

## **1.0 INTRODUCTION**

### **1.1 Background**

The Southern Appalachian Mountains Initiative (SAMI) is a voluntary partnership that includes state and federal agencies, industry, academia, environmental groups, and the interested public. Its goal is to identify and recommend strategies to remedy existing air pollution impacts to natural resources in the eight state Southern Appalachian Mountains region and to prevent future adverse impacts. Particular emphasis is placed on resource protection within the ten Class I national parks and wilderness areas<sup>1</sup> that occur within the SAMI domain (Figure 1-1).

SAMI is conducting an Integrated Assessment of air pollution sensitivities and effects that focuses on acidic deposition, ozone, and visibility. The assessment links emissions, atmospheric transport, environmental effects, and socioeconomic models to derive projections of future impacts under varying levels of emissions. Emissions management strategies represent air regulatory requirements that were being implemented at the time of SAMI's formation, expected emissions reductions under recent Federal regulatory actions, and alternative strategies that SAMI might recommend for regional, state, or community-based actions (Brewer et al. 2000).

The acidic deposition assessment has been conducted for SAMI in two phases. During Phase I, aquatic and forest responses to hypothesized changes in future sulfur and nitrogen deposition were evaluated for three watersheds located in Great Smoky Mountains National Park (Noland Divide) and Shenandoah National Park (White Oak Run and North Fork Dry Run). The former two watersheds are highly sensitive to streamwater acidification and have annual average streamwater acid neutralizing capacity (ANC) between 0 and 20  $\mu\text{eq/L}$ . The latter watershed is only slightly sensitive, with annual average ANC at about 90  $\mu\text{eq/L}$ . Aquatic and terrestrial responses were simulated with the MAGIC (Cosby et al. 1985) and NuCM (Liu et al. 1991, Johnson and Lindberg 1991) models, respectively. Results of the Phase I analyses, reported by Cosby and Sullivan (1999), Munson (1999), and Brewer et al. (2000), provided guidance to SAMI on assessment design and a preliminary indication of model results. Phase I results are summarized in Appendix A. Phase II, the results of which are reported here for aquatic effects, provides a regional characterization across the SAMI region, based on the same two

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<sup>1</sup> Class I areas are national parks over 6,000 ac and wilderness areas over 5,000 ac that were in existence prior to August, 1977. The Clean Air Act and its amendments provide the highest level of protection to Class I Areas, and indicate that federal land managers have "an affirmative responsibility to protect air quality related values (AQRV)... within a Class I area."

