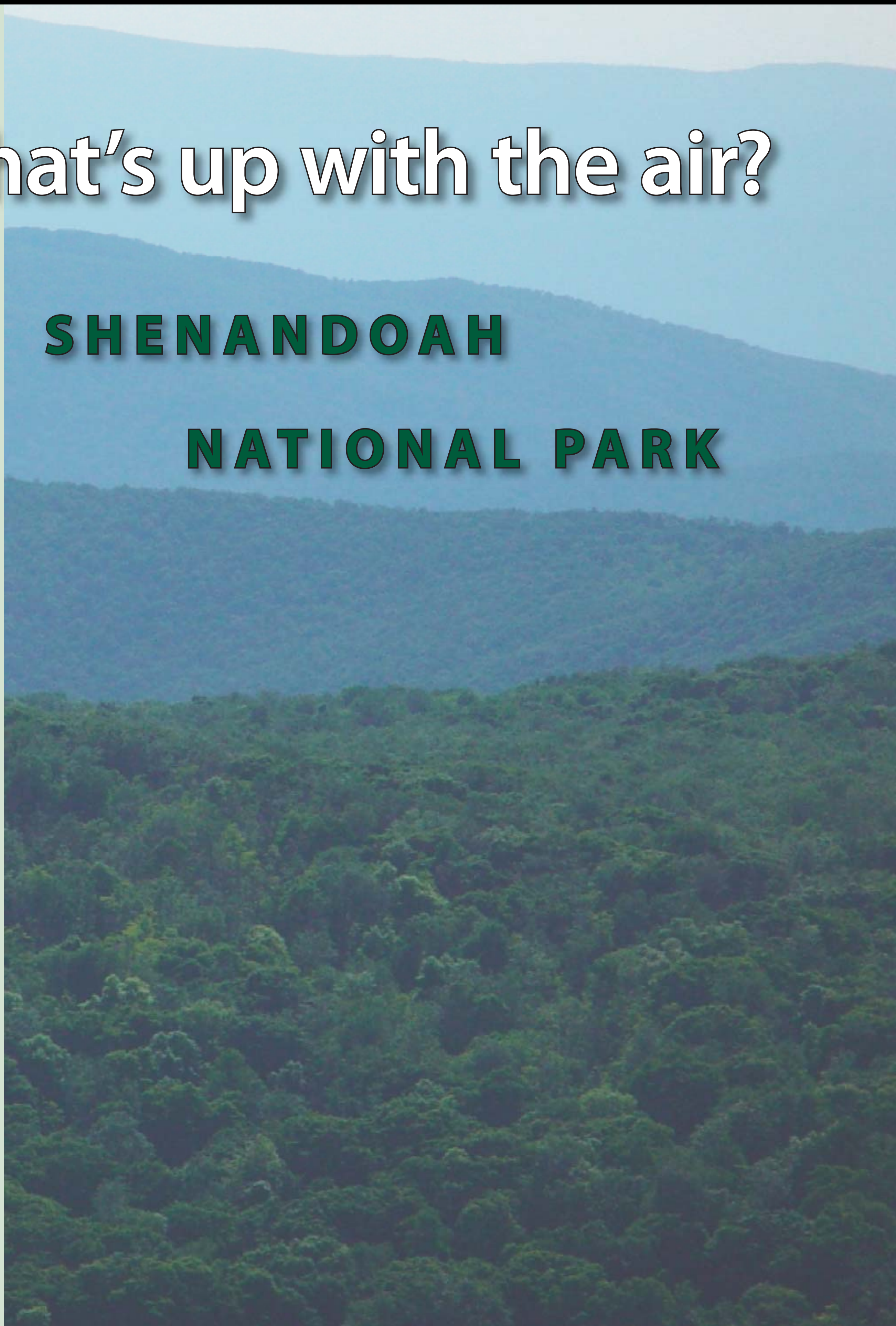
National Park Service
U.S. Department of the Interior

What's up with the air?

SHENANDOAH NATIONAL PARK



What’s up with the air?

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U.S. Department of the Interior
Washington, DC

“All things share the same breath - the beast, the tree, the man; the air shares its spirit with all the life it supports.”

Chief Seattle, Duwamish

This booklet tells the general story of air pollution effects in Shenandoah National Park. Particular topics are explored in greater detail within inset boxes. Key scientific terms are printed in boldface type the first time they appear and are defined on the inside back cover of this publication.

ON THE COVER
View of ridges from Shenandoah National Park
Photograph by Rick Webb

Background

Photo of autumn foliage taken in Shenandoah National Park, known for its scenic beauty and outstanding natural resources.

BACKGROUND

Shenandoah National Park, located along the crest of the Blue Ridge Mountains in Virginia, contains exceptional natural features. Few places in the country have more plant species than does this park. Views from Skyline Drive, especially at dawn and dusk, are among the most awe-inspiring in the eastern United States. Park streams teem with native brook trout, 33 other species of fish, and the insects and other life forms on which they feed. Air pollution threatens these valuable resources. Some damage has already occurred. Other damage is predicted to occur in the future under continued high levels of air pollution.

This publication describes the effects of air pollution on the natural and scenic resources of Shenandoah National Park. These effects are known to harm some of the plants, soils, streams, fish, insects, and scenic vistas that attract hundreds of thousands of visitors to the park each year. The story told here centers on aspects of the park resources that are sensitive to air pollution damage and how these resources interact with air pollution and with each other. This is a story of scientific exploration and ecosystem complexity. In addition, however, it concerns environmental awareness, ecosystem protection, and hope for a better future for our natural world. The scientific principles that govern these interactions are technical and complex, but the general explanation is understandable to everyone.

Currently, air pollution within the park is higher than in most other national parks in the country. Because of this, scientists have identified the various major environmental threats, quantified many of the resource sensitivities and damages, and measured environmental conditions and changes over time. In response to the Clean Air Act and its amendments, and also through a variety of other Federal and State legislation and policies, air pollution levels in Shenandoah National Park have been steadily declining since monitoring began in the early 1980s. Great progress has been made. More progress is needed.

The effects of air pollution on streams, soils, and vegetation often accumulate over time, are only partially reversible, and may persist into the future for centuries. Such effects began about one hundred years ago and continue to unfold even as we reduce the atmospheric emissions that give rise to air pollution. The aquatic effects of **acidic deposition** (commonly called "acid rain") are complex and variable. Similar amounts of deposition have acidified some streams in the park and left others relatively unchanged. Some fisheries have been devastated and others unharmed. Effects are seasonal, and therefore levels of deposition that are not harmful to certain streams in the summer or fall have

Some plants, animals, algae, and fungi are known to be sensitive to damage from air pollution. The sensitivity of most species is not known.

caused substantial harm in the winter or spring when the more sensitive life stages of some fish species are present. Visibility degradation and the effects of **ozone** air pollution on plants are also highly variable. Visibility is often worst during summer when park visitation is high. Some plant species, and some forest types, are more vulnerable to ozone injury than others. In some cases, effects entail gradual shifts in the relative abundance of the most sensitive species that suffer damage as well as the more tolerant species that eventually replace them. Such subtle changes can develop over many decades.

Many small streams in Shenandoah National Park are very sensitive to damage from air pollution.

