National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Conceptual Plan for Vital Signs Monitoring — Great Smoky Mountains National Park

Natural Resource Report NPS/GRSM/NRR—2014/854



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Deep Creek Valley, Great Smoky Mountains National Park
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Conceptual Plan for Vital Signs Monitoring — Great Smoky Mountains National Park

Natural Resource Report NPS/GRSM/NRR—2014/854

National Park Service
Great Smoky Mountains National Park
Resource Management and Science Division
Gatlinburg, TN 37738

September 2014

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

National Park Service. 2014. Conceptual plan for vital signs monitoring — Great Smoky Mountains National Park. Natural Resource Report NPS/GRSM/NRR—2014/854. National Park Service, Fort Collins, Colorado.

NPS 133/126595, September 2014

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Executive Summary

Great Smoky Mountains National Park is renowned for its biodiversity, abundant wildlife, cultural resources, scenic vistas, and a wide variety of outdoor recreational opportunities, among many other values. It has been recognized internationally as both an International Biosphere Reserve and a World Heritage Site.

The park's resources are maintained by strong natural ecological events and processes such as precipitation, temperature, and vegetation succession and natural disturbance regimes such as wild land fire. However the park is also subject to profound anthropogenic impacts caused by acidification, exotic organisms, loss and fragmentation of habitats, and possible climatic changes.

The Smokies has had a long-term ecological monitoring program since the early 1990s. A wealth of scientific information has been gained since then, which has allowed us to evaluate the program's current status. This monitoring program is now being re-focused toward critical natural resource issues, or Vital Signs, which reflect a new understanding of natural ecological processes and roles of an increased number of interacting stressors. It will require continuing scientific data collection to support management decisions in order to protect resources.

The conceptual plan is a result of a series of meetings and discussions by a team of park natural resource professionals, who systematically evaluated and prioritized all significant natural resource issues. The proposed program focuses on six critical Vital Signs: Acid Deposition, Vegetation Communities, Soil Quality, Water Chemistry, Freshwater Communities, and Climate Changes. Other vital signs may be accommodated if collaborations make them feasible.

The sampling design follows a scalable approach, where plot arrays are established in several watersheds selected to represent the park as a whole. Metrics for multiple Vital Signs will be collected in each plot, which will be tracked for changes/trends per plot, and also aggregated to the watershed scale, and eventually the whole park. Final decisions about specific sites, monitoring frequency, intensity, and instrumentation have not yet been made by the team, pending full review of this conceptual plan.

A key change will be the approach by park staff. The new program will focus on a team approach, as opposed to independent monitoring among subject matter specialists within the park's Division of Resource Management and Science. Much of the planning has been on integrating monitoring questions, field data collection/co-location, possible automation of data collection, and annual team analyses.

Detection and measurement of trends in resources will be the focus of annual reports to the Superintendent. Collection and management of quality data to professional standards is a required benchmark. After a transition period, it is anticipated that the program will provide confident guidance on which to base management decisions for the future.

Contributors

Tom Colson, Nancy Finley, Kristine Johnson, Rob Klein, Matt Kulp, Michael Kunze, Keith Langdon, Steve Moore, Becky Nichols, Tom Remaley, Jim Renfro, Janet Rock, Susan Simpson, Bill Stiver, Paul Super, and Glenn Taylor

1. Introduction

1.1 Purpose of this Document

The National Park Service (NPS) initiated its long-term ecological monitoring program, known as "Vital Signs Monitoring," to provide the minimum infrastructure needed to track the overall condition of natural resources in parks and to provide early warning of situations that require intervention. Park vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, effects of stressors, or elements that have important human values.

The primary purpose of this document is to articulate a set of new concepts for re-targeting and increasing efficiency of natural resource monitoring in Great Smoky Mountains National Park (GRSM). A secondary purpose is to describe how this conceptual planning process was conducted so that readers can understand how the park arrived at the monitoring actions proposed. This document provides:

- background on the legal and policy mandates regarding monitoring in the NPS, and on the former monitoring program in GRSM that became operational in 1993
- a discussion of the influential factors in monitoring and an outline of the processes the park undertook to determine vital signs
- an explanation of the steps taken to prioritize among many potential monitoring subjects and issues to arrive at the new proposed monitoring program
- a description of the sampling approach and design to be used for highest priority monitoring topics, including the monitoring questions that will drive eventual protocol development
- a discussion of other potentially important monitoring, including projects that can be done in collaboration with other agencies and organizations
- an update of available natural resources data; much of it newly acquired
- a list of supporting research questions that should be answered to effectively conduct monitoring.

1.2 Relationship to the Appalachian Highlands Network (APHN) Vital Signs Monitoring Plan (2005)

The original GRSM monitoring program was developed in the early 1990s. When the Service-wide Inventory and Monitoring program initiated development of 32 networks across the nation in 2002, GRSM was included in the Appalachian Highlands Network (APHN). The network also includes the Blue Ridge Parkway, Big South Fork National River and Recreation Area, Obed Wild and Scenic River, and the southern portion of the Appalachian National Scenic Trail. Although part of the APHN, GRSM is a prototype Inventory and Monitoring park and operates its program out of park base funding. The APHN plan can be consulted for additional general information for GRSM and the other parks in the network (NPS 2005).

1.3 Policy and Legal Mandates for Monitoring

(Excerpted in part from the APHN Vital Signs Monitoring Plan [NPS 2005])

The National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park system. The Act charges the Secretary of the Interior to "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of, and research on, the resources of the National Park System, and to assure the full and proper utilization of the results of scientific studies for park management decisions." Section 5934 of the Act requires the Secretary of the Interior to develop a program of "inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."

The 2006 NPS Management Policies (NPS 2006) updated previous policies and specifically directed the Service to inventory and monitor natural systems. The NPS Management Policies further state, "the Service will:

- identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents
- define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources
- use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals
- analyze the resulting information to detect or predict changes (including interrelationships with visitor carrying capacities) that may require management intervention, and to provide reference points for comparison with other environments and time frames
- use the resulting information to maintain and, where necessary, restore the integrity of natural systems."

1.4 Goals and Objectives

1.4.1 Service-wide Monitoring Goals

The NPS has five general Service-wide goals for planning Vital Signs Monitoring programs:

1. provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments
2. determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources
3. provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management

4. provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment
5. provide a means of measuring progress towards performance goals.

1.4.2 Park-level Goals

A successful Vital Signs Monitoring Program in GRSM will:

- contribute to understanding the natural dynamics of major ecological systems in the park, so that impacts of natural drivers can be distinguished from those of stressors
- provide baseline data from which to quantify future changes if new stressors are detected
- provide sufficient early warning of those stressors that potentially could exceed impact thresholds, so that management actions are effective
- select measurements that are appropriately integrated geographically, ecologically, and temporally to adequately understand and track complex interactions among selected resources
- allow for geographic scaling of measurements (i.e., summarize trends from the resolution of plots, up to watersheds, and to the park landscape)
- develop and nurture strong partnerships to expand ecological and geographic scope of the program
- be an activity that is practical, affordable, safe to conduct, and informative to park management.

1.5 Background of Monitoring at Great Smoky Mountains National Park

The NPS has a strong legislative mandate to conduct and use data from monitoring programs (see Section 1.3, above). The Long-Term Ecological Monitoring (LTEM) Program at Great Smoky Mountains National Park was one of the four original prototype monitoring programs initiated by the NPS in 1992. The prototype LTEM programs were established in the early 1990s as experiments to learn how to design scientifically credible and cost-effective monitoring programs in ecological settings of major importance to a number of NPS units. GRSM was selected as one of the two prototype parks in the Deciduous Forest Biome to develop sampling protocols and expertise for monitoring the condition of selected natural resources that would benefit other NPS units with similar natural resources.

After selection as a prototype, GRSM developed a comprehensive plan that established goals, monitoring questions, components, and funding amounts (NPS 1993). Three offices in the park, all of which already had some monitoring activities underway, developed the plan cooperatively: the Uplands Field Research Lab located at Twin Creeks (the Science Division of the park), the Cooperative Park Studies Unit at the University of Tennessee, and the Resource Management Division office at park headquarters. While there were outside peer reviews of individual components, there were no such reviews of the program's overall design. A substantial amount of base funding was eventually transferred to the park (NPS 1993), plus four FTE's. An additional four FTE's were added to the program by the park.

In the latter part of 1993, shortly after the plan was finalized, the Department of the Interior re-organized several agencies, which resulted in the transfer of park staff, funding, and authority for planning the program to the newly-created National Biological Survey (NBS). This was followed by a two-year period of re-organization at park, regional, and Washington offices of both agencies as they planned the direction of the Inventory and Monitoring program. The program implementation eventually returned to the NPS, and the NBS was subsumed into the US Geological Survey (USGS), as its Biological Resources Discipline.

Operationally in GRSM, the program was sub-divided into different components, which were the administrative offices of the subject matter specialists. Each component was overseen by a permanent employee supervisor with a specific budget and responsibility for developing and carrying out one or more sets of protocols. Minor components of the monitoring program were soon absorbed into larger components, and a major re-allocation of funding in water resources led to a change in emphasis. In the intervening years, the components have answered many monitoring questions, although some are no longer valid (e.g., "How significant a prey base is the Cades Cove deer herd for the re-introduced red wolf?").

The original 1993 plan called for monitoring at various scales, from population to community to watershed to ecosystem, and then scaling up the results and analyses to larger geographic areas; however, the various program components have operated independently for the most part, although the resources they monitor are inter-dependent, and the process of scaling has not yet been accomplished. Additionally, the data management goals in the 1993 plan were not fully realized. Data have been moved to professionally designed databases, but the anticipated development of a centralized database with the use of standardized features has not occurred, and cross-component analyses are largely lacking. These deficiencies are addressed in the most recent Data Management Plan for the Resource Management and Science (RMS) Division of GRSM (NPS 2008).

1.6 Description of Park Natural Resources and Drivers of the Ecosystem

GRSM encompasses over 2000 km² (521,490 ac) divided almost equally between the states of North Carolina and Tennessee (Fig. 1), and is one of the largest fully protected areas in the eastern US. Elevations in the park range from about 300 m (984 ft) to over 2000 m (6562 ft), and include several of the highest peaks in eastern North America.