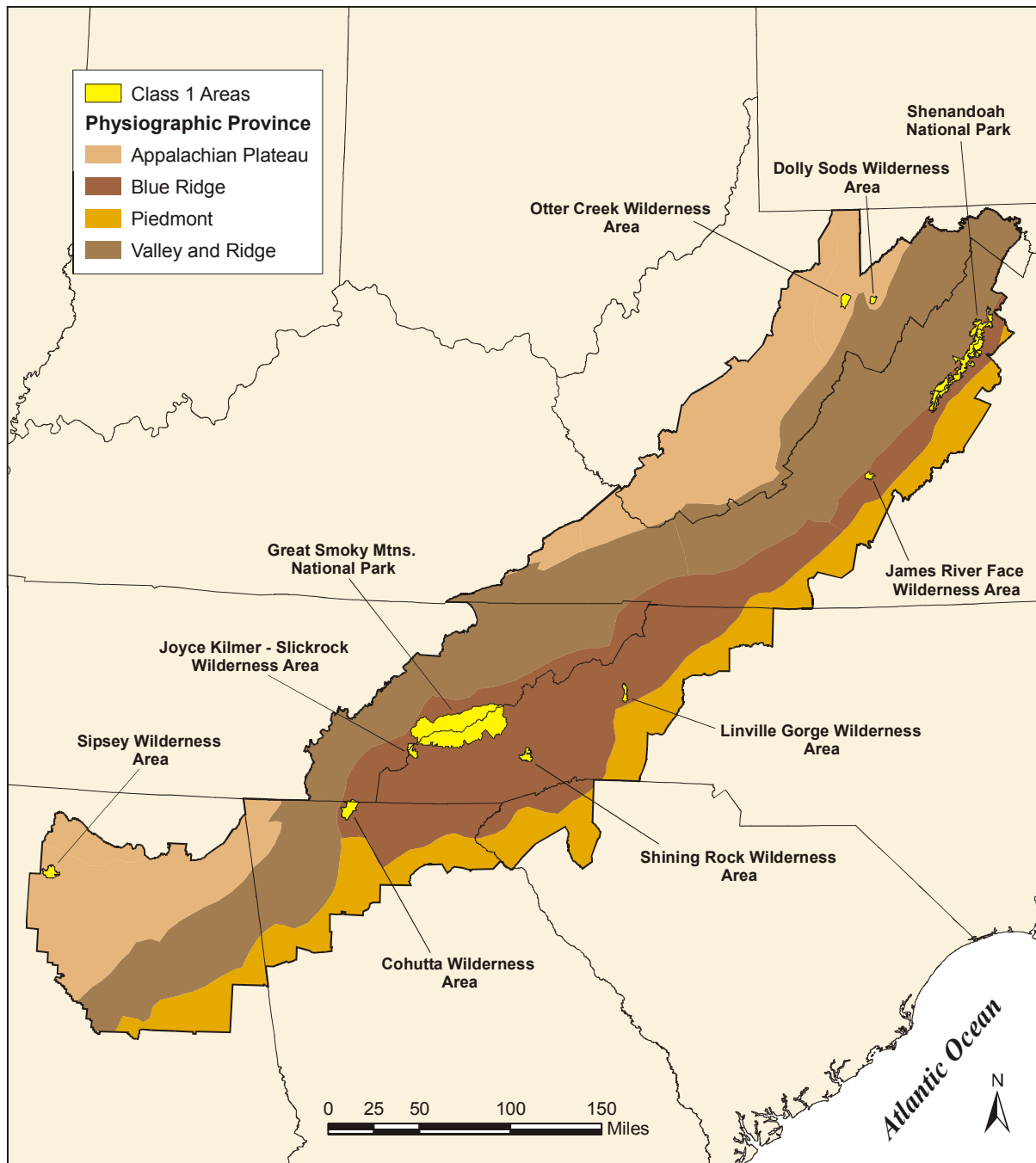


Figure 1-1. Map showing SAMI domain, physiographic provinces, and location of Class I areas.

models utilized in Phase I. Phase II results for terrestrial ecosystems are reported by Sullivan et al. (in review).

## **1.2 SAMI Region**

Forests cover most of the ridges throughout the SAMI region. It is largely on these forested ridges that most of the acid-sensitive aquatic and terrestrial resources are located. The forests are dominated by deciduous trees in most places, although coniferous trees are dominant in some of the higher elevation areas. Most of the forests are regenerating subsequent to nearly total harvest by the early part of the 20<sup>th</sup> century.

The Appalachian Mountain region constitutes an important region of concern with respect to the effects of acidic deposition. Many streams at higher elevation, particularly in the mid-Appalachian portion of the region (northern portion of the SAMI domain), have chronically low ANC values and the region receives one of the highest rates of acidic deposition in the United States (Herlihy et al. 1993). The acid-base status of streamwaters in forested upland watersheds in the southern and mid-Appalachian Mountains has been extensively investigated in recent years (e.g., Cosby et al. 1991, Church et al. 1992, Herlihy et al. 1993, Webb et al. 1994, van Sickle and Church 1995). Small first to third order streams dominate the mid-Appalachian Highlands; about 63% are first order streams and an additional 15% are second order (U.S. EPA 1998, Herlihy et al. 2000).

Wet sulfur deposition varies throughout the SAMI region from about 5.5 to 10 kg/ha/yr, and wet nitrogen deposition varies from about 4 to 8 kg/ha/yr, based on NADP data. Dry and occult (cloud) deposition are also highly variable, with highest known values at high elevations in the Great Smoky Mountains (Webb et al. 1999).