It would not be possible to tell the story of air pollution effects in Shenandoah National Park without having access to measurements (data) from the various national and local monitoring programs. Key monitoring programs relevant to air pollution and its effects in Shenandoah National Park are listed in the inset box below. Depending on the monitoring program, scientists have been measuring environmental conditions within the park since the 1980s or early 1990s, providing the foundation for determining current conditions, changes (trends) over time, seasonal and year-to-year variability, and the influence of other stresses, including climatic changes and disturbances such as those associated with forest insect infestations.

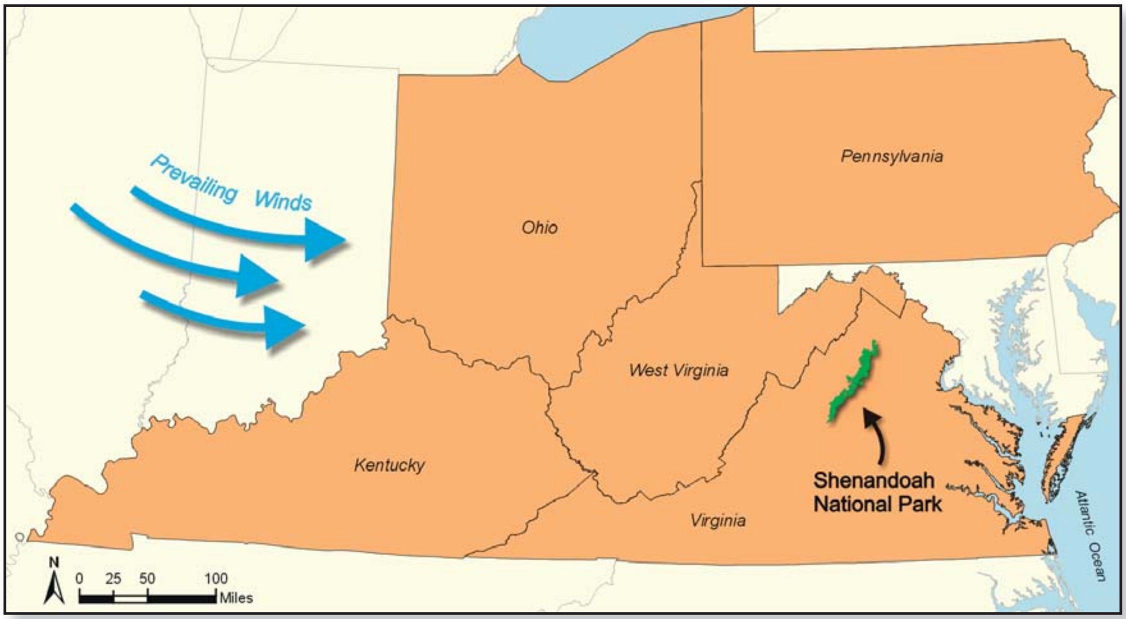
Shenandoah National Park receives some of the highest levels of air pollution (sulfur, nitrogen, ozone) of any national park. Over 20 years of scientific research and monitoring have shown that, despite some improvements, the park's sensitive scenic, vegetative, and aquatic resources remain degraded by human-made air pollution. Under the Clean Air Act, the National Park Service has a responsibility to protect sensitive resources in the park from the adverse effects of air pollution. Therefore, park managers assembled a team of leading scientists in 2000 to conduct a comprehensive, state-of-the-science assessment of Shenandoah's air quality, sensitive resources, and associated environmental impacts. The *2003 Assessment of Air Quality and Related Values in Shenandoah National Park* addresses the park's visibility, vegetation, soils, streams, fish, and aquatic insects, as well as the human-made air pollutants that most affect them. We wish to communicate those scientific findings to all of you, the park visitors and admirers of this great national park. Important findings from that assessment are summarized by major topic, and the full report is available from the National Park Service website at http://www.nps.gov/nero/science/FINAL/shen_air_quality/shen_airquality.html.

Key Air Pollution Monitoring in Shenandoah National Park

- Wet acidic deposition - National Atmospheric Deposition Program/National Trends Network
- Dry acidic deposition and ozone - Clean Air Status and Trends Network
- Visibility - Interagency Monitoring of Protected Visual Environments
- Ozone - National Park Service ozone monitoring efforts
- Streamwater chemistry, soil and biogeochemistry - Shenandoah Watershed Study

Monitoring station to measure levels of air pollution and the amount and chemistry of the rainfall.

Clean air contributes to the scenic quality of vistas within the park.



Location of Shenandoah National Park in northwestern Virginia. The five states that are the most important contributors of air pollution in the park are colored orange.

FACTORS ASSOCIATED WITH AIR POLLUTION

Emissions and General Air Quality

Air pollution in Shenandoah National Park at any given time can be attributed to a mix of pollutants emitted from pollution sources within the park itself, within Virginia, and within the larger region (see box below). Most of the park's air pollution originates outside park boundaries. Use of the atmospheric transport **model** RADM (Regional Acid Deposition Model; see mathematical model box on page 4), showed that the major source areas of atmospheric emissions of sulfur and nitrogen that impact sensitive resources within the park are located in the Ohio River Valley, northeastern West Virginia, southwestern Pennsylvania, and central and eastern Virginia. The effects on the park of individual emissions sources depend on the size and location of the source relative to prevailing wind patterns. Emissions sources within about 125 miles (200 km) cause proportionately greater impacts than more distant sources.

The states that contribute most to sulfur and nitrogen air pollution in Shenandoah National Park include West Virginia, Ohio, Virginia, Pennsylvania, and Kentucky (see adjacent graphic). Their importance as contributors of air pollution to the park depends on prevailing air movement patterns, the number and size of emissions sources in each state, and travel distances from source locations to the park. Other, somewhat less important (less than 10% each) contributors include Tennessee, Maryland, Indiana, North Carolina, and Illinois.

Emissions of sulfur upwind from Shenandoah National Park have been gradually decreasing since the early 1980s. In contrast, emissions of nitrogen have been relatively constant over that period of time, but began to decline in about 2000. In 1996, the total emissions from the top 10 contributing states were about 9 million tons of sulfur dioxide and 8 million tons of nitrogen oxide.