Due to the wilderness character of the park, it has few roads for access and many sections are relatively inaccessible, even by trail. Off-trail travel is difficult and often hazardous due to steep terrain and extensive thickets of *Rhododendron* and *Kalmia*, which cover 17% of the park. There are a number of published articles and books on the natural resources and history of management of natural resources in the park. Recent information and comprehensive treatments may be found in Brown (2000) and Linzey (2008).

Geology: Geologically, the park's mountains are old compared to other landforms in the US, having been created by tectonics between the North American and African plates approximately 300 million years ago (USGS 1997). The park has recently received new bedrock mapping from the USGS - Geology Discipline, including previously unmapped sections of the park (Southworth et al. 2005).



Figure 1. Map of Great Smoky Mountains National Park. The yellow line is the boundary between North Carolina and Tennessee.

The surface of the park has a wide array of geochemically diverse parent materials including metamorphosed sandstones, carbonate rocks, extremely mineralized acidic slates, and smaller areas of metamorphosed igneous rocks (Southworth et al. 2005). The differing geochemical foundations of the park are believed to exert significant control of some species distributions (Southworth et al. 2004). The area has not been glaciated, but some periglacial features are present, including relatively large boulder deposits on the Tennessee side of the park (Southworth et al. 2004). Some geologic formations, particularly slates in the higher elevations, are structurally unstable and are the sites of periodic debris slides. The park has several karst areas with caves, sinkholes, and sub-surface drainage.

Soils: The USDA Natural Resources Conservation Service (NRCS) recently categorized and mapped park soils for the first time (NRCS 2009). The mapping study was based on extensive field work and was completed in concert with USGS's bedrock mapping (Schultz et al. 1999). Overall, the park is well drained with porous soils and few flat areas. The slope and relative fertility of soils was probably a significant influence on the degree of human settlement and disturbance. Sixty-four soil series have been documented in three soil orders, with frigid soils appearing in the upper elevations. Frigid soils are ones that have developed over time in a very cold environment and are characterized by high organic matter content. The NRCS study resulted in the development of models depicting soil formations based on various factors (e.g., elevations, temperature, slope, etc.) (Fig. 2), and also led to the discovery of 20 soils new to science, illustrating another important facet of uniqueness of the Southern Appalachians.

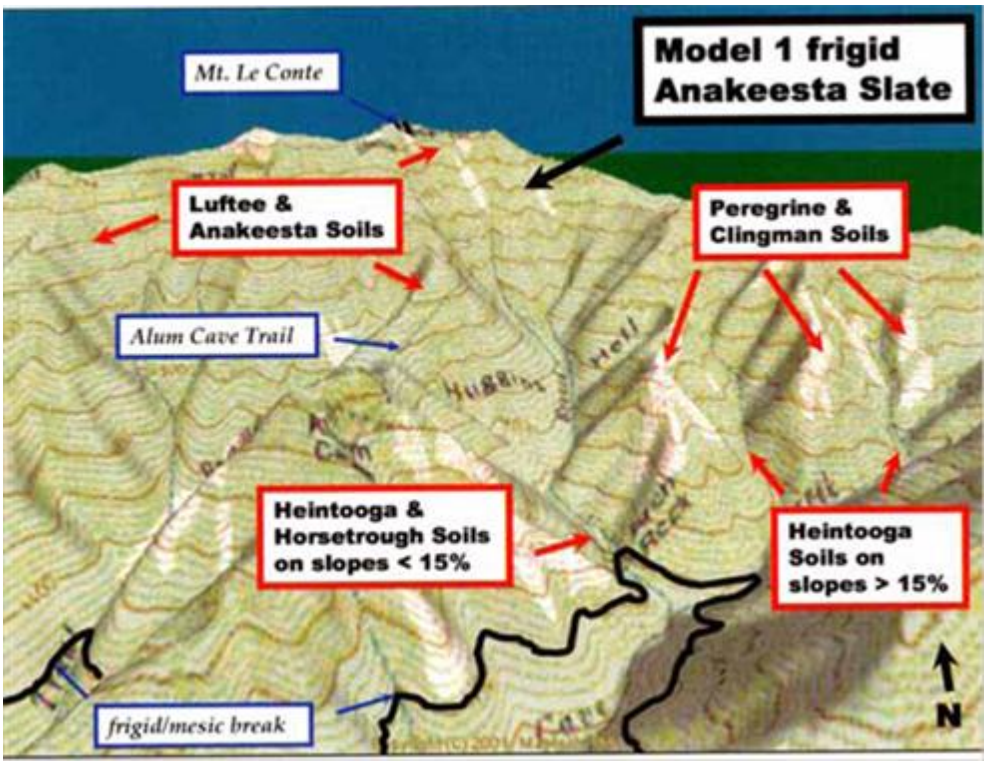


Figure 2. Example of a three-dimensional soil model created with GRSM soil data.

Climate: Precipitation levels in the park are among the highest on the North American continent, with annual averages of over 2 m (79 in) at high elevations and about 1.5 m (59 in) at low elevations. Models of precipitation across the park landscape are being developed, but are not yet complete. Temperatures vary not only with season and elevation, but with orientation of various slopes to solar radiation. Strong temperature gradients, especially in summer, are the rule across the park's steep terrain, which has horizontal distances of 400 m (1312 ft) that represent annual micro-climates as different as those 1000 km (621 mi) apart in flatter regions of the US (Fridley 2009).

Water Resources: At least 3400 km (2113 mi) of permanent streams, including the headwaters for local rivers, run through the park; the majority of these are small, first-order streams (Parker and Pipes 1990; Fig. 3). Five streams in the park have been designated as Outstanding Natural Resource Waters by the states of Tennessee and North Carolina: Abrams Creek (TN), Little River (TN), West Prong Little Pigeon River (TN), Middle Prong Little Pigeon River (TN), and Cataloochee Creek (NC).

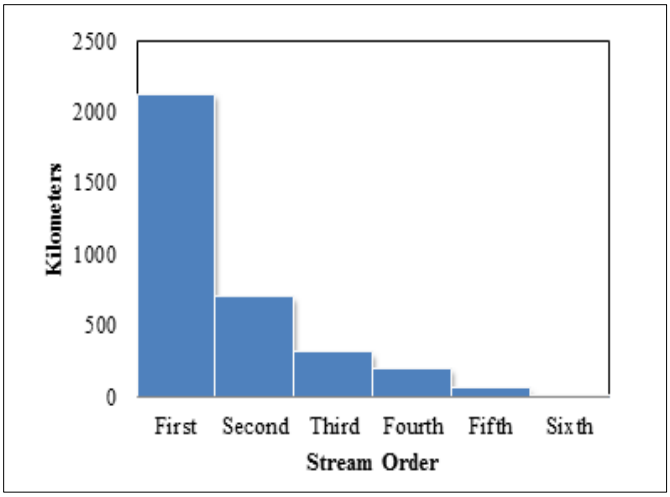


Figure 3. Lengths of surface streams in each stream order category in GRSM.

While there seem to be many wetlands in the park, most are too small and obscured by vegetation to be discovered by remote sensing. Park staff recently have begun to inventory some of these wetlands. There also are several natural ponds in the park, most of which are related to limestone solution or cut-off meanders of the few low gradient stream sections.

Biodiversity: GRSM is believed to be one of the most species-rich parks in the national park system. Factors that contribute to this diversity include the age and general north-south orientation of the mountains, their complex geochemistry, the abundant year-round moisture of the climate, and the mountains' apparent role as refugia for species during major climatic shifts over time. Compared to many other natural areas, life within the park is well studied, with ongoing projects that frequently discover new species. Highlights are listed below:

- The park contains 101 species of native trees, and probably the largest remaining fragment (over 40,000 ha) of uncut, old-growth forest left in the eastern US (Pyle 1988).
- Spruce-fir forests in the highest elevations represent about 75% of all such boreal forests in the southeast states (Dull 1988). While the number of plant species declines with elevation, the percentage of endemic and rare species and communities increases. In fact, many of the forest associations themselves are considered by NatureServe to be globally imperiled (White et al. 2003).
- The Tennessee River system is one of the most species-rich in the world (Stein et al. 2000). The park has mostly higher gradient, headwater streams within its boundaries; still, there are nearly 900 species of macroinvertebrates and 77 species of fish, although this latter group has lost members due to reservoir development adjacent to the park in the mid-20th century.
- The park is recognized as a regional, national and/or global center of diversity for salamanders, land snails, fungi, some plant groups, and a number of arthropod groups. There currently are about 17,000 species of life documented in the park, with distribution and relative abundance information known for many. The Southern Appalachians are one of six "hot spots" for biodiversity recognized nationally by NatureServe; these areas are based upon the number of imperiled species in a particular area (Stein et al. 2000; Fig. 4).

Natural Drivers: Parks are mandated to protect more than species and abiotic resources (NPS 2006); they also must preserve physical, biological, and ecological processes. There are many of these ecological processes, or drivers, that influence and sustain the natural resources of the park (Fig. 5). Precipitation and temperature variation, forest succession, and natural disturbances such as fires and herbivory, have profound impacts on natural resources, and occur in innumerable cycles of varying length. Together, these drivers provide a regime of natural change.

Monitoring and measuring natural drivers is critical to a monitoring program. Drivers are natural ecological processes which must be maintained, and any alteration in the frequency or magnitude forces a change in trajectory on park resources, and should be detected in a monitoring program. Anthropogenic changes, or stressors, are sometimes observed reinforcing or counteracting drivers. Differentiating between the two may be difficult in some cases (e.g., climate change), but measurement and comparison of both is the best method to assess stressor impact.