Sulfur-adsorption by soils is an important aspect of watershed acid-neutralization in the southeastern United States. Where S-adsorption is high, even relatively high levels of sulfur deposition have little or no impact on surface water chemistry, at least in the short-term. Over long periods of time, however, this sulfur adsorption in soils can be reduced under continued high levels of sulfur deposition, causing a delayed acidification response. Streamwater sulfate concentrations and stream discharge estimates suggest that sulfur outputs approximate inputs in some of the watersheds of the Appalachian Plateau, and therefore these watersheds are near steady-state with respect to sulfur. Sulfur-adsorption in soils is highest in the Southern Blue Ridge, where about half of the incoming sulfur is retained, and is somewhat lower in the Valley

and Ridge watersheds (Herlihy et al. 1993). Thus, there is a general pattern of increasing sulfur adsorption as you move from the north to the south and from the Appalachian Plateau to the Blue Ridge physiographic provinces in the mid- and southern Appalachian Mountains.

The Environmental Protection Agency's (EPA) Direct Delayed Response Project (DDRP) (Church et al. 1989) addressed questions regarding the extent to which watershed acidification responses are immediate (directly proportional to changes in deposition input) or lag in time due to soil processes. Such processes were described in detail by Turner et al. (1990). The principal mechanisms whereby acidification and/or recovery responses may be substantially delayed subsequent to a change in sulfur deposition include sulfur retention in soils and the supply and leaching of base cations. Where an appreciable percentage of sulfur deposition input is retained in watershed soils, acidification response will be delayed as the sulfur adsorption in the soil declines over time. Similarly, where base cation supply from weathering is low, continued leaching of base cations over time by acidic deposition can further deplete the soil base cation supply, causing acidification of both soils and drainage water. Within the SAMI domain, many watersheds exhibit strong sulfur retention. In addition, some watersheds have become depleted of their base cation reserves by some combination of: 1) low weathering rates and therefore low initial base cation stocks in soils, 2) accelerated leaching of base cations by acidic deposition, and 3) loss of base cations in response to land use (e.g., timber harvesting, agriculture). For these reasons, many watersheds within the SAMI domain exhibit delayed acidification. Thus, the soils and surface waters of the SAMI region have not yet realized the full effects of the elevated sulfur deposition received to date (Herlihy et al. 1993). This delayed response creates a situation whereby many streams will continue to acidify even if acidic deposition is not increased. In fact, some streams will continue to acidify even if acidic deposition levels in the future are decreased substantially. Whereas such delays occur to some extent elsewhere, they are far more pronounced in the SAMI region than in other areas of North America (Church et al. 1989, Baker et al. 1990, Charles 1991, Sullivan 2000).

The SAMI region includes three physiographic provinces in which acid-sensitive streams are found. These are oriented as southwest to northeastern bands: Blue Ridge Mountains, Valley and Ridge, and Appalachian Plateau (Figure 1-1). There are no historical data available on streamwater chemistry in the region. However, the National Stream Survey (NSS; Kaufmann et al. 1988) sampled streams throughout the region. In the Valley and Ridge Province, low ANC streams are generally absent from the valleys, many of which contain limestone bedrock. Ridge

streams are often acid-sensitive, however, and about one fourth are low in ANC ( $\leq 50 \mu\text{eq/L}$ ) in their upper reaches. The highest proportion of acidic (5%) and low ANC (31%) streams are found in the Appalachian Plateau Province (Herlihy et al. 1996), even after excluding those affected by acid mine drainage (Herlihy et al. 1990). Acidic and low ANC streams are more prevalent in the northern part of the region, in Virginia and West Virginia, than in the south. This gradient is due, at least in part, to the generally higher rates of sulfur and nitrogen deposition (high-elevation portions of the southern SAMI region are an exception) and the lower S-adsorption of soils in the northern part of the region. Throughout the region, acidic and low-ANC streams are generally confined to small ( $< 20 \text{ km}^2$ ) upland, forested watersheds in areas of base-poor, weathering-resistant bedrock (Herlihy et al. 1993).

Water bodies are regarded by residents of the SA region as extremely important. Multiple uses include drinking water, fishing, other aquatic recreation, transportation, livestock watering, irrigation, flood control, hydroelectric power, wildlife observation, and waterfront human habitation.