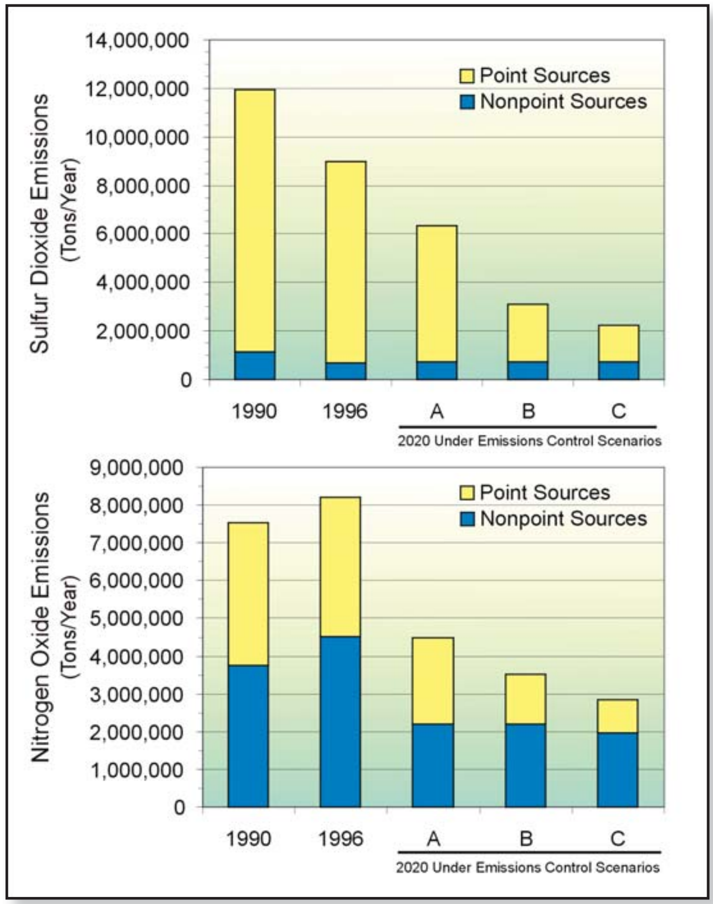
Emissions

Natural resources and valued scenic beauty in Shenandoah National Park can be affected by emissions into the atmosphere of a variety of pollutants, the most significant of which are sulfur (generally emitted as sulfur dioxide) and nitrogen (generally emitted as nitrogen oxides and ammonia). Both sulfur and nitrogen can contribute to acid rain. Nitrogen oxides are important contributors to the formation of ozone, which can affect human health and damage plants. Sulfur is an important contributor to haze and other types of visibility impairment.

About 90% of the sulfur dioxide emissions from the 10 states that contribute most to air pollution in Shenandoah National Park is derived from what are called **point sources**. These are mostly coal-fired electricity-generating facilities and industrial facilities. The other 10% of sulfur dioxide emissions is from what are called **nonpoint sources**. These include millions of scattered small sources, such as cars, trucks, construction and farm equipment, and various engines and machinery.

Whereas most of the sulfur dioxide pollution at Shenandoah National Park is derived from large point sources such as power plants and industrial facilities, much of the nitrogen oxide and ammonia nitrogen pollution at the park is derived from small, scattered nonpoint sources. Fuel combustion in cars, trucks, and heavy equipment, as well as point source emissions, are the principal sources of nitrogen oxide emissions into the atmosphere. Agriculture (mainly animal manure and fertilizer) is the principal source of ammonia emissions.

In general, emissions and associated air pollution levels are expected to decline in the future in response to emissions controls regulations. As the Assessment report was being developed in 2002, scientists worked with park staff to develop three scenarios (A, B, and C) of future pollution emissions controls. These scenarios ranged from controls that are expected to occur in response to already-enacted and pending (as of 2002) Federal and State legislation to very aggressive increased emissions controls on power plant, industrial, and mobile (including motor vehicle) air pollution sources. Scenario A provided the best estimate of emissions expected in the year 2020 due to regulations that were in place prior to 2002. It is expected that air pollution levels will continue to decline in response to those existing rules, as well as more recent rules. Scenario B added additional, more stringent controls on coal-burning electricity-generating facilities in order to reduce their sulfur dioxide emissions by an additional 90% compared with previously-existing requirements. Scenario C incorporated the more stringent controls of Scenario B plus an additional 50% reduction in sulfur dioxide emissions from other industrial point sources and mobile sources such as cars and trucks. It is expected that The U.S. Environmental Protection Agency's (EPA) 2005 Clean Air Interstate Rule (CAIR) will reduce nitrogen



Emissions of sulfur dioxide (top panel) and nitrogen oxide (bottom panel) within the 10 states that contribute most to air pollution in Shenandoah National Park. Emissions are shown in units of million tons of sulfur dioxide or nitrogen oxide emitted into the atmosphere per year for the years 1990 and 1996, with estimates for 2020. The estimates for 2020 are based on three different scenarios (labeled as A, B, and C) of future emissions control.

and sulfur emissions to midway between scenarios A and B. CAIR applies to emissions from electricity-generating facilities in eastern states, including the states responsible for much of the air pollution impact in Shenandoah National Park.

Scenarios A through C result in reduced emissions of sulfur dioxide in 2020 that range from 47% to 81% reductions, compared with 1990 values. Reductions in nitrogen oxide emissions under these scenarios ranged from 41% to 62% of 1990 values (see graphic above).

Ozone

Of all national parks, the air in Shenandoah National Park has among the highest measured concentration of ozone that can adversely affect human health and vegetation. During the period 1997 through 2001, the time frame upon which the assessment report was based, the park's air quality did not meet EPA's ozone standard to protect human health and welfare.

Mathematical Models

The environmental systems within Shenandoah National Park that are sensitive to air pollution damage are highly complex. A change in one part of an ecosystem often triggers changes to other parts. Because of this complexity, environmental scientists frequently employ mathematical models to predict ecosystem response to changing conditions. These models approximate key processes and ecosystem components as mathematical equations. As such, the models oversimplify highly complex natural systems. Nevertheless, a well-designed model represents state-of-the-art scientific knowledge about the ecosystem and how it would be expected to respond to changes in future conditions.

Within the Shenandoah National Park Assessment, the assessment team used several common models to predict future ecological responses to changing levels of air pollution:

- RADM models pollutant transport through the atmosphere and deposition to the earth surface,
- MAGIC models soil and streamwater chemistry,
- TREGRO models individual plant response, and
- ZELIG models forest community response.

Predictions using these models cannot be accepted with absolute certainty. But the models represent cumulative scientific knowledge gained through several decades of environmental research, and the model predictions therefore can be interpreted as realistic estimates, given current scientific uncertainties.

Scientists are now using such models to estimate the **critical load** of sulfur deposition for sensitive streams in Shenandoah National Park. Knowledge of the level of deposition load at which ecological effects begin to occur will allow resource managers to set interim emissions and deposition targets to allow for recovery from past acidification damage.

During winter, sensitive streams in Shenandoah National Park often have lower acid neutralizing capacity than at other times of the year. Also, the most sensitive life stages of some fish are present during winter.

Scientists have found that some sensitive plants in natural ecosystems may be injured at ozone levels of 8 to 12 parts per million-hour (a common unit for measuring ozone concentration in air) of a measurement that scientists call SUM06; a level of 25 parts per million-hour was suggested as a standard that would provide increased protection for many ecosystems where ozone levels are very high. The average cumulative ozone exposure at Big Meadows, a monitoring station in Shenandoah National Park, during the late 1990s was almost twice this 25 parts per million-hour threshold value. During the 1990s, ozone pollution levels in the park generally showed an increasing trend. Over the following several years, ozone concentrations stabilized.

Acidic Deposition

Sulfur and nitrogen air pollutants are deposited to the ground surface by a process called acidic deposition. This transfer is measured in units of kilograms (kg) per hectare, which reflects the mass (of sulfur for example) that is deposited over a given area of earth surface over the course of one year.