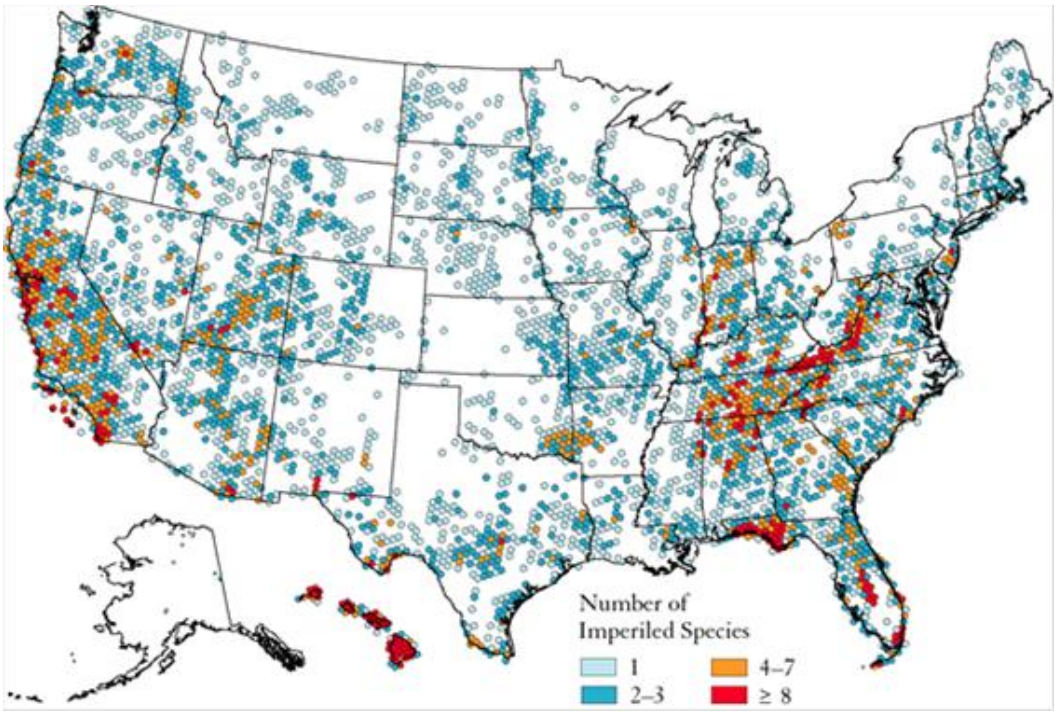


Figure 4. Imperiled species nationwide, depicted by equal-area hexagons. Note: These data are derived from vertebrate, vascular plants, and a very few invertebrate groups. (Stein et al. 2000).

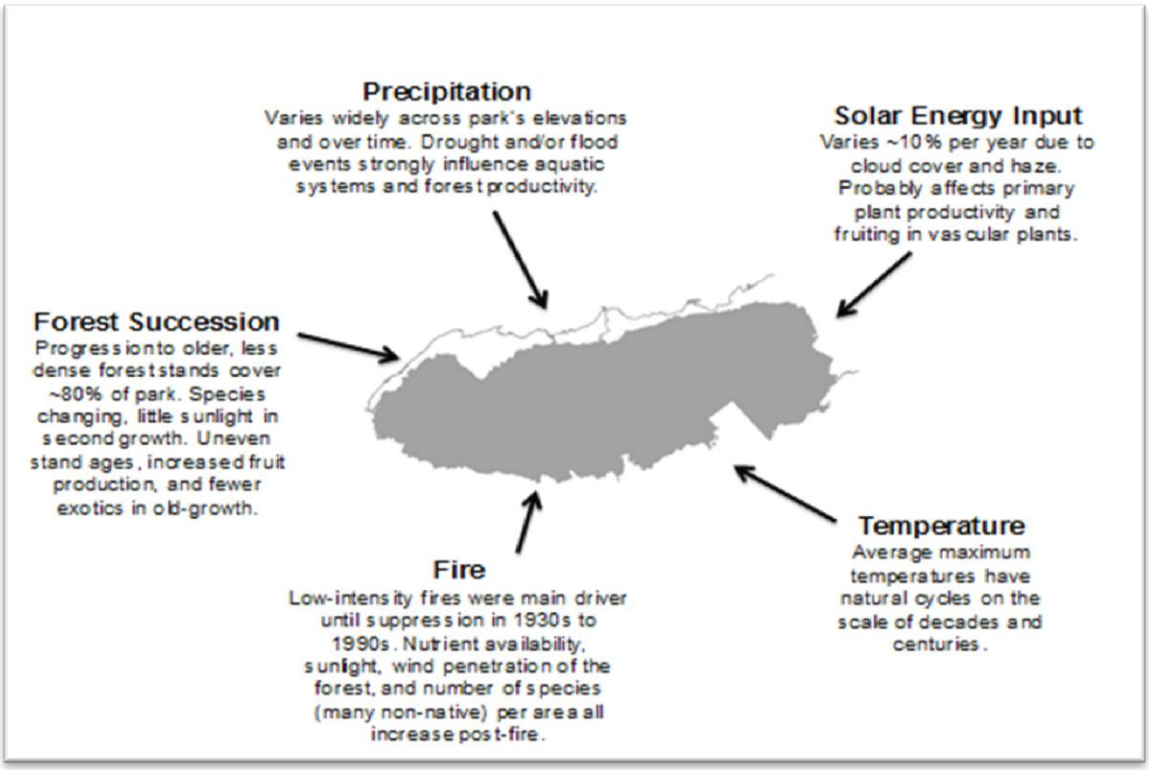


Figure 5. Major natural drivers of the GRSM environment.

1.7 Overview of Major Stressors

There are a host of threats to park health. These include air pollutants (nitrogen, sulfur, ozone, mercury, and pesticides), terrestrial threats (invasive plants, animals, and fungi that outcompete and/or destroy native species and habitats), and aquatic threats (pulses of acid coming from the higher elevations, abandoned copper mine drainage, and exotic fungi, mollusks, fish, and plants) (Fig. 6). Monitoring to detect new or increasing threats is vital to successfully managing park resources.

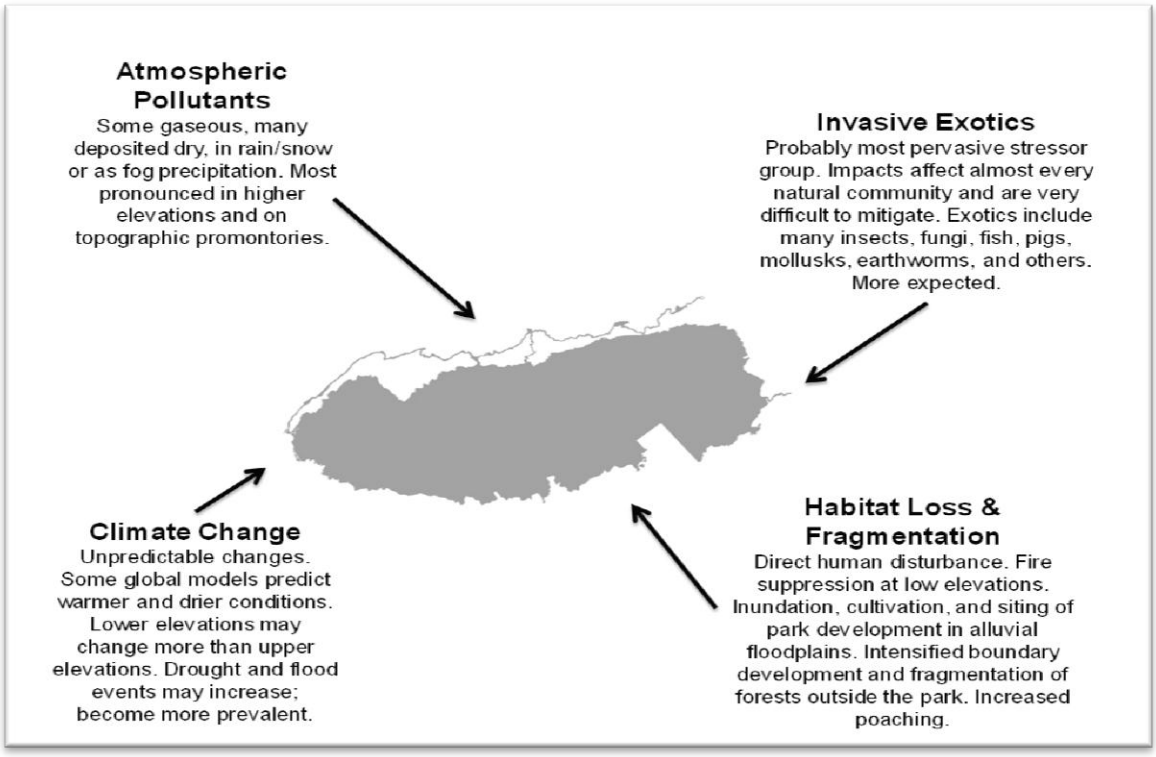


Figure 6. Major stressors to the GRSM environment.

1.7.1 Poor Air Quality

The park has one of the most comprehensive air quality monitoring and research programs in the entire NPS, and data collected over the past 30 years has shown that air pollution is significantly affecting park resources (streams, soils, vegetation, and visibility), visitor enjoyment, and public health. The problem originates primarily outside the park with burning of fossil fuels (coal, oil, and gasoline) that produce emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury (Hg). These are converted into harmful secondary pollutants (sulfates, nitrates, fine particles, ozone, and methyl mercury) as they enter the park via air masses and precipitation in both wet and dry forms. Winds coming into the southern Appalachians carry pollutants from the nearby Tennessee valley and from as far away as the industrial cities of the Ohio and Mississippi valleys.

The park experiences some of the highest measured air pollution of any national park in the US (Johnson and Lindberg 1992). Although air quality in most urban areas throughout the country improved during the 1980s and 1990s, air quality at GRSM deteriorated during this time period, due

to increased NO_x and SO_2 emissions in east Tennessee, and hotter summer weather conditions. The most recent NPS 10-year air quality national assessment shows that current air quality trends at the park are improving (ozone concentrations, visibility, fine particles, sulfate deposition, and nitrate deposition) or remaining stable (ammonium deposition). Despite these significant improvements over the past decade, air quality problems continue, including visibility impairment from regional haze, aquatic and terrestrial impacts from acid deposition and mercury, and the designation of non-attainment areas for ozone and particulate matter public health standards. Park managers are optimistic that air quality will continue to improve at GRSM in the near future from several recent air quality regulations and other related actions by EPA, TVA, and state and local programs.

Ozone concentrations at GRSM have exceeded standards (both at the old 85 ppb standard and the more recent 75 ppb standard) that are set to protect public health and vegetation. There have been 255 unhealthy (i.e., exceeding the legal standard) ozone days since 1997 under the 85 ppb standard and over 500 days under the 75 ppb standard. Over 30 species of plants show visible foliar damage from ozone pollution. Visibility on the worst days averages about 24 km (15 mi), much less than the estimate of natural visibility conditions of 124 km (77 mi). Sulfate particles account for 84% of the haze on the worst days and, along with nitrates, are responsible for acidic precipitation. High levels of mercury deposition pose a threat to park food webs, and although extensive work has not been completed, high levels have been found recently in bird feathers (e.g., 3744 µg/kg) and in stream-side salamanders (Simons and Keller 2010).

