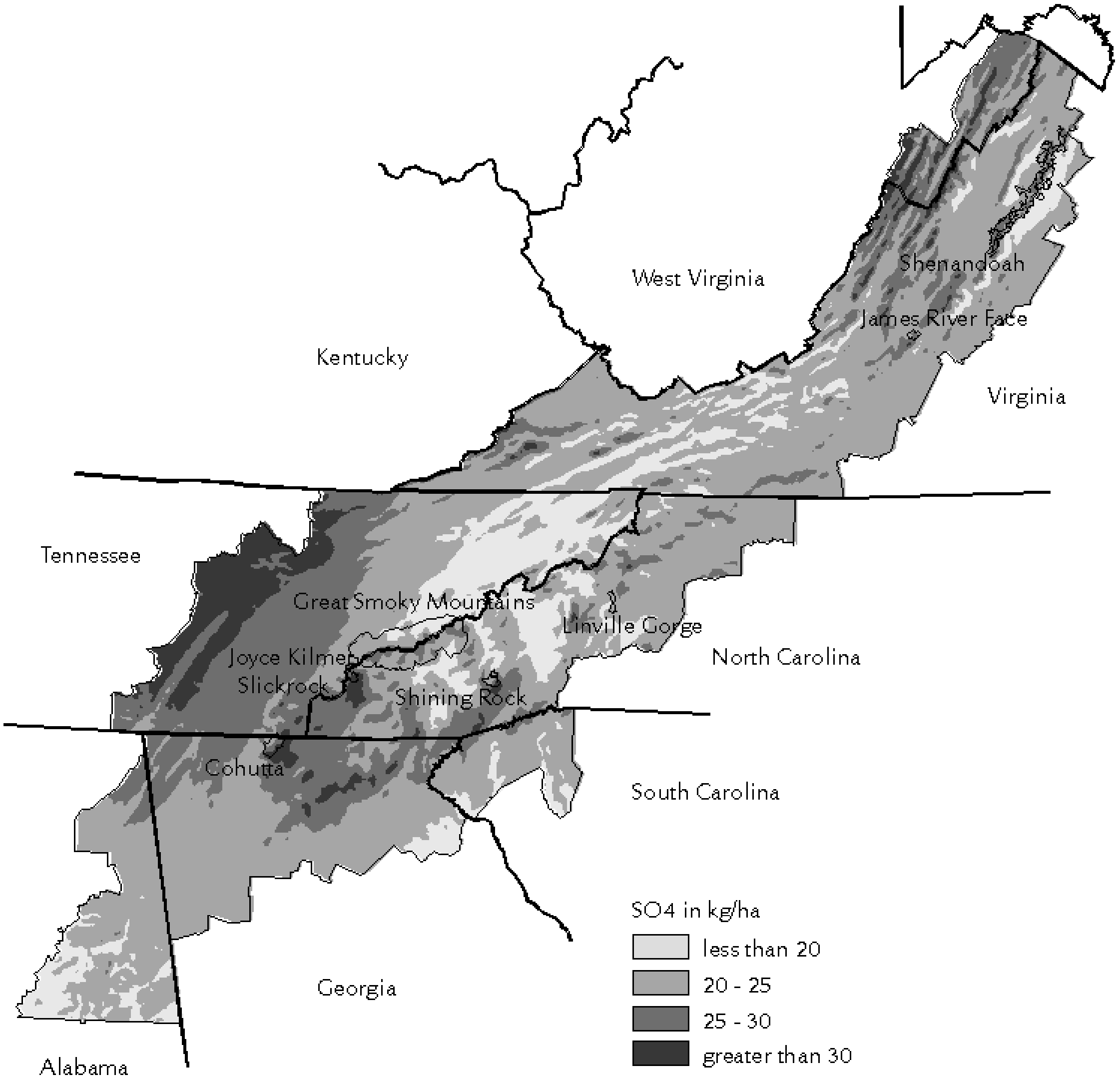

AT501

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.