Several networks operate monitoring sites throughout the United States to measure atmospheric pollutant concentrations and wet and dry deposition of pollutants from the atmosphere to the earth surface. One such monitoring station is located at Big Meadows. Based on monitoring data from this site, the park has among the highest measured deposition of both sulfur and nitrogen of all national parks. Sulfur deposition in the park peaked sometime during the 1970s or early 1980s and has been declining steadily since then (see box on page 6). Nitrogen deposition was high throughout the 1980s and 1990s, but shows some indication of decline since 2000. Sulfur deposition has been high enough to cause the **acidification** of many streams within the park, with associated harmful impacts on fish, aquatic insects, and other life forms. Nitrogen deposition has been only a minor contributor to stream acidification. Based on a mathematical model of air pollutant transport and deposition, it is expected that deposition of both sulfur and nitrogen will decrease further in the future in response to emissions reductions required by amendments to the Clean Air Act, the newly approved Federal CAIR emissions controls rule, and other Federal and State legislation.

EFFECTS OF POOR AIR QUALITY

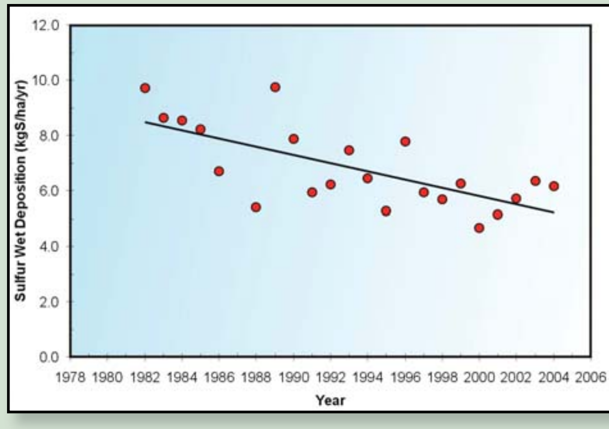
Stream Water and Stream Organisms

Scientists estimate the sensitivity of a stream to potential acidification and also the degree of streamwater acidification or recovery that occurs over time using a measurement that is called the **acid neutralizing capacity**, or **ANC**. ANC reflects the ability of water in the stream to neutralize strong **acid**. Strong acid can be added in the form of sulfate or nitrate, each of which can be contributed to a **watershed** by air pollution in the form of sulfur or nitrogen deposition, respectively. ANC values can be positive or negative. Streams that have ANC below zero microequivalents per liter (a common unit of chemical concentration) during the spring season when it has not been raining are defined as chronically "**acidic**." Streams having spring ANC less than 50 microequivalents per liter are generally considered potentially "sensitive" to acidification. Those having higher ANC are generally considered less sensitive or insensitive. When ANC is low, and especially when it is negative, streamwa-

Acidic Deposition

The old adage "what goes up must come down" doesn't necessarily hold true for all air pollutants, but it works pretty well for sulfur and nitrogen, the two major contributors to acidic deposition. Emissions of sulfur and nitrogen from point and nonpoint air pollution sources eventually fall out of the atmosphere and land somewhere on the earth's surface. Although we commonly call this transfer "acid rain," rain only accounts for part of the transfer. Atmospheric pollutants move to the ground within Shenandoah National Park in rain, snow, clouds, and as dry particles and gases. Scientists refer to the overall transfer process as acidic deposition, which can be broken down into wet, dry, and cloud components. Wet deposition has been monitored at Big Meadows within Shenandoah National Park for over 20 years by continuously collecting and analyzing samples of rain and snow. Dry and cloud deposition are more difficult to measure and are often estimated as a fraction of measured wet values. In Shenandoah National Park, dry deposition can be estimated from measurements of pollutant concentrations in the air, assuming a rate of transfer from the air to the earth surface.

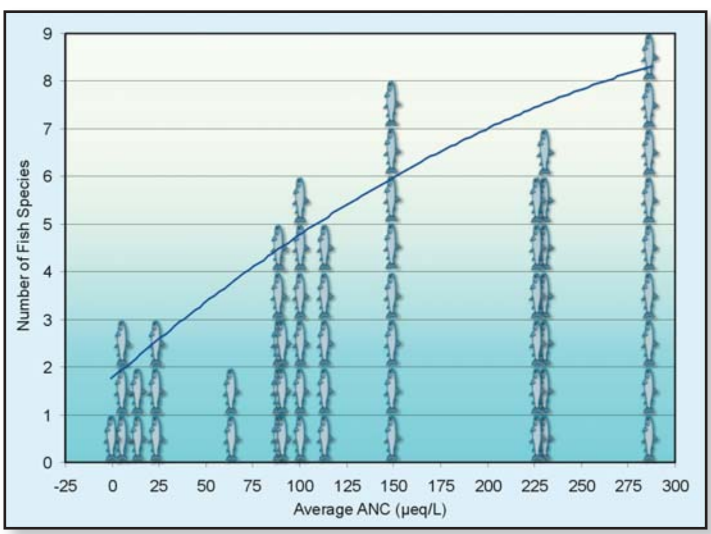
Wet, dry, and cloud deposition of sulfur or nitrogen to any part of a watershed can potentially lead to the movement of that element through the watershed soil and into a stream. Along the way, the sulfur or nitrogen can contribute to a variety of ecological effects, including acidification of soil and water and depletion of important plant nutrients, such as calcium and magnesium, found in the soil.



This graph shows wet sulfur deposition for the period of record at the Big Meadows monitoring station in Shenandoah National Park. Total sulfur deposition, including both wet and dry forms, is probably at least one and a half times these measured wet-only values. Sulfur deposition in the park has decreased by about a third over the past two decades in response to emissions control legislation.

ter **pH** is also low (less than about 5 to 6), and there may be adverse impacts on fish and other life forms that live in the stream. A low pH measurement means that the level of acidity is high. For example, lemon juice, with pH below 3, is very acidic, whereas milk, with pH above 6, is not.

The process of decreasing ANC over time is called "acidification." The capacity of a watershed to resist decreases in ANC, and associated decreases in streamwater pH, is determined mainly by the relative amounts of **base cations** (positively charged ions), such as calcium, compared with acidic anions (negatively charged ions), such as sulfate and nitrate, in the water. The base cations are mostly derived from the soils and ultimately from the rocks that decompose to form those soils.



Results of the Shenandoah Watershed Study show that the number of fish species found in 13 park streams is correlated with average stream ANC. Each stacked fish bar represents one stream, and each fish represents one species. Streams having low ANC host fewer species of fish than streams having higher ANC. Streams having ANC consistently below 75 microequivalents per liter (μeq/L) had three or fewer species, in part because acidification has eliminated the more sensitive species.

The sensitivity of streams in the park to acidification from acidic deposition is determined mainly by the types of rocks found beneath the stream and the characteristics of the watershed soils that surround it. Effects can be complicated. As an example, in very general terms, the geology controls soil characteristics which interact with precipitation and air pollution to determine water chemistry, which affects fish. If the underlying geology is **silica**-based, the soil and water in the watershed will have poor ability to neutralize acids deposited from the atmosphere. About one-third of the streams in the park are located on this type of geology. Model estimates using the watershed model MAGIC (Model of Acidification of Groundwater in Catchments) suggest that such streams have typically lost most of their natural ANC, largely in response to a century of industrial emissions and acidic deposition. As a consequence, stream pH values in many streams are low, especially during winter and spring. Prior to human-caused air pollution, most streams in Shenandoah National Park probably had pH above about 6. Many park streams currently have pH as low as about 5. A stream with a pH of 5 contains 10 times more acidity than does a stream with a pH of 6.