Deposition of pollutants in the park has been modeled (Fig. 7) based on the work of Weathers et al. (2006). Refining ecosystem budgets and evaluating biological responses to chronic acid deposition require accurate deposition values; however, these values can be highly heterogeneous, particularly in mountainous areas with complex terrain and vegetation distribution. Although wet deposition has been monitored extensively since the 1980s, measurements of total deposition (cloud, fog, dry, and wet) are sparse. Weathers et al. 2006 developed an empirical modeling approach that characterizes total deposition as a function of landscape features such as vegetation type, elevation, topographic exposure, slope, and aspect. Specifically, using indices of throughfall sulfate deposition and soil lead concentrations, they coupled the observed dry deposition and the observed wet deposition fluxes at base stations in the park with the empirically-derived patterns of enhanced deposition. The end result was a high resolution (30 m) total sulfur and nitrogen deposition GIS mapping tool that can be updated using varying deposition from the monitored sites.

1.7.2 Poor Water Quality

Compared to some units in the national park system, GRSM is fortunate that its streams almost entirely originate within the boundaries of the park; however, the deposition of atmospheric pollutants in the park is ubiquitous and deposition rates increase with elevation. High elevation soils, which are porous and on steep slopes, are losing their ability over time to buffer the acidity of the water that percolates through them to springs, seeps, and smaller streams. The resulting influx of anthropogenic chemicals, and those being leached out of the soil, has led to an elevated acidity in

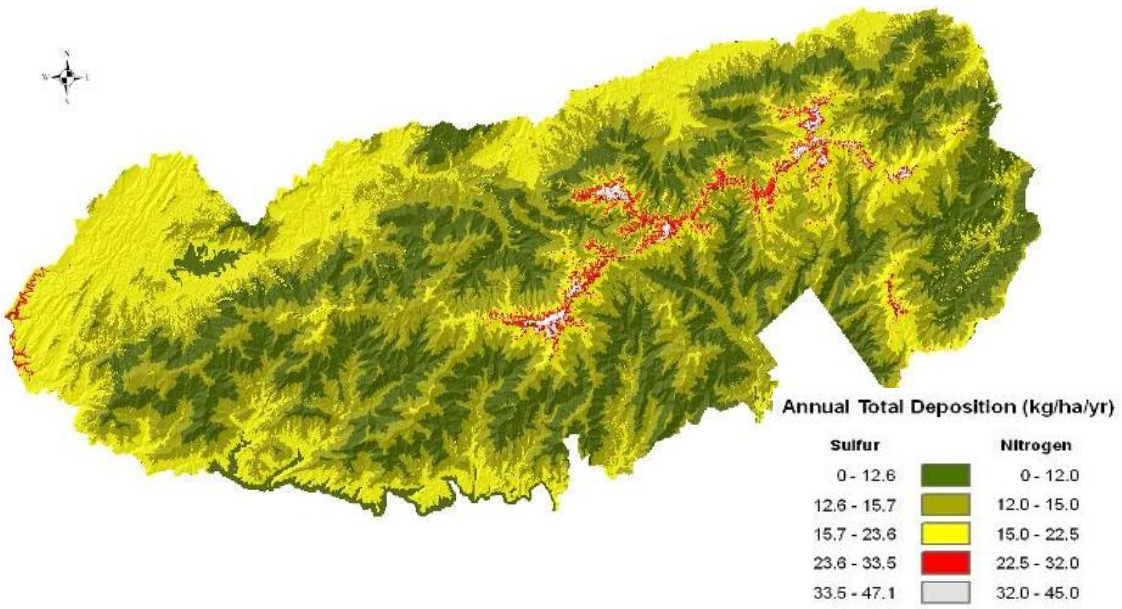


Figure 7. Modeled sulfur and nitrogen deposition in GRSM for the year 2000. Note that the highest elevations of the park along the main ridge receive the highest deposition of air pollutants (from Weathers et al. 2006).

high elevation streams, and more recently in mid-elevation streams. These stream systems are complex, and the acidity observed depends on various factors, including differing parent material chemistry among watersheds, recent geologic landslides, and organic acids released by vegetation (see Fig. 8). The Clean Water Act of 1977 requires that streams have a mean baseflow pH of at least 6.0, and if $\geq$10% of the recorded values are below 6.0, the stream must be listed as impaired and placed on the state's 303(d) list. In 2006, the state of Tennessee listed 65.6 km of 12 streams in the park as impaired (Fig. 9).

1.7.3 Exotic Invasive Species

Invasive, non-indigenous species pose serious threats to GRSM. Over 300 species of exotic plants have been documented in the park, of which about 43 pose some threat to native species and communities by competitive invasiveness and persistence once established. The park has had an active exotic plant control program for decades.

Some of the greatest forest losses in the park have been caused by Eurasian forest insects and diseases. For example, in the 1920s and 1930s the American chestnut (*Castanea dentata*) was completely decimated by the Chinese chestnut blight fungus (*Cryphonectria parasitica*). The chestnut was once one of the largest and most common overstory trees, and served an important ecological role by providing consistent nut crops for many wildlife species. Trees that existed at the time of the blight continue to sprout but no longer produce nuts. Other exotic forest insects and diseases arrived later, including the balsam woolly adelgid (*Adelges piceae*) from Europe, which caused major losses of Fraser fir at high elevations and necessitated chemical control programs, and dogwood anthracnose (*Discula destructiva*), an Asian fungal pathogen that eliminated flowering dogwood (*Cornus florida*) from some of its preferred habitat (Jenkins and White 2002).

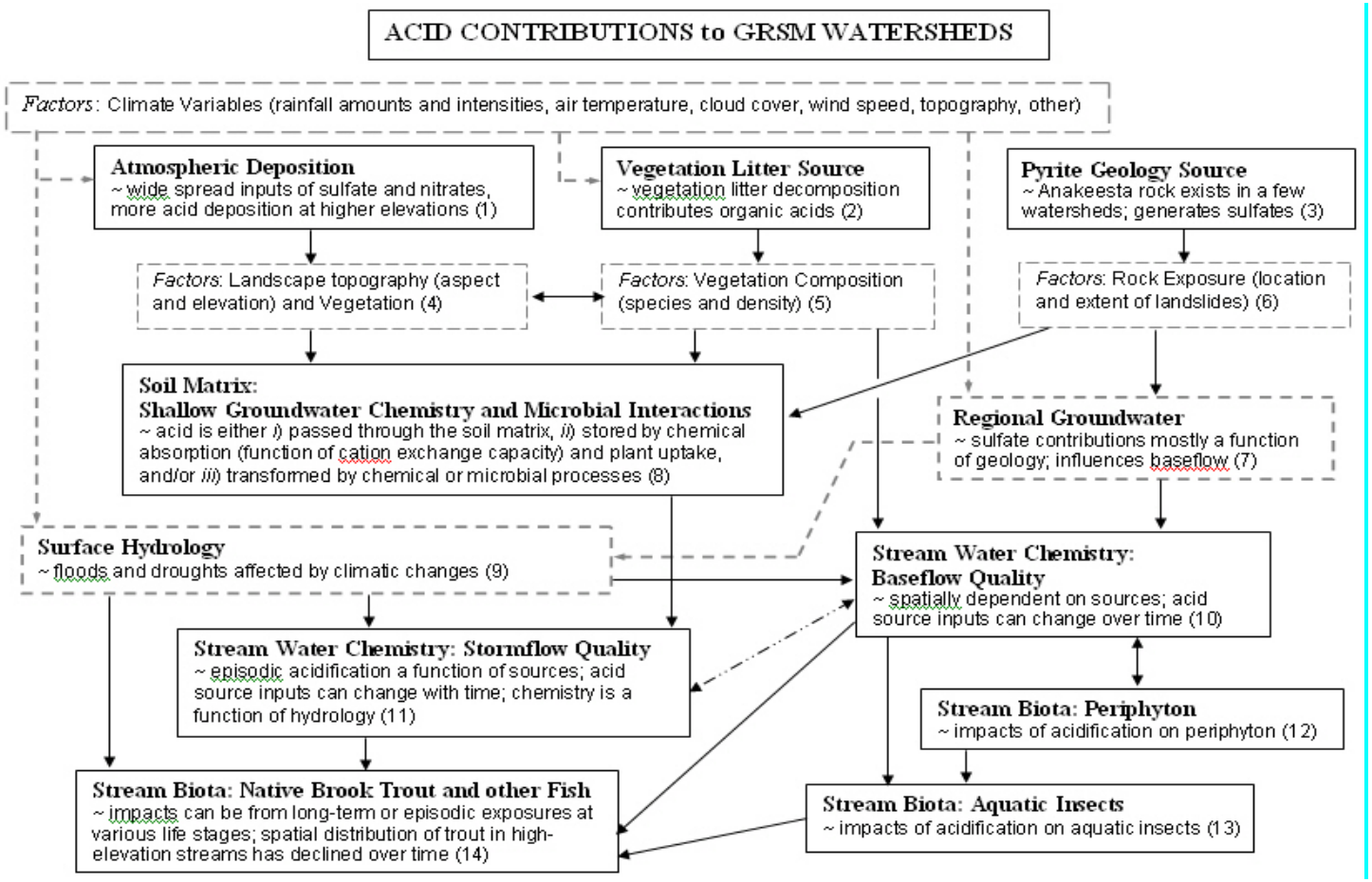


Figure 8. Acid contributions to GRSM watersheds (Schwartz et al. 2008).