A 1977 NC survey of resource managers demonstrated that the most important management priority is maintenance of high quality streams; the survey concluded that both the general public and municipal leaders view stream degradation as their greatest resource problem. A more-recent and broadbased survey (SAMAB 1996) concluded that trout populations in particular are regarded by residents as one of the region's most valuable aquatic natural resources, and trout populations and trout habitat are major concerns to the public in the SA. Sources of concern generally fall into three categories: 1) fisheries for native brook trout (*Salvelinus fontinalis*) and introduced rainbow (*Oncorhynchus mykiss*) and brown (*Salmo trutta*) trout; 2) "existence value" for brook trout, regarded as a beautiful and intrinsically valuable native species; and 3) the presence of trout as indicators of high water quality. Acidification is a conspicuous threat to all three trout species in the region. Of the three, native brook trout is the most acid tolerant, brown trout introduced from Europe is intermediate in acid tolerance, and rainbow trout introduced from the western US is most sensitive.

### 1.3 Biological Resources at Risk

The lack of recent glaciation in the Southeast versus the Northeast has contributed to high species richness in aquatic environments, but also to acid-sensitive, base-poor soils. The Southeast was not glaciated during the last glacial period (about 100,000 to 10,000 years ago).

As a result, the soils of the Southeast are largely residual, relatively deep, and highly structured vertically, versus those in glaciated areas to the north. The lower horizons of southeastern soils are also rich in iron and aluminum, which can strongly affect stream chemistry via efficient retention of many negatively charged solutes (e.g. sulfate, phosphate, organic anions associated with dissolved organic carbon [DOC]), of which sulfate is of major interest in the context of acidification. Ultisols represent one of the dominant soil groups in the Southeast; these are characterized by sandy or loamy surface horizons and subsurface horizons that are loamy or clayey in texture. They are typically acidic soils that are low in base saturation (Adams and Hackney 1992).

The lack of glacial activity has had a greater impact on aquatic than terrestrial biodiversity; most northeastern terrestrial communities "migrated" south, then north again with onset and ending of the glacial period. Aquatic forms, especially fish and mollusks, had less opportunity for southward movement, and either adapted to colder conditions or became extinct in the northeast, resulting in substantially lower aquatic biodiversity in glaciated versus unglaciated areas (Adams and Hackney 1992).

The Southeast contains some of the most evolutionarily significant areas on the continent, with the greatest known diversity for several aquatic groups, notably fish, salamanders and macroinvertebrates (Adams and Hackney 1992, Jenkins and Burkhead 1993, Walsh et al. 1995). The Nature Conservancy (1998) identified about 325 watersheds of about 2200 in the contiguous 48 states that were considered critical to conserve aquatic biodiversity; more than half of these are in the Southeast. With respect to mountain streams specifically, more than 60 high-gradient streams and rivers of the Southern Appalachians (SA) were recognized as outstanding for their high scenic, recreational, geologic and wildlife values (National Park Service 1981, Wallace et al. 1992). A large percentage of regional streams are dilute, low-ANC waters (Elwood 1991), including the most dilute water bodies in the eastern United States (Elwood et al. 1991). Dilute surface waters, with their low concentrations of buffering materials, are sensitive to acidification.

Of the 37.4 million acres in the SA region (as defined by SAMAB 1996), 14.6 million acres (39%) are in the range of wild trout, with up to 33,000 miles of potential wild trout streams. The distribution of trout stream mileage percentage by state is 39% in Virginia, 32% in North Carolina, 10% in Georgia, 10% in Tennessee, 7% in West Virginia, 2% in South Carolina, and 0% in Alabama (SAMAB 1996).

Southern Appalachian streams contain a rich diversity of invertebrate, fish and salamander species. Local species richness depends on thermal regime, water chemistry, patterns of discharge, plus substrate type and geomorphology (Wallace et al. 1992).

### Invertebrate Communities

Aquatic invertebrate species richness in the region is probably the greatest in North America, with many endemic species. Indeed, the regional invertebrate fauna includes many as yet undescribed species. The invertebrate fauna in the cool high mountain streams in the region contain species that are elsewhere only found further north. Many regional taxa have evolved rather elaborate morphological and behavioral adaptations for maintaining their positions in high-gradient streams with high current velocity (Wallace et al. 1992).