The effects of acidic deposition on Shenandoah National Park streams have been studied for over 25 years by the Shenandoah Watershed Study, the longest-running watershed study program in any of the national parks (see http://swas.evsc.virginia.edu and adjacent graphic). This program has determined

Threats to Aquatic Ecosystems

Brook trout in their natural habitat, from oil painting by Deian Moore.

There are 34 fish species found in various park streams, 13 of which are common and widely distributed. These fish differ in their sensitivity to acidification. Some are harmed at pH values below about 6, whereas others are tolerant of pH values near 5. In addition to such differences among species, there are differences in tolerance among life stages of an individual species. In general, eggs and immature forms are more sensitive than adult fish. Thus, rather low-level acidification impacts can interfere with fish reproduction and cause a gradual decline in fish abundance over time, as opposed to a rapid die-off of adult fish.

Acidification poses a threat to the three trout species found in park streams: brook, brown, and rainbow trout. Particular concern has been expressed about impacts on brook trout, the least sensitive of the three, because this species is native to Appalachian Mountain streams, whereas brown and rainbow trout have been introduced from elsewhere. Other fish species, although perhaps not as well known to park visitors, are also sensitive in varying degrees to stream acidification. These include various species of dace, chub, sculpin, darter, and bass.

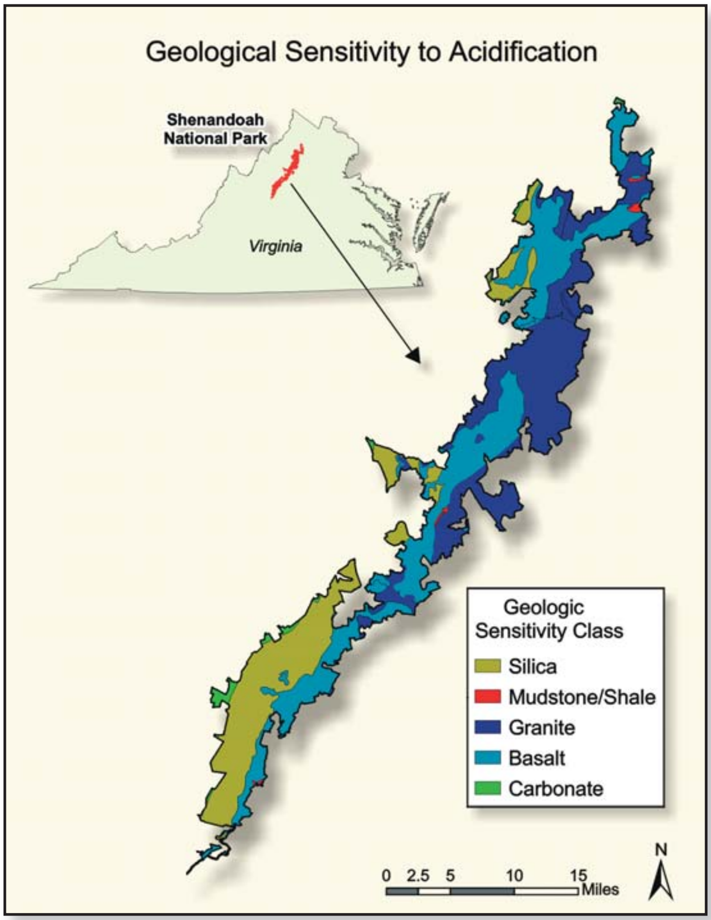
Many species of small aquatic animals known as **benthic macroinvertebrates** occur in park streams. They exhibit a wide range of sensitivity to acid conditions. These stream bottom animals have been monitored within the park for about two decades. Of particular importance to the ecology of the streams are the aquatic insects. They play critical roles in the breakdown of leaves and other organic materials in the stream and provide food for fish and other members of the food web. Mayflies, caddisflies, and stoneflies are groups of insects that are important food sources for brook trout, are of great interest to fly fishers, and tend to be very sensitive to acidification.

that the high rate of atmospheric deposition of sulfur, combined with naturally low contributions from some rock types of calcium and other base cations (that serve to neutralize acidity), is the most important cause of low streamwater ANC in many park streams. Some park streams can also become temporarily acidic for short periods (hours to days) during rainstorms or snowmelt. This is termed “episodic acidification” and, like chronic acidification, can harm aquatic life. During rainstorms or snowmelt, ANC decreases in response to changes in the concentrations of chemicals dissolved in streamwater.

The acidification of streams in the park is linked to effects that are occurring in the watershed soils. Over time, the ability of soils to adsorb sulfur, thereby effectively negating sulfur’s potential to acidify water, is decreasing. In addition, the amount of stored calcium and magnesium in the soil is gradually declining in response to acidic deposition. Therefore, streams are expected to acidify more in the future than they have so far, relative to the amount of acidic deposition received. This means that the effects of acidic deposition are not totally reversible, and that some damage may persist even if we stop all air pollution inputs today.

This prognosis is consistent with recent analysis of national lake and stream response to reductions in air pollution emissions. Unlike a number of other regions of the country, streams in the region that includes Shenandoah National Park are generally not recovering from acidification.

Low values of ANC and pH can harm biological resources in the stream, including fish and aquatic insects (see box above). MAGIC model simulations suggest that acidic deposition would have to be decreased substantially in order to improve and maintain acid-sensitive streams at levels of ANC that would be expected to protect against ecological harm. In addition, it took a long time for these streams to acidify in the past; because of complexities related to soil conditions, it will take even longer for them to recover in the future. In order to protect against chronic acidity in the year 2100, with associated probable lethal effects on brook trout, sulfur deposition to the most sensitive silica-based watersheds in the park will have to be kept below about 9 kg per hectare (8 lb/acre) per year for the next 100 years. Prior to the industrial revolution, most streamwater in the park had ANC higher than about 50 microequivalents per liter. In order to promote ANC recovery



Map of Shenandoah National Park, showing that there are five types of geology in the park. Only three are common; they are dominated by rocks composed largely of silica-based materials, granite, or basalt. These rock types that underlie a watershed have a major influence on the sensitivity of soils and stream water to acidification. Silica-based rocks produce little calcium when they break down, and therefore provide little buffering of the acidity in acidic deposition. As a consequence, soils and streams on these rock types tend to be acid-sensitive. Soils and streams on granite rocks are occasionally acid-sensitive. Those on basalt are not sensitive.

to 50 microequivalents per liter in the future, to protect against general ecological harm, sulfur deposition to silica-based watersheds in the park will have to be kept below about 6 kg per hectare (5.3 lb/acre) per year. Some watersheds will likely not recover streamwater ANC to values above 50 microequivalents per liter over the next century even if sulfur deposition is reduced to zero. Total sulfur deposition during the period 2002 to 2004 was about 9 to 12 kg per hectare (8-11 lb/acre) per year.

Model estimates suggest that substantial reductions in sulfur deposition would result in biological improvements in many of the streams found on silica-based geology (see map above). Such projected improvements would include the return of one to two species of fish to the streams, improved conditions for brook trout and a fish species called blacknose dace, and increased numbers of species of aquatic insects (mayflies, caddisflies, and stoneflies).