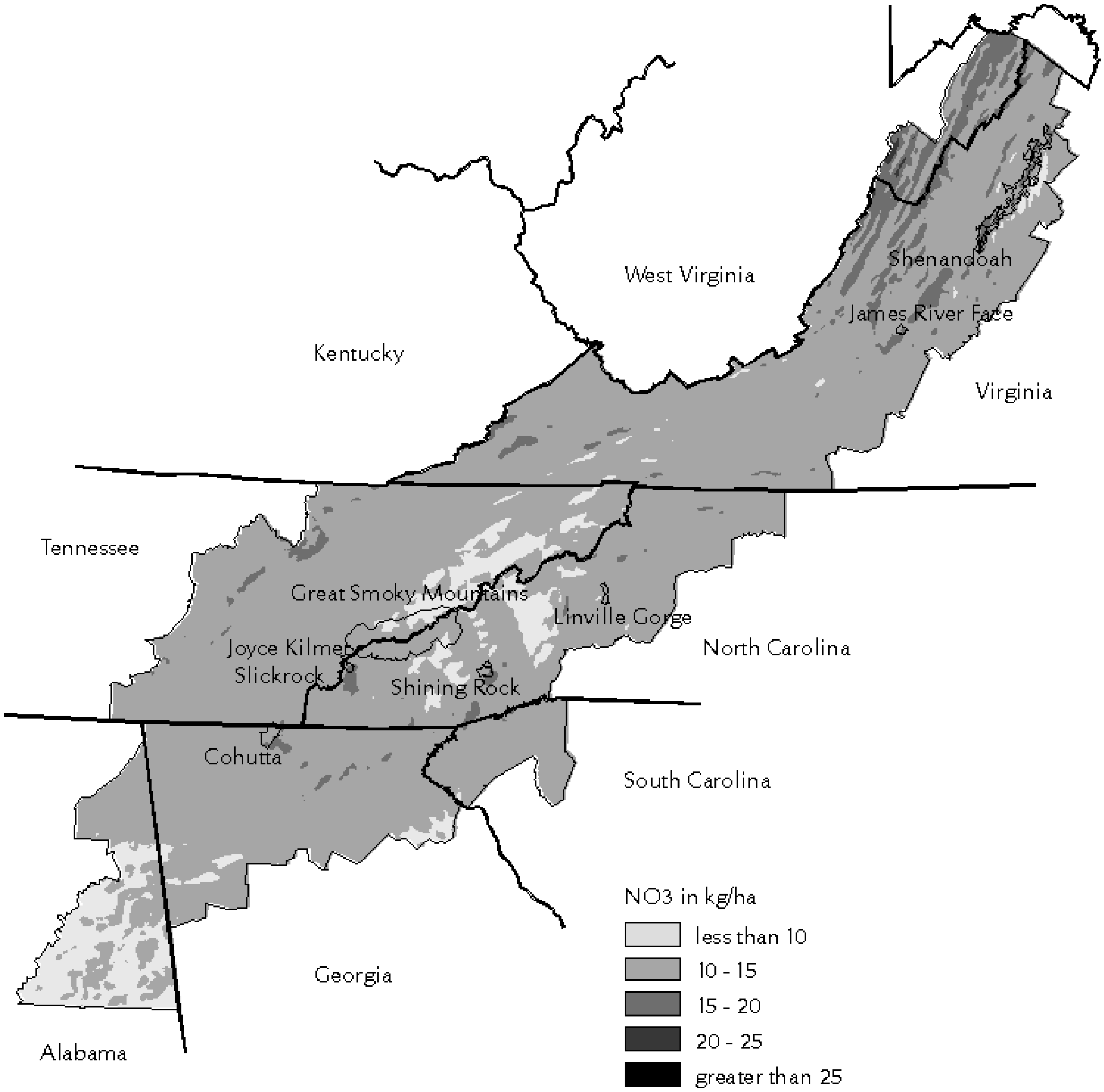

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Figure 5.2 Modeled distribution of mean wet nitrate loadings (in kilograms/hectare/year) during the period 1983-1990. Outlined are the political boundaries and the Class I area parks and wilderness areas.

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.

