
Episodes are hydrologic events accompanied by rapid increases in stream flow. These events or episodes are driven by rainfall and snowmelt and can result in rapid loss of acid-neutralizing capacity and depression in pH. Other chemical changes that may affect fish populations during episodes include increases in aluminum concentrations and decrease in calcium concentrations during these flow increases.

Episodic Response Program:
Research program sponsored by the Environmental Protection Agency under the NAPAP program to determine the frequency, severity, and effects of acidic episodes in streams in the Adirondacks, Catskills, and Appalachian Plateau of western Pennsylvania.

exceedence of standard:
A situation where the stated maximum concentration in a standard such as NAAQS is exceeded without triggering a "violation" of that standard. For example, the NAAQS-Ozone 24-hour standard of 120 parts per billion is expected to be exceeded no more than once per year.

extinction coefficient:
The atmospheric extinction coefficient, B_{ext} (loosely referred to as just "extinction"), represents the ability of the atmosphere to absorb and scatter light. In this report, extinction coefficient is provided in inverse megameters (Mm^{-1}). Conversions between Mm^{-1} and other commonly used units of extinction coefficient are:

1,000 Mm^{-1} = 1 km^{-1}

1,000,000 Mm^{-1} = 1 m^{-1}

Extinction coefficient measurements can be converted to SVR or deciview values.

The conversion from B_{ext} to SVR is:

$$\text{SVR (in km)} = \frac{3910}{[B_{ext} - B_{\text{Rayleigh at Site}} + 10] \text{ (in } Mm^{-1})}$$

The conversion from B_{ext} to haziness index is:

$$\text{Haziness (in dv)} = 10 \ln [B_{ext} \text{ (in } Mm^{-1})/10 \text{ } Mm^{-1}]$$

fine particles:
Particles smaller than 2.5 microns (PM2.5). Fine particles are responsible for most atmospheric particle-induced extinction.

forest management burning:
See "prescribed burn."

growing season:
That portion of the year during which plants normally initiate, continue, and cease active biomass accumulation. In the SAA area, this season typically begins in early April and ends in mid-October.

light extinction:
The absorption and scattering of light.

loadings:
Reflect both the concentrations of chemicals in precipitation and the total amount of wet deposition that falls during the year. These values can be used to estimate total loading of pollutants to ecosystems (in kilograms/hectare/year). Total loading of such chemicals as hydrogen ion, sulfate, and nitrate would ideally include wet and dry deposition.

Mm^{-1}:
Inverse megameter. A unit of extinction related to SVR and dv by the equations above. Higher extinction coefficients correspond to lower SVR values and higher deciview values.

NAAQS:
The acronym for the National Ambient Air Quality Standards, established and maintained by EPA under Authority of the Clean Air Act.

National Stream Survey (NSS):
This was a water chemistry survey of stream reaches located in suspected sensitive regions of the southeastern United States sponsored by the Environmental Protection Agency during spring 1986. This survey allowed researchers to identify areas of the Southern Appalachian Assessment region that had stream reaches that had already acidified, and those that are sensitive to acidification.

National Acid Precipitation Assessment Program (NAPAP):
The ten-year (1980-1990), interagency research program designed to investigate acid deposition and its effects nationwide. The products of this program are the series of State of the Science and Technology documents that summarize what we know about the severity of acid deposition and the resources it affects.

National Atmospheric Deposition Program (NADP):
A national network of about 200 sites where wet deposition is collected weekly and sent to the Central Analytical Laboratory in Illinois for chemical analysis. This network has operated since 1977 and is funded by seven federal agencies, and numerous cooperators in agencies, universities, and industry. This network of predominately rural sites is designed to represent broad, regional patterns of deposition.

nephelometer:
A tool that allows accurate measurement of the atmospheric scattering coefficient (B_{scat}) of ambient air by directly measuring the light scattered by aerosols and gases in a sampled air volume.

nitric oxide:
A gas formed under high temperature and/or high pressure during combustion in furnaces and internal combustion engines. The nitric oxide is converted to nitrogen dioxide in the presence of oxygen.

nitrogen oxides:
A designation of all the oxides of nitrogen which includes nitrogen dioxide, nitric oxide, and nitrous oxide, all of which are precursors in the formation of atmospheric ozone.

nitrogen dioxide:
A brown-colored gas produced as a result of nitric oxide combining with oxygen in the atmosphere. Nitrogen dioxide is used as the basis in mass calculations for NAAQS. Nitrogen dioxide can be converted to nitric acid and nitrates can be transported to water bodies or land as either wet or dry deposition.

nitrogen saturation:
This is a situation in watershed soils when there is an excess supply of nitrogen that cannot be used by biota. This excess nitrogen is then leached into surface waters and exported from the watershed. This condition can be caused by nitrate and ammonium in deposition, and by changes in nutrient cycling due to forest maturation and insect infestation.

non-attainment area:
For NAAQS, where the pattern of "violations of standard" is sufficient to require remedial action; a boundary is determined around the location of the violations. The area within that boundary is designated to be in non-attainment of the particular NAAQS standard and an enforceable plan is developed to prevent additional violations.

optical monitoring:
Optical monitoring refers to directly measuring the behavior of light in the ambient atmosphere.

orographically-enhanced deposition:
When moisture-laden air masses encounter upland areas, such as the Southern Appalachian mountains, the effect is to increase wet deposition on slopes and mountain tops. These upland areas also intersect clouds, resulting in increased deposition of cloudwater and chemicals in these areas.

ozone:
In the context of this paper, ozone refers to ground level or ozone that occurs in the atmosphere near the earth surface, where it may cause injury on plants and animals. Ozone is an air-quality parameter for which a standard is maintained within NAAQS.

pH:
The negative logarithm of hydrogen ion activity. The pH scale goes from 1 (most acidic) to 14 (most alkaline). The difference of one pH unit indicates a ten-fold change in hydrogen ion activity. pH is a quantitative measure of the acidity of a lake or stream.