Visibility

Visibility can be defined in different ways related to how well or at what distance a human can see a distant object clearly. The concept, and therefore definition, of visibility also involves value judgments of an observer viewing a scenic vista. Thus, visibility is associated with conditions that allow appreciation of the inherent beauty of landscape features.

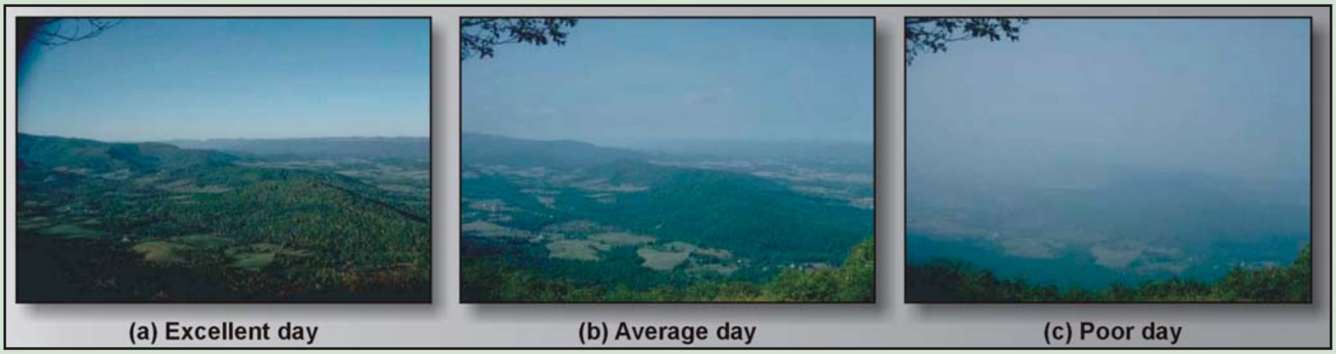
Visibility can be degraded by both natural processes and human activities. Smoke from fires, blowing dust, and even humidity influence visibility conditions, as do several forms of air pollution. Visibility degradation is caused by the scattering and absorption of visible light by gases and particles in the atmosphere. Some light scattering occurs from natural air molecules, and this is responsible for the blueness of the sky. Too much light scattering causes haze, which obstructs our ability to see. In a park such as Shenandoah National Park, with its exceptional scenic beauty, haze can be a major problem which affects people's enjoyment of the park.

Visibility is currently degraded throughout the park, detracting from visitor enjoyment of scenic vistas, especially along Skyline Drive, which is designated a Virginia State Scenic Highway. These scenic vistas are also enjoyed by visitors hiking the Appalachian National Scenic Trail through the park (see box on page 9). The current annual average **visual range** is approximately 23 miles (37 km). This is only about 20 percent of the estimated natural visual range of about 115 miles (185 km). Even the mean of the clearest 20 percent of days, which occur mostly in winter, are degraded by human-made particles in the air. Changes in visibility over time are mainly caused by changes in the concentration of tiny particles of ammonium sulfate in the atmosphere. Atmospheric ammonium sulfate is primarily derived from human sources of air pollution.

In 1977, Congress passed a law that established a national goal of no human-caused visibility impairment in national parks and wilderness areas that are classified as requiring the

Spectacular mountain scenery is a fundamental aspect of the visitor experience in Shenandoah National Park. Pollutants can degrade visibility and impact visitor enjoyment.

Effects of Air Pollution on Visibility



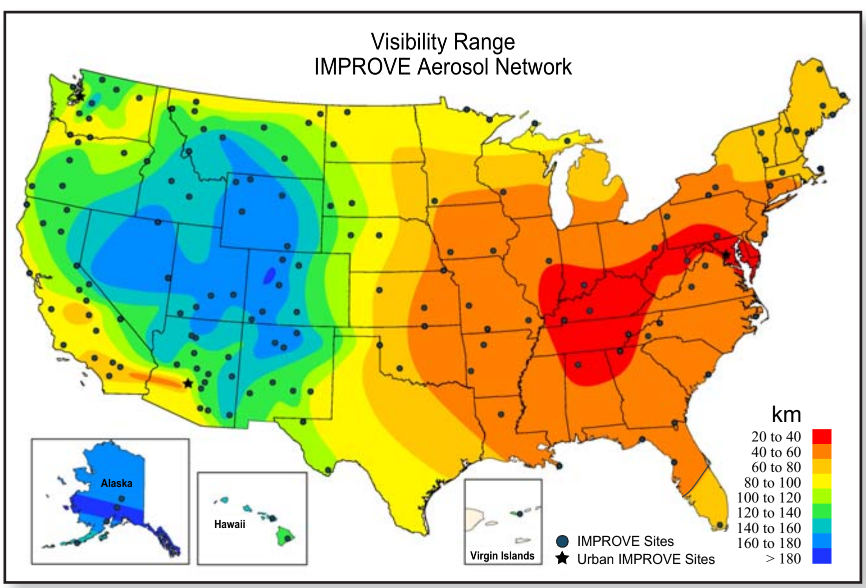
Photographs illustrating visibility conditions at the Dickey Ridge vista in Shenandoah National Park. The left photograph shows visibility on an excellent day; the middle photograph illustrates an average day; and the right photograph a poor day.

The pollutants that contribute to light scattering differ depending on whether we are considering particle pollution or gas pollution. Light scattering by particles depends on the size and chemical composition of those particles. Important light-scattering particles in the atmosphere at Shenandoah National Park include sulfates, nitrates, organics, soil (dust), and soot. The only important light-scattering gas in the park is nitrogen dioxide.

Scientists use several measurements to quantify visibility conditions and degradation. These include the light extinction coefficient (attenuation of light per unit of distance traveled), visual range (greatest distance that a large black object can be seen), and the haziness index (a reflection of a human's ability to perceive changes in visibility). Although scientists generally prefer to work with the extinction and haziness measurements, visual range is perhaps more easily understood. If you cannot see across a valley to distant horizons, your visual enjoyment of park vistas may be reduced.

highest level of protection. These areas were designated as **Class I areas** and they include Shenandoah National Park. In 1999, Congress approved a rule requiring states to develop and carry out plans to make continuous progress toward that goal of zero human-caused visibility impairment, using a measurement of visibility called the **light extinction** coefficient as the basis for demonstrating progress.

Assessment of progress toward the national goal requires atmospheric particle monitoring, which is accomplished through the IMPROVE (Interagency Monitoring of Protected Visual Environments) program (see map below). This effort involves monitoring of fine and coarse particles in air samples, optical monitoring to measure light extinction, and view monitoring using photography.



Average 3-year visibility in the United States, represented as standard visual range in kilometers. Visibility is limited throughout the southeastern United States, including the area of Shenandoah National Park.

One IMPROVE monitoring station has been located within Shenandoah National Park for many years. Overall, there has been little change in recent average visibility conditions. However, when the days were split into groups based on haziness conditions, the haziest 20 percent of days did show some degree of improvement between 1988 and 2000, but the clearest 20 percent of days did not. This result suggests that some progress has been made in recent years toward improving visibility.