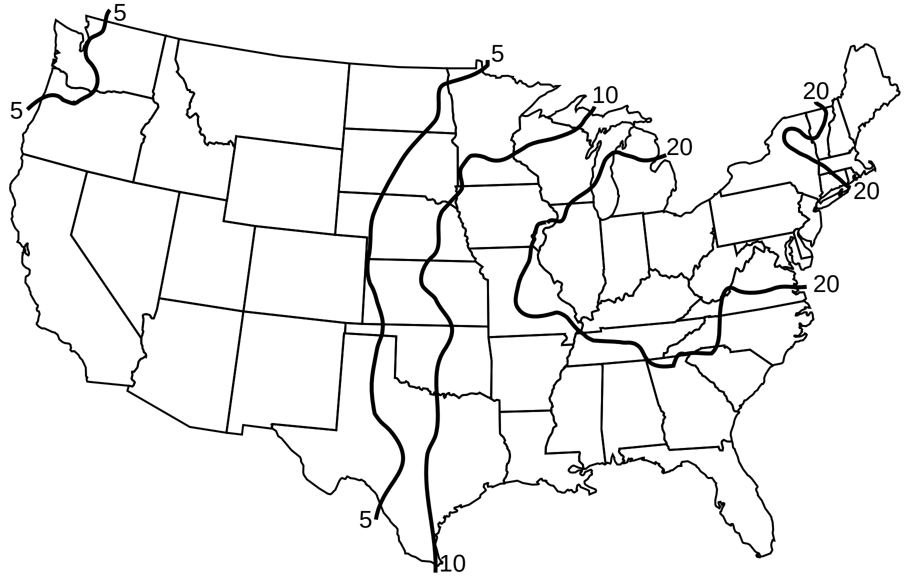

Figure 5.3 National Atmospheric Deposition Program (NADP) map of contours of sulfate loading (kg/ha) for 1993. (Source: NADP 1994)

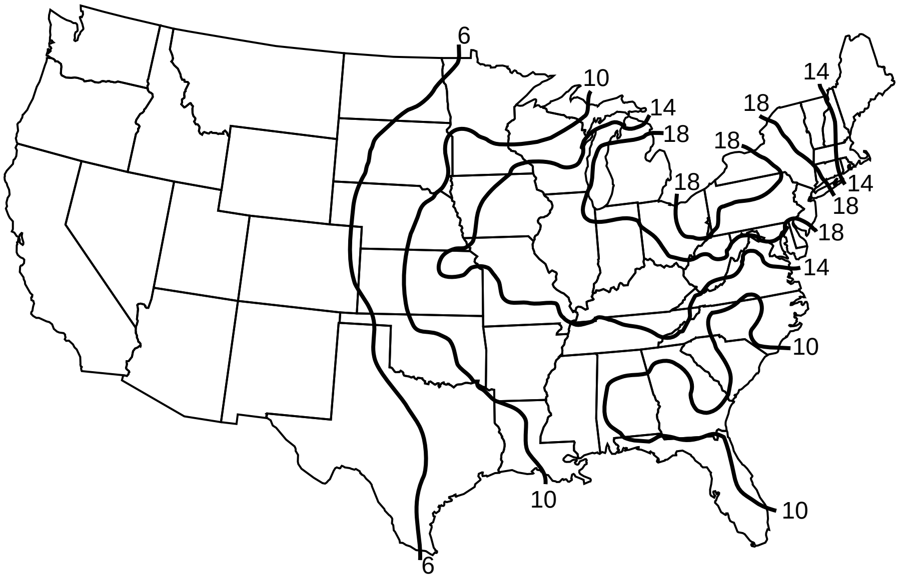

Figure 5.4 National Atmospheric Deposition Program (NADP) map of contours of nitrate loading (kg/ha) for 1993. (Source: NADP 1994)