Macroinvertebrates are defined as animals without backbones, which can be seen with the unaided eye, usually larger than 0.01 inches in at least one dimension. Aquatic benthic macroinvertebrates occur on the bottoms of streams or lakes, in or among substrates such as stones, plants, or wood. In the SA, immature aquatic insects represent most of the macroinvertebrates, together with mollusks and crustaceans. The community contains many species of known sensitivity to stresses such as acidification or sedimentation. As with other groups, counts of taxa (such as families, genera or species) at impacted versus unimpacted sites are often lower, due to loss of sensitive taxa, so lower species richness or absence of specific taxa is often taken to indicate impacts (SAMAB 1996).

Benthic invertebrates play important roles in the breakdown of terrestrial and detrital material in streams, as well as nutrient regeneration. Many fish, waterfowl and other bird species rely on benthic invertebrates as their primary food source. Acidification could therefore affect structure, function and trophic relations in stream ecosystems. Because benthic invertebrates are diverse, relatively easy to collect (though time-consuming to identify), and have short generation times, they are used as indicator species for a number of potential pollutants. This is true in the case of acidification and recovery from acidification, because communities typically contain some species with known acid sensitivities (Baker et. al. 1990).

### Fish Communities

The SA area is widely regarded as one of the most diverse landscapes in the Temperate Zone (SAMAB 1996). Fish diversity in the Southeast region is quite high. There are about 950

freshwater fish species in North America (Jenkins and Burkhead 1993), of which about 485 species can be found in the Southeast, and about 350 species can be found in the SA south of the Roanoke and New Rivers (Walsh et al. 1995). The total numbers of fish species by state in the region is very large: 107 in Maryland, 164 in West Virginia 199 in North Carolina, 210 in Virginia, plus the richest state freshwater fish fauna in the country, 307 in Tennessee (Jenkins and Burkhead 1993). Regional habitat and intraspecific genetic diversity are also regarded as high. Thus, the Southeast is a unique national biodiversity resource for fish. Unfortunately, the Southern Appalachian Assessment concluded that 70% of sampled stream locations show moderate to severe fish community degradation, and that about 50% of the stream miles in WVA and VA regions show habitat impairment (SAMAB 1996).

Fish communities of high-gradient southeastern streams may contain a variety of species, but are often dominated by trout, especially brook trout (Table 1-1). There has been little regional ecological research on other species except in biogeographic and systematic studies. However, Jenkins and Burkhead (1993) provided much ecological information on the fish species of Virginia, many of which are found elsewhere in the Southeast. There are clear patterns in species distribution from headwater streams to rivers, which can also be seen in community comparisons among reaches at different elevations; the clearest pattern is that species richness (total number of species present) increases in a downstream direction. This is thought to result from the rather small number of upstream species, which must tolerate simultaneously highest current velocities and lowest pH. Fish are absent from the highest headwaters, where they are replaced by salamanders. The highest-elevation fish species is usually brook trout, typically joined downstream by dace (e.g., blacknose dace [*Rhinichthys atratulus*]), a sculpin (e.g. mottled sculpin [*Cottus bairdi*]) and a darter (e.g. fantail darter [*Etheostoma flabellare*]), and perhaps by introduced brown or rainbow trout (Wallace et al.

Parameter	Elevation (m)						
	>1219	1067-1219	914-1067	762-914	610-762	457-610	<457
Total fish biomass (g/m <sup>2</sup> )	1	1.55	1.74	2.1	2.1	2.15	1.66
Trout contribution (% total biomass)	99.9	86.8	63.5	26.6	33	36.3	25.7
Brook trout (as % total trout numbers)	93.1	30.7	29.7	30.7	7.8	5.8	9.1

1992). In the context of acidification, the introduced trout are both more acid-sensitive than brook trout, and will not be present in acidified waters.

Proceeding downstream, other dace, darters, chubs, shiners, suckers and others are added (Table 1-2). In larger downstream reaches, still regarded as high-gradient, the important gamefish smallmouth bass (*Salmoides dolomieu*) is most abundant in riffles over substrate which is about 40% clean gravel, boulder or bedrock, and at gradients of 0.8-4.8 m/km and depth at least 1.2 m (Wallace et al. 1992).