Plants

There are two aspects of air pollution that can potentially affect the growth and health of plants within Shenandoah National Park: trophospheric (or ground-level) ozone and soil acidification. Ozone is formed when pollutants from cars, power plants, and other sources react chemically in the atmosphere in the presence of sunlight. Ozone is a concern during the summer

Illustration of injury caused by ozone on a yellow poplar leaf at Shenandoah National Park.

months when there are many hours of sunlight and when weather conditions occur which help to form ozone. Ozone-causing pollutants can originate from various distant pollution sources and be transported to the park by regional weather systems and events (see box below).

Ozone causes visible injury to the leaves of some plant species in the park, including milkweed and at least three tree species: black cherry, yellow poplar, and white ash (see illustrations above and below). Scientists have observed injury to leaf tissues of some plant species at levels of ozone exposure measured during the 1990s. Such injury is seen as dark or light mottling on the leaf surface. However, even though such injury to plant leaves has been observed, scientists are less certain how this visible injury to foliage might directly damage the growth or vitality of the affected plants.

The mathematical model TREGRO (Tree Growth: Response of Plants to Interacting Stresses) simulates the effects of ozone on individual trees. This model estimated that ozone exposure measured in the 1990s reduced the growth of the highly-sensitive white ash trees by about 1 percent over a short time period of three years.

There are several kinds of forests within the park. Three forest types are especially sensitive to the effects of ozone on tree species composition within the forest: chestnut oak, cove hardwood, and yellow poplar forests. Long-term (100-year) model simulations using the model of forest stand response ZELIG (ZELIG Tree Simulator Model) suggested a 50 percent decrease in the abundance of white ash trees in chestnut oak forests within the park if ozone exposure continued at levels measured during the period 1997 through 1999. The abundance of white ash trees was also projected to decrease in cove hardwood and yellow poplar forests. According to the ZELIG model simulations, a 15 percent decrease in future atmospheric ozone concentrations in the park compared with pre-2000 values would be required to protect against such changes in tree species composition.

The white ash tree is likely the most sensitive to ozone damage of all tree species in Shenandoah National Park.

Ozone is not the only air pollutant that can stress forest ecosystems in Shenandoah National Park. Acidification of soils from sulfur and/or nitrogen deposition can affect forest health. Effects include depleting forest soils of their stored calcium reserves, lowering the pH of soil water, and causing the movement of aluminum from solid soil into soil water. Each of these changes can harm the health of sensitive plants. However, based on what is known about such acidification effects on forests, scientists believe it is unlikely that the typical deciduous forests found in Shenandoah National Park have experienced sufficiently high deposition of sulfur or nitrogen to cause widespread forest damage. Nevertheless, more subtle effects on high-elevation and isolated coniferous forests and/or effects on highly-sensitive **herbaceous plant** species cannot be ruled out at this time.

Creation and Measurement of Ozone

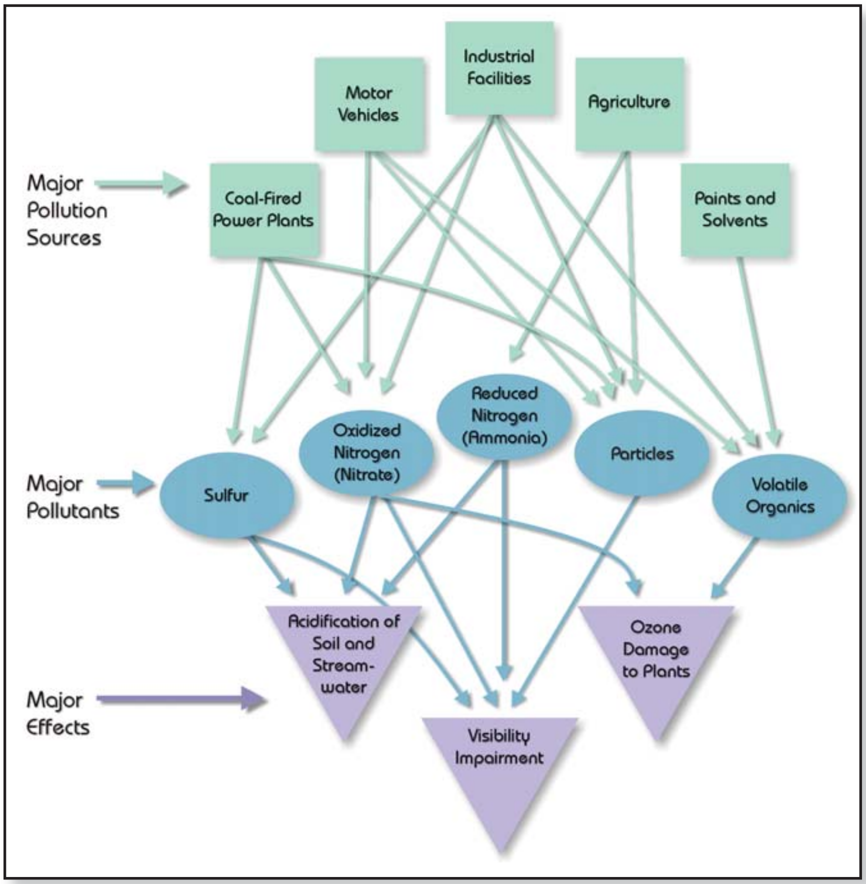
Ozone pollution is not caused by ozone emissions. Rather, ozone at Shenandoah National Park actually forms in the atmosphere in or on its way to the park.

Ozone in the troposphere (atmosphere near ground level) forms by interactions of sunlight with two different kinds of atmospheric pollutants: nitrogen oxides and volatile organic compounds (VOCs). The nitrogen oxides are the same pollutants, largely emitted from motor vehicles and point sources, that can contribute to acid rain. The VOC category of pollutants includes thousands of different organic compounds that can be volatilized (converted to gas form). Important human-caused sources of VOCs include motor vehicle exhaust, gasoline vapors, and vapors from paints, solid waste, and various commercial and industrial processes. Vegetation also emits natural organic compounds that participate in the formation of ozone.

Ozone near ground level is considered a pollutant. However, ozone in the upper atmosphere (stratosphere) provides an important protetctive function by blocking some of the sun's ultraviolet radiation.

Formerly, the national standard to protect human health and welfare from possible ground level ozone damage was based on the average concentration measured over a period of one hour. This standard was revised in 1997 to an average measured over an eight-hour period. This change was based on research indicating that prolonged exposure to ozone at concentrations lower than the one-hour standard could have significant impacts on human health. Ecological research has further indicated that exposure to ozone over much longer periods of time, perhaps months or seasons, might be more relevant to vegetation injury and damage than the eight-hour standard applied for the protection of people. One such index of long-term exposure is called the SUM06 (sum-oh-six). It is computed by adding only the hourly ozone measurements that are very high (above 60 parts per billion) during the times that plants are photosynthesizing (daylight hours between May and September). The U.S. Environmental Protection Agency, a Federal agency having policy and pollution regulatory responsibility, plans to focus additional research on the question of cumulative impacts and then reevaluate in the future the possible need for a seasonal cumulative exposure index such as SUM06 to protect plants from ozone injury and damage. This is a good example of how scientific research and public policy are linked. Scientists will never know all of the answers to critical questions. But as scientists learn more about a particular issue, Federal and other governmental policy could be changed.