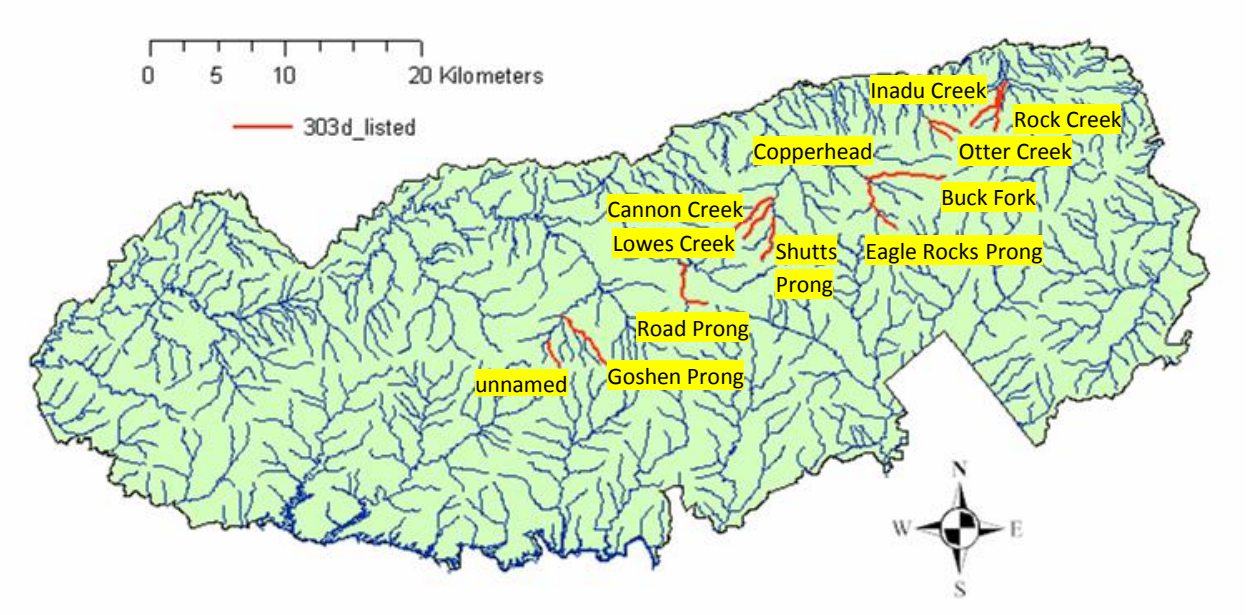


Figure 9. Map of 303(d) streams listed as impaired (pH <6.0) in Great Smoky Mountains National Park.

Currently, the eastern hemlock (*Tsuga canadensis*) is suffering massive mortality from the invasive hemlock woolly adelgid (*Adelges tsugae*). The park is attempting to save some stands with chemical and bio-control treatments. Additionally, stands of American beech (*Fagus grandifolia*) trees are dying from beech bark disease, an insect/fungal complex from Europe. Both of these trees are common canopy dominants, and once significant mortality occurs, ecological shifts will occur throughout the associated natural communities (Vandermast 2005).

The most recent forest pest to arrive in GRSM is the emerald ash borer (*Agrilus planipennis)*, or EAB, which is a wood boring beetle from Asia that attacks and kills ash trees (*Fraxinus* spp.). EAB can be easily transported in firewood, and was first documented in GRSM in May, 2012. The park plans to treat selected frontcountry trees with pesticides and is developing an EAB management plan.

In streams, introduced rainbow trout (*Oncorhynchus mykiss*) from western North America, and European brown trout (*Salmo trutta*), have displaced the native brook trout (*Salvelinus fontinalis*) from the majority of its natural distribution in the park (Larson and Moore 1985). For many of the larger park streams that have not yet been restored, introduced fish species are the dominant carnivores.

European wild hogs (*Sus scrofa*) have been rooting and disturbing roadsides, fields, and wetlands in the park for decades. The impacts of wild hogs are mitigated by an active trapping and shooting program that removes ~300 animals per year (B. Stiver, pers. comm.). Some sites are being disturbed on a regular basis, including those that are habitat for rare and/or endemic plant species.

Imported fire ants (*Solenopsis invicta x richteri*) have recently been invading disturbed low-elevation sites in the park. Research conducted in other parts of the region have shown the detrimental effects

of these ants on native invertebrate and vertebrate species, including salamanders and ground nesting birds that utilize the ground layer of forests and grasslands (Allen et al. 1994, Wojcik et al. 2001).

Another invertebrate species that recently has been discovered in the park is the Chinese jumping earthworm (*Amynthas agrestis*), which consumes partially decomposed leaf litter and other organic layers of the forest floor. Their activity reduces the number of native invertebrates that inhabit the litter layer (Synder 2008), and also may impact plants, and change long-term patterns of nutrient cycling in forested sites (Perala and Alban 1982). Biodiversity inventories indicate that the forest duff and litter layers are probably the most species-rich habitat type in the park; therefore, the park has sponsored research to look at impacts of this earthworm and potential controls.

The European bumble bee microsporidian, *Nosema bombi*, is a parasite native to European bumble bee species, and is believed to have extirpated multiple species of North American bumble bees in the last few years (Xerces Society 2010), including species within the park. This disease-causing organism threatens a number of bumble bee species, which are among the most efficient pollinators of plants. One of the missing species, *Bombus affinis*, is a known pollinator of a plant that is a strict endemic to the park (*Rugelia nudicaulis*). Research has been initiated in the park to confirm the *N. bombi* infestation (from museum specimens), and to gain insights on method of infection.

White-nose syndrome (WNS), a disease of bats caused by the fungus *Geomyces destructans*, has spread from New England to the south and west, and was first detected in GRSM in 2010. WNS affects colonies of cave-hibernating bats and appears as a whitish fungus on the nose, wings, and feet. The fungus irritates the bats, causing them to wake repeatedly, and eventually their energy is depleted so much that they freeze to death or are forced out of the cave to look for insects. Because there aren't many active insects in winter, the bats quickly succumb to starvation, freezing temperatures, and predators. Across the east, WNS has caused over 1 million bats to die, including species that are considered rare in GRSM.

Thousand cankers disease (TCD) is a beetle-vectored pathogenic fungal disease that affects walnut trees (*Juglans* sp.). The vector is the walnut twig beetle, *Pityophthorus juglandis*, and the fungus is *Geosmithia* sp. In January, 2013, TCD was confirmed on two black walnut trees (*Juglans nigra*) from the North Carolina side of GRSM in Haywood County. TCD causes branch dieback with tree mortality usually occurring within three to four years after infection. GRSM contains black walnut (*Juglans nigra*), an occasional species found in previously disturbed areas, and butternut (*Juglans cinerea*), a scarce tree and federal species of concern that has been affected by butternut canker disease *(Sirococcus clavigignenti juglandacearum*) since the late 1980s. TCD can be transported via firewood movement but walnut is not a typical firewood species.

Other exotic diseases of native plants and animals have been documented, and in all probability, many undocumented diseases occur as well. Some diseases are of unknown origin and are suspected to be non-indigenous.

1.7.4 Future Exotics

Other significant exotics will probably arrive in the near future, including the "didymo" diatom (*Didymosphenia geminata*), which can cover sun-lit stream bottoms with its fibrous mats. This species may be more of a problem in streams with a higher pH, such as in Abrams Creek, where many rare aquatic species are found. The invasive diatom is within sight of the park, although it has not been detected here to date.

The gypsy moth (*Lymantria dispar*), a European exotic, is known for defoliating oaks but will feed on nearly 300 species of trees and shrubs. It has generally infested the eastern US as far south as North Carolina and is spreading into the Midwest. Spot infestations have been discovered all around the park in east Tennessee, western North Carolina, and north Georgia; all of these infestations have been or soon will be eradicated. An exotic fungus, *Entomophaga maimaiga*, has been controlling gypsy moth populations further north for several years, and may now be slowing the moth's movement. In 2012, no male moths were captured in the 62 pheromone traps placed in the park.

The Asian long-horned beetle (ALB; *Anoplophora glabripennis*) could pose a serious threat to the park's hardwood trees. The ALB has a preference for maples, birch, buckeye, true poplars, willows, elm, and other species. The current range of this species in the US is primarily in the NE states; however, in 2011, a new infestation was discovered in southeast Ohio, which is only 300 miles from the northern edge of GRSM. Reducing firewood movement is considered a high priority.

It is not always possible to predict what the next non-native organism to arrive in the park will be. Predictions of exotic invasions can sometimes be made based on tracking novel infestations as they spread from their point of entry on the continent across the US. The generally undisturbed habitats in the park may make it harder for some exotics to establish themselves, since they often prefer disturbed areas, which are more abundant outside of the park.

1.7.5 Habitat Loss, Fragmentation, and Alteration

Habitat losses include fragmentation of naturally extensive habitats or ecologically significant corridors. For example, a number of the park's major creeks were embayed during the Fontana reservoir construction along the south side of the park in North Carolina in the 1940s, and in the late 1950s the Chilhowee reservoir was created at the west end of the park in Tennessee. Embaying these creeks destroyed important habitat and the corridors that aquatic and terrestrial wildlife used to move across the landscape. At least 10 species of fish have been extirpated from the park due to these impoundments (Simbeck 1990).

The past two decades have witnessed a significant development of the land area immediately outside the park boundary for new residential and vacation homes. This has fragmented and destroyed natural habitats that extended beyond the park's boundary, presumably affecting species that live primarily inside the park but that require habitats or seasonal ranges that exist or extend outside park boundaries. Adjacent development also facilitates dispersal of exotic species across the park boundary. Pre-park settlers heavily utilized the rich, moist, flat lands along the major streams for agriculture and homesites, and when the park was established, the NPS continued to develop these already disturbed lands for roads, campgrounds, and other visitor recreation and administrative

facilities (NPS 1982). Some natural communities are obligate to these topographic sites, such as montane alluvial forests, which have been virtually eliminated outside the park (White et al. 2003).

Sixty years of wildland fire suppression has gradually affected the park's habitat quality. Among these effects are increased shade, increased leaf litter accumulation, and altered species density and distribution. For example, in the xeric ecosystems in the west end of the park and at lower elevations, fire suppression has been a significant stressor to many plants and animals that rely on open sunlit conditions for survival. Many rare plants that require light gaps (e.g., members of Liliaceae, Orchidaceae) are now relegated to cleared trails and roadsides. Additionally, the dense woody growth and unnaturally deep forest litter inhibits reproduction in many plant species (Rock and Langdon 1991). The park is instituting prescribed burning to address this problem.

1.7.6 Climate Change

The climate is dynamic and constantly changes, but we may see changes of unprecedented magnitude in the near future. The Intergovernmental Panel on Climate Change (IPCC 2007) reviewed all global circulation models and concluded that warming over most land areas, with fewer cold days and more warm days, is virtually certain for the rest of the 21st century. There is uncertainty in model projections of the magnitude and timing of the warming trend, but there is agreement on the direction of the trend. In addition to temperature increases, climate change may bring unexpected and increased variations in local weather. Models predict more frequent occurrences of extreme weather events and these extreme weather events could alter the park's forest communities, stream flows, and fire regimes.

There is concern about increased warming and the response of natural communities in the park. A number of taxa could be lost as communities follow their thermal requirements and/or hosts by moving into the increasingly smaller areas upslope, or as they fail to adapt and die. Initial analysis of data from the GRSM All Taxa Biodiversity Inventory (ATBI) indicates that for some groups of arthropods, which are by far the most species-rich group of multi-cellular life, population size increases with elevation (N. Sanders, pers. comm.). This means that a larger percentage of the park's species is more vulnerable than we previously thought, as high elevation micro-climates disappear. A number of endemic plant species could also be at risk, since the number of endemic species seems to increase with elevation as well.