PM:
The acronym for airborne "particulate matter," an air quality parameter for which standards are maintained within NAAQS.

PM2.5:
The acronym for that portion of PM that has an aerodynamic diameter of 2.5 microns or less.

PM10:
The acronym for that portion of PM that has an aerodynamic diameter of 10 microns or less.

precursor:
A substance or condition whose presence generally precedes the formation of another, more notable, condition or substance.

prescribed burn:
A wildland fire whose progress has been controlled by a combination of strategies, including: construction of artificial fire breaks, selection of natural firebreaks and burnout of vulnerable fuels within the fire control line. A wildfire may be declared a controlled burn if ignition occurs within an area for which an approved burning plan exists and weather conditions fall within the acceptable range. While a forest management burn is referred to as a prescribed burn in the planning stage, the same project may be referred to as a controlled burn in the implementation stage.

Rayleigh scattering:
Light scattering (principally blue light) by atmospheric gases. Perfectly clean air (100 percent Rayleigh scattering) would correspond to an SVR of 391 km at an elevation of 5000 feet, which is the theoretically maximum for an SVR. Rayleigh scattering also corresponds to B_{ext} = 10 Mm^{-1}, and is defined as 0 deciview.

scattering efficiency:
The relative ability of aerosols and gases to scatter light. A higher scattering efficiency means more light scattering per unit mass or number of particles, this in turn means poorer visibility. In general, fine particles (diameter less than 2.5 microns) are efficient scatterers of visible light.

scene monitoring:
Scene monitoring is the monitoring of a specific vista or target. Optical and aerosol monitoring measure an abstract but easily quantifiable parameter of the atmosphere. Scene monitoring captures the effects of all atmospheric parameters simultaneously, but in an inherently difficult manner to quantify. It is, for example, difficult to determine quantitatively which of two photographs represent "better" visibility conditions. Scene monitoring is generally done to help relate quantitative data in a "user-friendly" format.

sight path:
The path between an observer (or piece of monitoring equipment) and a target on the landscape.

standard visual range (SVR):
Visual range is the furthest distance that a human observer can resolve a large dark target under the prevalent atmospheric conditions. Standard visual range is visual range standardized to Rayleigh scattering at an elevation of 5000 feet (10 Mm^{-1}).

stream reach:
Or stream segment is that part of the stream channel between two stream tributary confluences. This term is often used to refer to a length of stream with uniform physical and morphological characteristics.

sulfate adsorption:
The process by which sulfate is chemically exchanged or adsorbed onto positively charged sites on the soil matrix; under some conditions this process is reversible, and the sulfate may be desorbed and enter stream waters.

sulfur dioxide:
A colorless gas produced by industrial processes, especially the burning of fossil fuels, such as coal and oil. Most SOx emissions come from large power plants, refineries, and smelters. This gas is transformed in the atmosphere to sulfate particles and sulfuric acid, which can be transported to surface waters and soils in wetfall or dryfall. The form of sulfur that provides the basis of emission mass calculations for NAAQS.

SAMI (The Southern Appalachian Mountain Initiative):
A consortium of government agencies, industry and environmental groups, formed to investigate the status of air quality and its effects in the highland regions of the southeastern United States. The objective of this regional cooperative is to determine the current and future impacts of regional air pollutants, such as ozone and acid deposition, and to recommend regional air management strategies to control the formation of these pollutants.

transmissometer:
An instrument designed to continuously and directly measure light transmission properties of the atmosphere along a selected sight path. Total light extinction is measured by integrating light scattering and absorption properties of the atmosphere.

TSP:
The acronym for total suspended particulates, that portion of PM that is captured by a PM sampler which does not attempt to discriminate according to particle size.

violation of standard:
A regulatory situation, i.e. NAAQS, where the pattern of "exceedences of standard" is greater than the frequency allowable under that standard.

VTSSS (Virginia Trout Stream Sensitivity Survey):
Survey of the water chemistry of 344 native brook trout streams in western Virginia carried out by researchers from the University of Virginia in partnership with the Virginia Department of Game and Inland Fisheries, USDA Forest Service, National Park Service, and Trout Unlimited.

wet deposition:
Also known as precipitation, includes chemicals and water collected as rain, snow, sleet and hail, along with "occult" deposition (fog and cloudwater). Chemicals measured in wet deposition when assessing the impact of acidic materials include hydrogen ion, sulfate, nitrate, ammonium, and base cations.

wildfire:
Any wildland fire that requires a suppression response. A controlled burn may be declared a wildfire if part of it escapes from the control line or if weather conditions deteriorate and become unacceptable, as described in the burning plan.

W126:
Statistically weighted function to describe ozone exposures for a predefined time period.