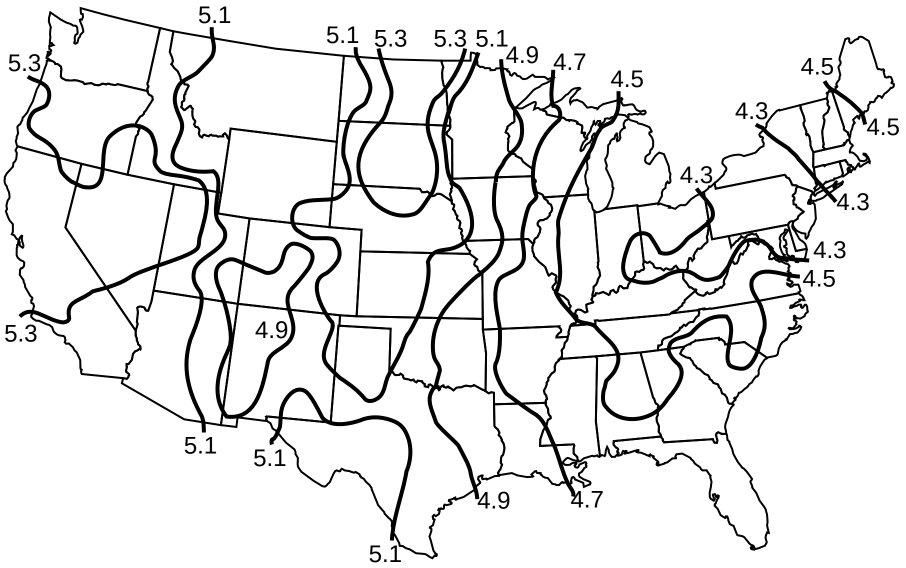

Figure 5.5 National Atmospheric Deposition Program (NADP) map of contours of pH for 1993. (Source: NADP 1994)

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

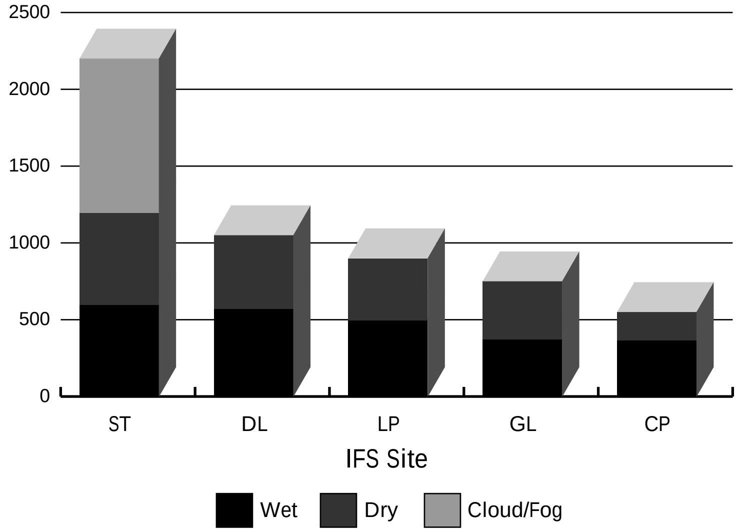

Figure 5.6 Total loading of sulfate (eq $ha^{-1}y^{-1}$) to Integrated Forest Study (IFS) sites (during 1986-1989), at Great Smoky Mountains National Park (ST), Duke Forest (DL), Oak Ridge (LP), B. F. Grant Forest, Georgia (GL) and Coweeta Hydrologic Laboratory (CP). (Source: Johnson and Lindberg 1992)

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,

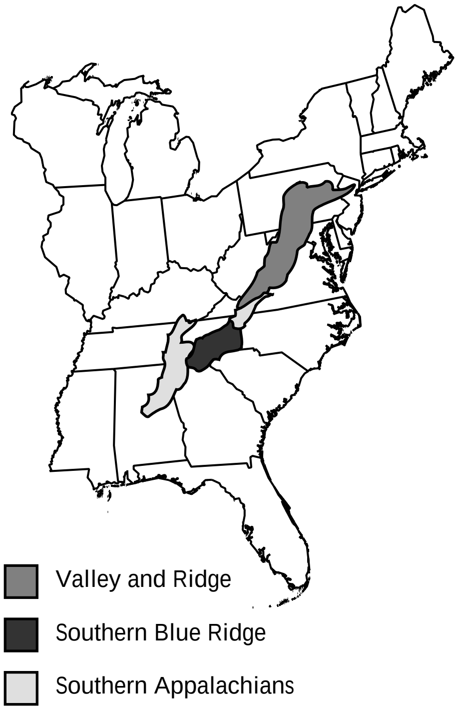

Figure 5.7 Subregions of the National Stream Survey - Phase I. (Source: Kaufmann and others 1988)

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.**