Recent field research by Fridley (2009) has resulted in a temperature model of the park. The model has been synchronized to the park's climate monitoring stations, which have been operating since the 1930s, allowing backcasting as well as forecasting. Preliminary modeling shows that a rise in regional temperature may only slightly increase temperatures at the highest elevations in the park, due to increased orographic moisture (i.e., moisture from clouds that develop in response to being forced upwards due to mountainous topography) cooling the landscape. If this hypothesis is correct, the temperature gradient will increase, and the greatest displacement of organisms may occur at the lower elevations.

The park offers a wide range of micro-climates within relatively short geographic distances. These are due to large differences in elevation, solar aspect on slopes, proximity to sheltered stream valleys,

orographic moisture, and other factors. Climate change may be favorable for survival of some sedentary species groups, which may not have to migrate very far to escape inhospitable micro-climates. Currently we do not know to what degree climate change will affect the park's species and the ecological processes that sustain them; however, it is clear that changes are occurring, and it is probable that they could be accelerating in the future.

1.7.7 Summary: About Stressors in General

The GRSM monitoring program must include measures of both anthropogenic and natural drivers. The relative importance of the types of drivers will change with time and location. Stressors confronting the park change over time; early in the park's history, resource concerns included the exotic white pine blister rust, the southern pine beetle, and soil erosion (Catton 2008). Some of the stressors that drove the formation of the 1993 plan (NPS 1993) led to questions that were stressor-specific and some of these questions have been answered, or are otherwise no longer viewed as critical. These include anglers' impact on fish resources, deer as prey for red wolves, or monitoring to determine rates of bear poaching. These were significant resource management issues, but as we learn more about the natural systems of the park, priorities need to be periodically re-examined.

The park is a complex natural system, and a better understanding only comes with years of data collection. Well-designed and implemented long-term monitoring helps us to avoid misleading interpretations (Pelton and Van Manen 1996) and to eventually make predictions with some confidence. Conversely, some natural resource issues, although serious and time-critical, are best resolved through short-term research or focused monitoring programs designed to support operational management actions. These issues do not need to be formalized into a long-term monitoring program focused on strict protocols and overall ecosystem health over a long period of time.

It is counter-intuitive to have a long-term monitoring program that is reconfigured for every new incoming or discovered threat. Rather, new threats should be anticipated, and certain "vital signs" should be selected to quantitatively measure trends in key park resources at an ecological resolution that makes sense for detection and subsequent measurement of impacts. After differentiating the impacts of anthropogenic stressors from natural trends, program personnel should recommend new research where necessary, and utilize results to establish quantitative criteria for management actions. Modification of monitoring protocols is sometimes appropriate, but this should not be undertaken lightly. It is preferable to invest time in carefully selecting what to monitor, and then developing protocols that minimize the need for future changes. The development and refinement of conceptual models enable us to determine what aspects of a vital sign should be monitored.

2. Conceptual Modeling

A conceptual model is a structure to organize complex information about ecosystems and the interactions of drivers, stressors, and the resources within it. Throughout the life of a monitoring program, managers can reference the conceptual models they developed to check progress, and discuss protocols, results, and new issues. Having a group-generated document can facilitate group communication. Once the program is underway, articulation of explicit key linkages in conceptual models is essential to justifying and interpreting ecological measurements and monitoring data (Kurtz et al. 2001).

GRSM staff and cooperators have compiled lists of natural resource issues over the past few years as part of periodic re-prioritization of projects and programs in the park. From this beginning, the process of developing conceptual models followed three steps, described below:

Step 1: GRSM resource managers and scientists held many workshops to discuss how drivers, stressors, and resources interact. A good representative model of general interactions among drivers and stressors in the Appalachians is presented by the APHN in their Vital Signs Monitoring Plan (Fig. 10). Park staff used this region-specific model as a start for their discussions about what influences are operating in GRSM.

Step 2: Matrices were developed that explicitly state ecological relationships. These matrices are structured, comprehensive listings of resources and the drivers/stressors that are believed to cause change. Matrix entries were derived from research in the park and elsewhere, inventories, current monitoring programs, other agencies, and park staff experience (see Table 1 for a matrix example).

Step 3: The matrices were transposed into general graphic models which were frequently revised as team discussions evolved. These helped define some of the monitoring themes, questions, and considerations as the process went on. As the modeling process continued in group discussions, a convergence of some aspects of the models occurred. A general conceptual model was developed for the entire park (Fig. 11), and then refined for specific vital signs (see Section 3).

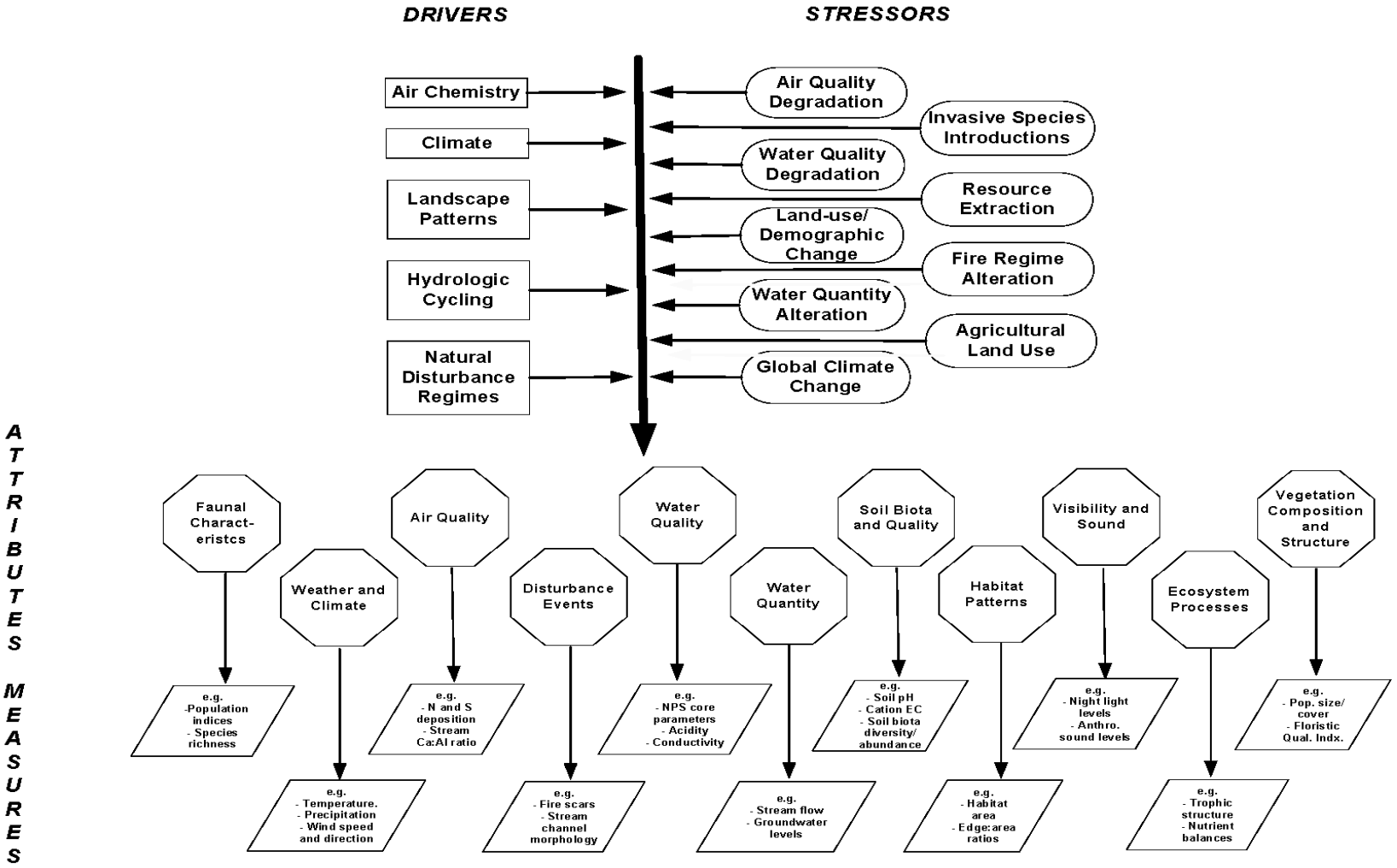


Figure 10. Conceptual model for the Appalachian region, from the APHN Vital Signs Monitoring Plan (NPS 2005). Drivers refer to natural systems and regimes that may be altered by stressors.

Table 1. An example of the framework used by GRSM, modified from the NPS Ecological Monitoring Framework (see Fancy et al. 2009), with levels 1, 2, and 3 unchanged.

LEVEL 1: Key Ecosystem Condition	**LEVEL 2:** Key Ecosystem Condition	**LEVEL 3:** Vital Sign Category	**LEVEL 4:** What category or ecosystem does this condition affect?	**LEVEL 5:** What group or species does this condition affect?	**LEVEL 6:** How does the condition manifest itself in this species (e.g., impact or process)?	**LEVEL 7:** How/what should be monitored to better understand or evaluate this dynamic?
Air and Climate	Air Quality	Wet and Dry Deposition	Terrestrial Forests	Primary native plant productivity	Inhibits native plant regeneration	Regeneration of select native plants in plots
				Native plant reproduction	Inhibits native plant reproduction	Abundance of age-0 native plants in plots
				Plant/animal diversity	Reproductive difficulties or acidification of soils	1. Abundance of age-0 northern flying squirrels 2. Soil chemistry in plots
				Animal populations: mammals, bats	Abundance declines due to loss of insects	Insect diversity and relative abundance
				Animal populations: birds	Abundance declines due to loss of habitat/food	1. Forest and vegetation diversity and relative abundance 2. Insect diversity and relative abundance
				Animal populations: amphibians	Acidification of habitat beyond tolerances	1. Distribution of native amphibian species 2. Pond water chemistry
			Soils	Microbial fauna	Acidification of habitat beyond tolerances	1. Distribution of soil species 2. Soil water chemistry
				Invertebrates	Acidification of habitat beyond tolerances	1. Distribution of species 2. Soil water chemistry