Species	Stream Section		
	Upper	Middle	Lower
Brook trout	60	61	14
Mottled sculpin	29	18	27
Blacknose dace	10	9	9
Torrent sucker	1	5	4
Bluehead chub	<1	5	37
Fantail darter	<1	<1	
Longnose dace		1	4
Rosyside dace		<1	3
Mountain redbelly dace			<1
Rock bass			<1
Smallmouth bass			<1
Total fish production (g/m <sup>2</sup> /yr)	2.84	3.16	3.96
Total fish biomass	2.14	2.56	4.74

In the study of stream fish, four factors, in addition to stream chemistry, are related to patterns of distribution and abundance: temperature regime, gradient, stream order, and flow regime. Streams are divided into cold versus warm water; cold water streams have temperatures that rarely exceed 24-26 °C for extended periods, and are characterized by trout and sculpin. Even at low temperatures, trout have relatively high metabolic rates, and are more active than most fish. They can thus use food resources more effectively than other fish at cold or cool temperatures (Moyle and Cech 2000).

Whereas temperature is of importance in determining broad distributional patterns, gradient (number of meters drop per km of stream) is often of greater importance locally. This is because

gradient has great influence on water velocity, substrate size, number and size of pools, and oxygen content. High-gradient streams may have little slow water, with bottoms of bedrock, boulders and cobbles (Moyle and Cech 2000).

Stream order is a classification of streams based on branching patterns. In most river systems, first order streams are the highest, smallest, coldest, highest-gradient streams, with fewest species of fish. As stream order increases, species richness also increases, usually regarded as a consequence of increase in habitat diversity; turbidity, temperature, and stream size increase as well. As stream order increases, usually new species of fish are added at a higher rate than upstream fish are subtracted from the community (Moyle and Cech 2000).

The trophic structure (food web) of the fish community changes with stream order. In first order streams, the dominant fish (e.g. trout) usually feed on insects that drop into the water from the overhanging vegetation or on detritus. In higher order streams, predators of aquatic insects are added, then piscivores. However most stream fish are opportunistic feeders and may feed on a wide variety of foods (Moyle and Cech 2000).

There is a general pattern of increasing fish species richness and abundance from lower order to higher order streams, probably resulting from a greater variety of habitat types (including spawning and nursery areas) and food sources in higher-order reaches. Perhaps because of the greater possibility of isolation, low-order streams are likely to host species unique to each drainage (Adams and Hackney 1992).

Streams change continuously in physical and chemical characteristics from headwaters to river mouth. Changes include shift from primarily terrestrial (in the headwaters) to in-stream organic matter contributions and changes in nutrient and water retention times, water volume and velocity, oxygen content, substrate size, gradient, and temperature regime. These shifts play important roles in determining the biological communities in different stream and river sections. For example, localized differences in gradient have great effects on fish and invertebrate occurrences, and may result in markedly discontinuous distributions of individual species (Adams and Hackney 1992).

These factors that affect the distribution and abundance of aquatic biota are also important from an acidification standpoint because the effects of acidification interact with other habitat characteristics to determine the species and biological communities that will occur in a given stream reach. Suitable streamwater acid-base chemistry is a necessary, but not necessarily sufficient, prerequisite for supporting brook trout, or any other species or biological community.

## **1.4 Recent Studies**

There are a number of locations within the SAMI domain where watersheds have been the subject of intensive hydrogeochemical study. These include:

Fernow Experimental Forest - West Virginia (c.f., Adams et al. 1997, Peterjohn et al. 1996)

Shenandoah National Park - Virginia (c.f., Ryan et al. 1989, Cosby et al. 1991)

Great Smoky Mountains National Park - North Carolina and Tennessee (c.f., Johnson and Lindberg 1991, Nodvin et al. 1995, Flum et al. 1997)

Coweeta Hydrologic Laboratory - North Carolina (c.f., Swank and Vose 1997)

Oak Ridge Reservation - Tennessee (c.f., Mulholland 1992)

Each of these locations includes multiple study watersheds, some with rather lengthy periods of record for streamwater chemistry, extending back to the early 1970s (Fernow and Coweeta) to early 1990s (Walker Branch at Oak Ridge Reservation). Some watersheds have been the subject of experimental watershed acidification and nutrient cycling experiments.