Conclusions and Prognosis for the Future



Overview of the most important sources of air pollution in Shenandoah National Park, the associated pollutants of greatest concern, and major kinds of environmental effects. Note that there are also other pollutants of possible concern that are not discussed here. Also, some pollutants can affect human, as well as environmental, health.

CONCLUSIONS AND PROGNOSIS FOR THE FUTURE

Conclusions

As described in this booklet, there are a variety of air pollutants that affect Shenandoah National Park. Human activities are responsible for a large part of the emissions into the atmosphere of these pollutants. Each type of pollutant is associated with one or more effects on park resources (see graphic above). Model estimates and scientific judgments of the effects of air pollution on sensitive resources within Shenandoah National Park reveal a mixed picture.

The good news for the park is that:

- Atmospheric deposition of sulfur to park watersheds has been declining for two decades and continues to decline. Existing Federal and State rules and regulations are expected to result in further reductions in sulfur and nitrogen deposition in the near future.
- Ozone air pollution within the park is declining, and it is expected to continue to decline.
- Only some of the aquatic and terrestrial resources in the park are sensitive to existing air pollution levels, and many remain largely unaffected.
- Visibility on the haziest days is improving.

The bad news is that:

- The park still experiences some of the highest air pollution levels of any national park in the United States.
- Despite some recent improvements, Shenandoah National Park still experiences levels of acidity in many streams that are harmful to many species of fish and aquatic insects.
- Continued exposure of park vegetation to high atmospheric ozone levels will cause damage to plant foliage and a gradual decline in the abundance of the more sensitive plant species.
- Some of the damages that have occurred to soils and aquatic ecosystems are only partially reversible over the next century.
- In order to restore park resources to relatively clean conditions, further reductions in regional emissions of air pollutants will be required.

Prognosis

Application of emissions controls scenarios (A, B, and C) to the effects models resulted in projection of a range of future conditions. In general, however, the modeling suggested that resource conditions will deteriorate in the future if sulfur and nitrogen emissions remain high. Projected future improvements in resource conditions were generally proportional to the level of emissions reductions achieved.

Animals depend on plants that can be affected by air pollution. All parts of the ecosystem are connected.

Model results estimated that Scenario A would contribute to:

- additional large decrease in the ANC of many streams,
- small further decrease in the number of fish species in some streams,
- continued leaf injury on sensitive plant species from ozone exposure,
- long-term decrease in the growth of white ash trees, and
- lack of progress towards the national visibility goal.

In contrast, modeling results for Scenario B suggested modest improvement in all of these effects areas. More substantial improvement would be expected under Scenario C.

We, as a nation, must continue to make important decisions concerning what levels of air pollution are acceptable. The future of Shenandoah National Park, and other highly-valued natural areas, will be affected by the decisions we make. If you would like to learn more about air pollution and its effects in Shenandoah National Park, there are many books, scientific reports, and journal articles available on this topic. For some general sources of information, see the short list of titles in the box below.

Scientists are working to better understand the subtle effects of air pollution on the ecosystems found in the park.

Some Sources of Additional Information about Air Pollution and its Effects in Shenandoah N.P.

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Shenandoah Watershed Study: http://swas.evsc.virginia.edu
IMPROVE: http://vista.cira.colostate.edu/improve/
EPA-Air Quality trends: http://www.epa.gov/airtrends/
Shenandoah National Park: http://www.nps.gov/shen
EPA Air Quality forecasts: http://airnow.gov/

Some Useful Terms and Their Definitions

ACID - a compound which has extra hydrogen ions (protons); lemon juice is a well-known example.
ACIDIC - for this publication, streamwater is defined as being acidic if it has acid neutralizing capacity less than zero.
ACIDIC DEPOSITION - transfer of acids and acidifying compounds from the atmosphere to the ground and eventually to stream waters via rain, snow, sleet, hail, cloud droplets, particles, and gas. Commonly called "acid rain."
ACID NEUTRALIZING CAPACITY (ANC) - capacity of a stream or lake to neutralize added strong acids, such as from acidic deposition.
ACIDIFICATION - decrease of acid neutralizing capacity, and usually also pH, of water.
BASE CATION - an alkaline earth metal cation, such as calcium, magnesium, potassium, or sodium. These are carried in soil water from soil to streamwater, and act to neutralize the acidity in acidic deposition.
BENTHIC MACROINVERTEBRATE - animal without a backbone that can be seen with the unaided eye and that is found on the bottom of a stream, for example attached to a stone in the streambed. This term includes the immature (larval) forms of many insects.
CLASS I AREA - national park or wilderness area that receives the highest level of Federal protection from air pollution under the Clean Air Act.
CRITICAL LOAD - atmospheric deposition load (or amount) that will cause ecological damage to a sensitive receptor, such as a stream, according to current scientific understanding.
HERBACEOUS PLANT - small non-woody plant species, including various kinds of wildflowers.
LIGHT EXTINCTION - a measure of how much light is attenuated (scattered, blocked, or absorbed) as it moves through air.
MODEL - mathematical representation of an ecosystem or set of ecosystem processes.
NONPOINT SOURCE - relatively small and diffuse source of pollution, such as motor vehicle, farm, or residential area.
OZONE - molecule comprised of 3 oxygen atoms. It is detrimental to human health and toxic to some plant species. In this context, we are discussing ozone in the atmosphere at ground level. Ozone is also an important compound in the upper atmosphere (stratospheric ozone) that helps to block ultraviolet radiation that causes sunburned skin.
pH - the negative logarithm of the hydrogen ion concentration in solution. The pH scale is generally presented from 0 (most acidic) to 14 (most alkaline); a difference of one pH unit indicates a ten-fold change in hydrogen ion activity. pH 7.0 is neutral.
POINT SOURCE - relatively large individual source of pollution, such as a power plant or industrial facility.
SILICA - hard, glassy mineral found in some geological formations, as in quartz and sandstone.
VISUAL RANGE - longest distance at which a large black object can be seen.
WATERSHED - the geographic area from which rainfall and snowmelt drain into a particular lake or point along a stream.

ACKNOWLEDGEMENTS

This booklet was prepared for Shenandoah National Park by E&S Environmental Chemistry, Inc. (E&S), Corvallis, Oregon. The content of the booklet was based on a technical assessment prepared by a multidisciplinary scientific team in 2003: *Assessment of Air Quality and Related Values in Shenandoah National Park*, by T. J. Sullivan, B. J. Cosby, J. A. Laurence, R. L. Dennis, K. Savig, J. R. Webb, A. J. Bulger, M. Scruggs, C. Gordon, J. Ray, E. H. Lee, W. E. Hogsett, H. Wayne, D. Miller, and J. S. Kern. The technical report was peer-reviewed by internal National Park Service (NPS) and external scientists.

E&S was assisted in this effort of preparing a booklet for public dissemination by members of the technical assessment team. Timothy Sullivan was responsible for writing and editing, and Deian Moore prepared graphics and was responsible for formatting and layout. The brook trout painting was done by Deian Moore (www.deianmoore.com). Draft versions of this booklet were reviewed by NPS scientists and external peer reviewers. Gordon Olson provided guidance and NPS project management.

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U.S. Department of the Interior

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