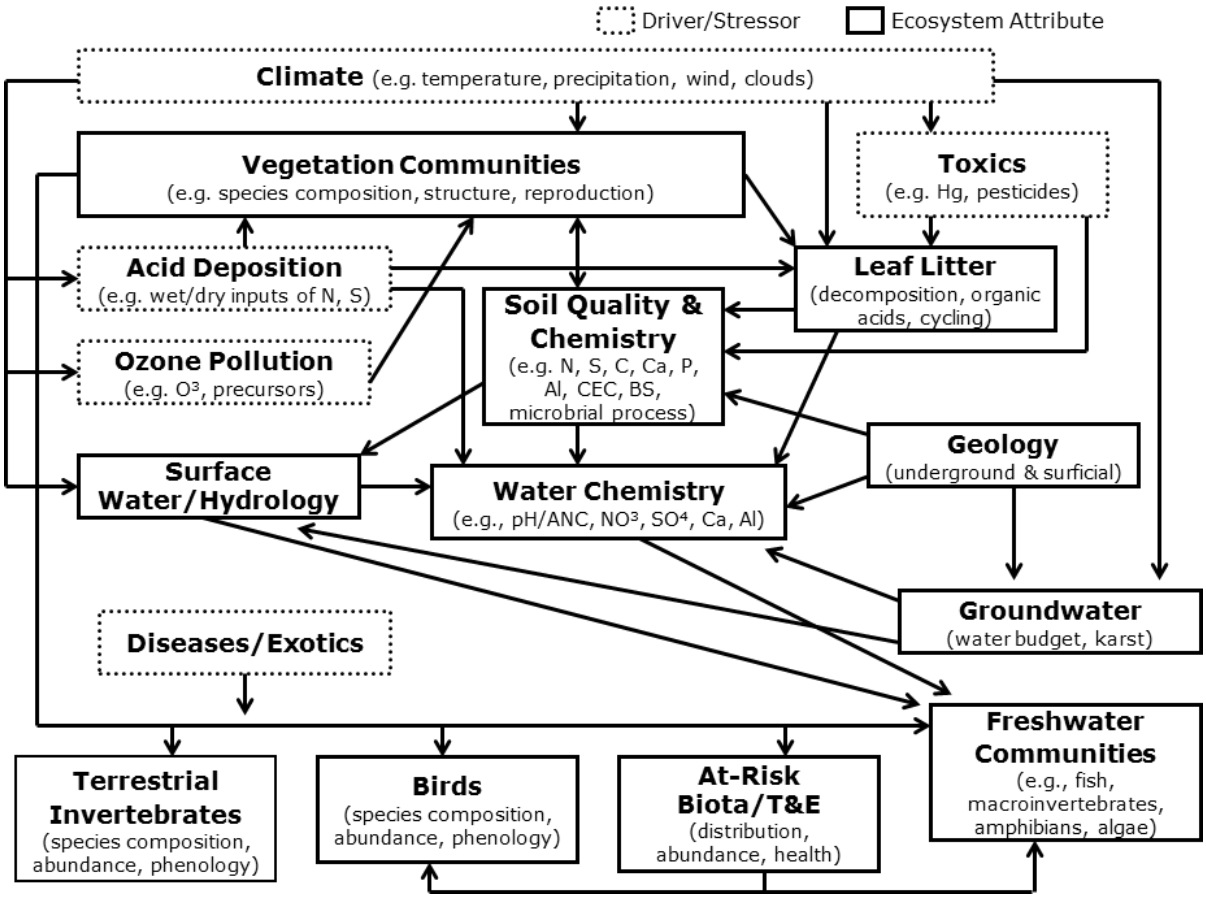


Figure 11. General conceptual model for GRSM showing ecosystem attributes, their interactions, and the drivers/stressors impacting them. Arrows refer to direct relationships and/or influences.

3. Vital Signs

3.1 GRSM Process for Vital Sign Identification and Prioritization

Our goal is to create one integrated program of monitoring protocols, with all components informing the others. By doing so, the results will yield more information for the park as a whole than would be possible with the same number of independently derived protocols.

Typically, there are four dimensions to integrating monitoring programs which are considered key to a successful program, and are being used throughout the development process for GRSM.

1. **Ecological:** Take into account the ecological linkages between resource groups, ecological pathways, nutrient and stressor flow, etc.
2. **Spatial:** Consider the best sites to co-locate measurements for multiple protocols and ensure that sampling is designed to make statistically valid assumptions about the geographic scale being sampled.
3. **Temporal:** Determine the best monitoring re-measurement interval and season for the target guild or community, and how the interval is related to data needs of other protocols.
4. **Programmatical:** Use standard observation methodologies that contribute unique information to the overall monitoring program of the park.

Designing a new monitoring program requires a process and a comprehensive understanding of the park's ecological interactions, resources, and threats. With nearly 20 years of monitoring experience, and most of the original program supervisors still in the park, GRSM's monitoring program has extensive institutional experience on which to draw. Additionally, several recent scoping sessions on science needs helped document the breadth of resource issues, drivers, and stressors (Appendix A). Given the unique history of the GRSM prototype monitoring program, some modifications to the network approach were necessary. The network process involved multiple parks, boards of directors, and other steps that were not relevant to the GRSM program. While the overall process and goals of GRSM are the same as that followed by networks, specific steps are sometimes different.

3.2 Development of Conceptual Models for Ecological Processes

In 2009, a team of 12 natural resource specialists from GRSM began development of the new monitoring program. Existing models and newly developed ones from recent research, inventories, and monitoring were discussed as a group. They were improved, modified, and discussed again until the team reached a consensus. These models were examined at different scales, including at a park ecosystem scale.

3.3 Organizing Candidate Vital Signs

Using the ecological monitoring framework provided by the Service-wide Inventory and Monitoring program (NPS 2010), a comprehensive list of potential resource monitoring topics was developed through staff and recent science scoping efforts. Over 120 potential monitoring-related questions were identified for consideration and further prioritization. Topics ranged from air, water, and climate concerns to natural communities, biological groups, rare species, and geology. Current and

former monitoring components were included in the discussion, but were not weighted; rather, they were ranked objectively with the other potential vital signs. See Appendix A for the complete list of monitoring questions that were developed. This process also identified important resource questions that did not seem to fit within the monitoring plan; these were identified as topics for future research or inventory. Research topics that support monitoring, including ideas developed independently of this monitoring plan process, are listed in Appendix B.

3.4 Ranking of Vital Signs

The three major categories of evaluation criteria usually considered for ranking vital signs are: 1) ecological significance, 2) legal mandates, and 3) management priorities (NPS 2010). Extensive discussion resulted in a phased evaluation of these three categories. GRSM had already integrated management and legal issues into many programs, projects, and other activities; therefore, ecological significance was selected as the major focus of ranking. Management priorities and legal issues were addressed after selection, and in conjunction with all other monitoring, research, and inventories undertaken in the park.

The complete list of over 120 monitoring questions was too long to practically rank; therefore, questions that were research or inventory-oriented were removed. This brought the number of questions down to 100. The list was then refined to include only monitoring questions that directly related to significant resource attributes considered to widely reflect the overall health of the park's ecosystems. These questions were then placed into ecological monitoring categories, or potential vital signs. The resulting list of 24 potential vital signs was then ranked by each of the 12 team members using six standard ranking criteria (below):

1. The potential vital sign is of long-term, high ecological importance to the park (versus a short-term critical issue, or of moderate importance)
2. Monitoring of the potential vital sign would detect/quantitatively track long-term ecological trends
3. The potential vital sign is a leading indicator of change in the ecosystem (versus some which are better at quantifying after-the-fact impacts)
4. Monitoring of the potential vital sign would contribute to the understanding of ecosystem function and is representative of the overall health of the park
5. The potential vital sign is ecologically inter-related/linked with other monitoring components
6. The implementation of a monitoring protocol is practical as related to: cost, staff time, impact to park, safety, etc.

The six top scoring potential vital signs (Fig. 12), which all scored above 550 points, were designated as critical, and therefore were considered the highest priority for implementation. The remaining 18 were regarded as important vital signs and will receive subsequent consideration for implementation, but only as a second priority after planning for the critical vital signs which are best viewed as the

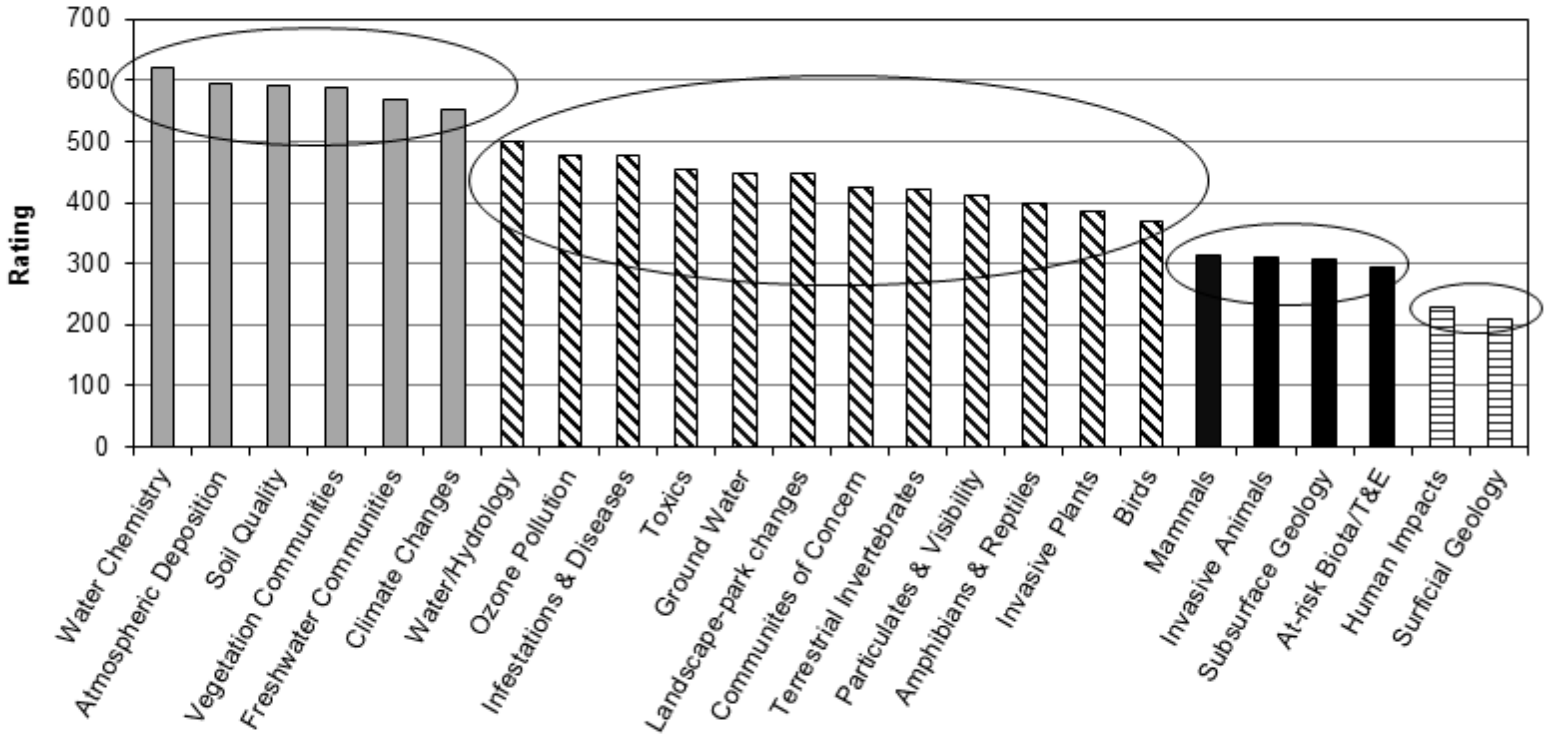


Figure 12. Combined ratings of the 24 I&M ecological monitoring categories at GRSM. Ratings were based on the team's average numerical score for each of the six ranking criteria.