As part of the National Acid Precipitation Assessment Program (NAPAP), the U.S. EPA conducted the National Stream Survey (NSS), which sampled streams throughout most of the SAMI domain, except for the western part of the Appalachian Plateau. The NSS was conducted during spring baseflow in 1985 and 1986 and represents chronic, rather than episodic, chemistry. Because the NSS used a statistical (probability) design, it provides the best available picture of the regional status and extent of chronic acid-base chemistry in the region (Baker et al. 1990).

The NSS sampled streams represented on 1:250,000-scale USGS topographic maps and having watersheds smaller than 155 km<sup>2</sup>. Stream segments were selected for sampling using a randomized systematic approach, and were sampled at both the upstream and downstream ends (nodes) of each segment (Kaufmann et al. 1991).

In 1993 and 1994, the U.S. EPA, through the Environmental Monitoring and Assessment Project (EMAP), sampled approximately 400 streams across the Mid-Atlantic Highlands, which includes the northern portion of the SAMI domain (western VA and WV) and also portions of MD, PA, and NY. A statistical selection process was adopted in order to allow for unbiased population estimates of stream chemistry, habitat characteristics, and biology.

The Virginia Trout Stream Sensitivity Study (VTSSS) conducted a synoptic survey of streamwater chemistry for 344 (~80%) of the native brook trout streams in western Virginia.

Subsequently, a geographically-distributed subset of the surveyed streams were selected for long-term monitoring and research (Webb et al. 1994). About half of the streams included in the VTSSS had ANC < 50  $\mu\text{eq/L}$ , suggesting widespread sensitivity to acidic deposition impacts. In contrast, the ANC distribution obtained by the NSS (Kaufmann et al. 1988) for western Virginia suggested that only about 15% of the streams in the NSS target population had ANC < 50  $\mu\text{eq/L}$ . Webb et al. (1994) attributed these chemical differences to the smaller watershed size, more mountainous topography, and generally more inert bedrock of the VTSSS watersheds. Thus, the VTSSS focused on a subset of watersheds that were somewhat more acid-sensitive than the population of watersheds represented by the NSS.

Webb et al. (1994) devised a watershed classification scheme for western Virginia based on ecoregion maps, geologic maps, and streamwater chemistry data. Watershed response classes were designated, in decreasing order of acid-sensitivity, as siliclastic, minor carbonate, granitic, basaltic, and carbonate classes. Median streamwater ANC in the siliclastic class was only 3 to 4  $\mu\text{eq/L}$  in the Blue Ridge Mountains and Allegheny Ridges subregions. The minor carbonate and granitic classes were somewhat less acid-sensitive, with median ANC values of 20 and 61  $\mu\text{eq/L}$ , respectively.

Streamwater chemistry within the SAMI region varies seasonally. Results of chemical analyses of water samples collected between October 1987 and April, 1993 in VTSSS headwater streams (n=78) showed that ANC values tend to be lower by about 10  $\mu\text{eq/L}$  (in acidic and near-acidic streams) to 40  $\mu\text{eq/L}$  (in intermediate ANC streams) during winter and spring than they are during summer and fall.

Studies at a few stream sites in the mid-Appalachian Mountains have documented toxic stream water chemistry conditions during hydrological episodes, fish kills, and loss of fish populations, as a result of increased acidity. An estimated 18% of potential brook trout streams in the mid-Appalachian Mountains are too acidic for brook trout survival (Herlihy et al. 1996).

An effort to assess the effects of acid-base chemistry on fish communities in upland streams of Virginia was initiated in 1992 (Bulger et al. 1995). The study streams experienced both chronic and episodic acidification. A number of differences in fish communities were apparent between the low and high-ANC streams in this study. These included differences in such factors as age, size, and condition of individual fish, survival, number of fish species, and population size. Young brook trout exposed to chronic and episodic acidity experienced increased mortality

(MacAvoy and Bulger 1995); the condition of blacknose dace was poor in the low-ANC streams compared to the high ANC streams (Dennis and Bulger 1995).

Recent analyses (Bulger et al. 1998, 2000) divided VA's streams into four categories of acid-base status, to compare the number of streams currently in each category, versus estimated numbers in pre-industrial times and in the future.

- Chronically Acidic: ANC values less than or equal to 0  $\mu\text{eq/L}$  indicate streams that are no longer able to neutralize acidity and cannot host populations of brook trout or any other fish species.
- Episodically Acidic: Streams with an ANC between 0 and 20  $\mu\text{eq/L}$  experience regular episodic acidification at levels harmful to brook trout and other aquatic species and host, at best, reduced fish communities.
- Indeterminate: Streams whose ANC values fall between 20 and 50  $\mu\text{eq/L}$  are extremely sensitive to further acidification; they may or may not host brook trout populations, depending on the frequency and magnitude of acid events and other habitat characteristics. They certainly host fewer fish species than streams with higher ANC values.
- Not Acidic: Streams with ANC greater than 50  $\mu\text{eq/L}$ , a level which is unlikely to immediately threaten the survival of brook trout populations (although levels as low as 50  $\mu\text{eq/L}$  are too acidic for many other fish species).

Streams in the SAMI domain are affected by a host of environmental factors, including but not limited to acidic deposition. Meteorology, geology, land use, and forest health can also have important influence on streamwater chemistry. Water chemistry data collected as part of the VTSSS between 1987 and 1993, and presented by Webb et al. (1994), provide an excellent example of complex interactions between terrestrial biota and drainage water chemistry. Since its introduction to North America during the last century, the gypsy moth has expanded its range to include most of the northeastern United States. Since about 1984, the area of forest defoliation by the gypsy moth has expanded southward about 30 km/yr along the mountain ridges of western Virginia. Infestation and accompanying forest defoliation occurs at a given site over a period of several years.

Webb et al. (1994) compared quarterly pre- and post-defoliation streamwater chemistry for 23 VTSSS watersheds. Nitrate concentrations increased dramatically with defoliation in most of the streams, typically to 10 to 20  $\mu\text{eq/L}$  or higher. The most probable source of the increased streamwater nitrate concentration was the nitrogen content of the forest foliage consumed by the gypsy moth larvae (Webb et al. 1994). Additional observed changes in streamwater chemistry

included decreased sulfate concentrations and ANC, which were also hypothesized to be attributable to the gypsy moth defoliation. Increased nitrification in response to the increased soil nitrogen pool may have caused soil acidification, which in turn would be expected to increase sulfur adsorption in soils (c.f., Johnson and Cole 1980). In addition, declines in sulfur deposition during the comparison period may have played a role in the observed sulfate response.

Streamwater chemistry in two headwater catchments in Shenandoah National Park (White Oak Run and Deep Run) showed trends of increasing sulfate concentrations in the 1980s (Ryan et al. 1989). In the 1990s, however, the sulfate concentrations were altered as a consequence of gypsy moth defoliation. These changes induced by insect damage masked any continued change in sulfate concentration that may have been occurring in response to changes in atmospheric inputs of sulfur and progressive decline in the sulfur adsorption of watershed soils (Webb et al. 1995).

Eshleman et al. (1998) examined nitrate fluxes from five small (< 15 km<sup>2</sup>) forested watersheds in the Chesapeake Bay Basin during the period 1988 to 1995. Four of the watersheds were located in Shenandoah National Park, within the Blue Ridge Province, and the fifth in Savage River State Forest in western Maryland, within the Appalachian Plateau Province. The five watersheds varied in geology and acid sensitivity, with baseflow ANC typically in the range of 0 to 10 µeq/L in Paine Run to the range of 150 to 350 µeq/L in Piney River. Forest vegetation was also variable. The composition of oak species (*Quercus* spp.), which are a preferred food source of gypsy moth larvae, ranged from 100% in Paine Run to about 60% in three of the other watersheds. Nitrate concentrations increased markedly in at least three of the watersheds during the late 1980s to early 1990s, with peak annual average nitrate concentrations of about 30 to 55 µeq/L. The increased leakage of nitrate occurred contemporaneously with a period of intense defoliation by the gypsy moth larva. Nitrate leaching was shown to occur primarily during storm flow conditions.