core of the new program. The six critical vital signs that were provisionally selected are presented in the following sections. Thresholds will be set for each metric in consultation with the most authoritative sources available. In some data sets, not enough of a trend has been established to define reliable thresholds yet. In those cases, the threshold may be arbitrarily set (with justification), and will likely need to be re-set in the future. Initially, thresholds for general resource groups and phenomena may be set with more flexibility than those for specific, vulnerable resources. A specific indicator that reaches a threshold will mean increased scrutiny to explain the change. This investigative effort is expected to be commensurate to the magnitude of the change detected.

3.4.1 Critical Vital Sign: Acid Deposition

3.4.1.1 Background and Justification

The Clean Air Act of 1970 was amended in 1977 to provide tools that could be used to protect air quality and related values (including visibility, flora, fauna, surface water, ecosystems, and historic resources) in national parks and wilderness areas (42 U.S.C. 7470-7469). In particular, Congress established a new program to prevent significant deterioration of air quality in areas where the air was cleaner than national standards. The highest degree of protection was given to areas referred to as Class 1, which included all 156 national parks that exceeded 2428 ha (6000 ac) in size as of 1977. GRSM is designated as a Class 1 area.

Air-borne pollutants (i.e., sulfur, nitrogen, ozone, particulate matter, mercury, carbon), mostly from emissions outside the park, are degrading park resources and visitor enjoyment of scenic vistas (SAMI 2002), and fossil fuel combustion from power plants, factories, and motor vehicles are the primary source of these emissions (SAMI 2002). The height and physical structure of the southern Appalachians combined with predominant weather patterns tend to trap and concentrate these anthropogenic emissions and pollutants. Although many significant air quality issues exist at the park, acid deposition will be the focus of this particular vital sign.

3.4.1.2 Current Sampling Design and Approach

Since 1993, the overall air quality monitoring program has significantly expanded its efforts to comprehensively cover the spatial, temporal, and jurisdictional scales of the park, with the following goals and objectives in mind:

- determine compliance with NAAQS (e.g., O_3 and $PM_{2.5}$)
- establish baseline visibility conditions and air pollutant concentrations and deposition
- identify air pollutants which may injure or damage park natural resources, and measure them (e.g., sulfur, nitrogen, ozone, particulate matter, mercury, carbon)
- identify and assess trends in air quality
- determine sources of air pollutants affecting park resources (e.g., utilities, vehicles)
- determine the relative importance of atmospheric constituents to visibility impairment, ozone formation, and acid deposition

- provide data for the development and revision of national, regional, and local air pollution control policies that are protective of park resources (e.g., Regional Haze Plans)
- provide data for atmospheric model development and evaluation.

The park air quality section operates one of the most comprehensive air quality monitoring programs in the US, including monitoring ozone and trace gases (SO_2, CO, NO-NO_y, NO_2, NH_3), wet/dry/cloud/throughfall deposition (N, S, Hg, base cations), visibility, particulate matter, and meteorology. Air quality data is collected and summarized annually from the seven established air monitoring stations in the park (Fig. 13).

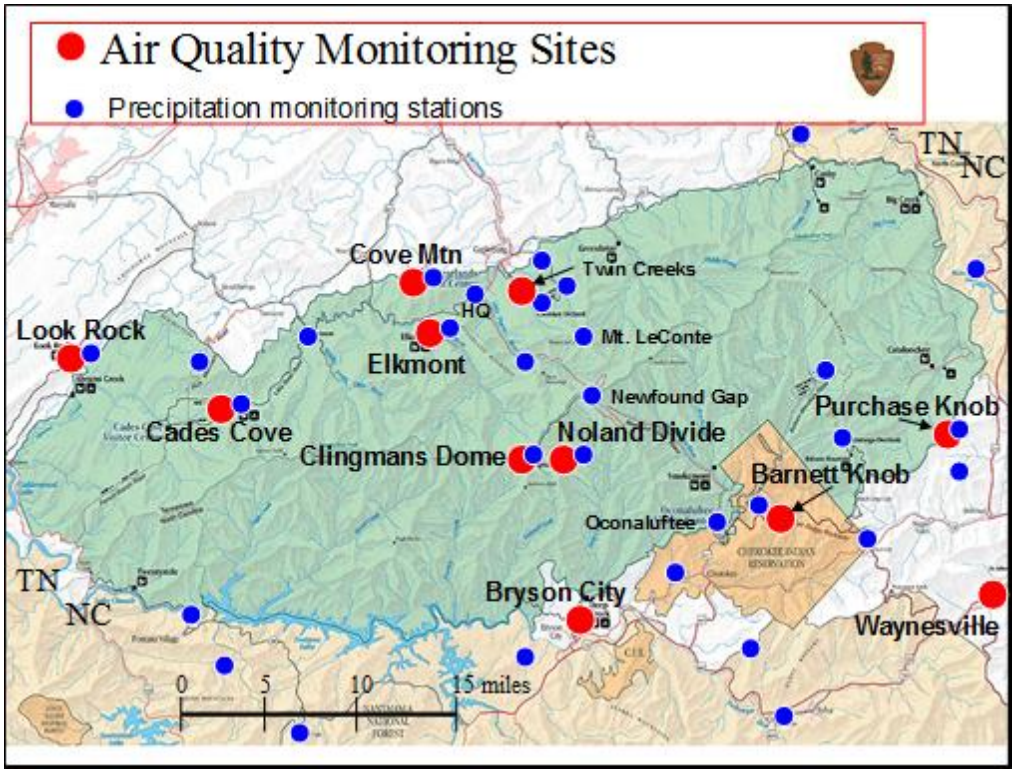


Figure 13. GRSM air quality and precipitation monitoring sites.

Information collected from these sites have allowed for the park to be evaluated under existing and future air quality conditions (e.g., new public health standard, trends analysis, proposed federal emission control program) by the NPS, states, US Environmental Protection Agency (EPA), industry, environmental groups, media, and the general public. The park will continue to be evaluated for potential changes from actions the US will take in air quality management.

The park receives some of the highest measured amounts of sulfate and nitrate deposition in the US (Lindberg 1992, NADP 2008). The park maintains two wet deposition collector sites; one at Elkmont, a low-elevation valley site (640 m), and Noland Divide, a high-elevation ridge top site (1737 m). These pollutants are deposited not only via wet processes (rainfall and snowfall) but from dry particles, gases, and cloud water/fog.

The acidity of precipitation is a good indicator of air quality. The average annual pH of rainfall in GRSM is 4.7; approximately 10 times more acidic than natural rainfall, which has a pH of 5.6 (NAPAP 1990). Cloudwater acidity measured at Clingmans Dome averages 3.6 pH, and can be as low as 2.0 pH. These clouds bathe the high elevation forests during much of the growing season and are a significant source (approximately 50%) of nitrogen and sulfur deposition to the higher elevations of the park (Li and Aneja 1992, MADPro 2007, Lovett et al. 1982).

3.4.1.3 Acid Deposition Monitoring Questions

- What are the park-wide statuses and trends of wet and dry atmospheric deposition of sulfur, nitrogen, and major cations?
- How does acid deposition relate to critical loads for aquatic and terrestrial resources, Total Maximum Daily Loads (TMDLs) for park streams, and progress toward ecological restoration?

3.4.1.4 Metrics Needed to Answer these Questions

- annual wet, dry, cloud, and throughfall acid deposition (major acid anions/cations) as measured by weekly wet (including precipitation) and dry chemistry and deposition samples
- park-wide GIS models of total nitrogen and sulfur deposition
- periodically updated/validated/re-evaluated park-wide acid deposition model due to changing climate, landscape features, and deposition rates.

3.4.1.5 Acid Deposition Monitoring Design Considerations

- ability to correlate with water quality monitoring sites using models
- ability to correlate with freshwater community, and soils monitoring sites using models
- co-location with water quality, hydrology, climate, and vegetation sites.

3.4.1.6 Acid Deposition Monitoring Approach

The park will continue to maintain the current acid deposition monitoring stations at Elkmont and Noland Divide. Wet deposition of nitrogen, sulfur, and the major cations are measured at Elkmont (Fig. 14), which is part of the National Atmospheric Deposition Program (NADP) - a network of 250 monitoring stations in the US. Throughfall deposition, wet deposition, and cloud deposition will continue to be measured in the Noland Divide watershed (Fig. 15), and Clingmans Dome air quality stations will continue cloudwater deposition monitoring.

The park is one of approximately 70 CASTNet (Clean Air Status and Trends Network) monitoring stations in the US. Established in 1987, CASTNet is considered the nation's primary source for atmospheric data to estimate dry acidic deposition. The only CASTNet site in GRSM is located at Look Rock, on the Tennessee side, and it is monitored weekly for atmospheric concentrations of sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid, and hourly for concentrations of ambient ozone and meteorological conditions, which are required for calculating dry deposition rates at high and low elevations. Dry deposition rates (Fig. 16) are calculated using atmospheric concentrations, meteorological data, and information on land use, vegetation, and surface conditions.

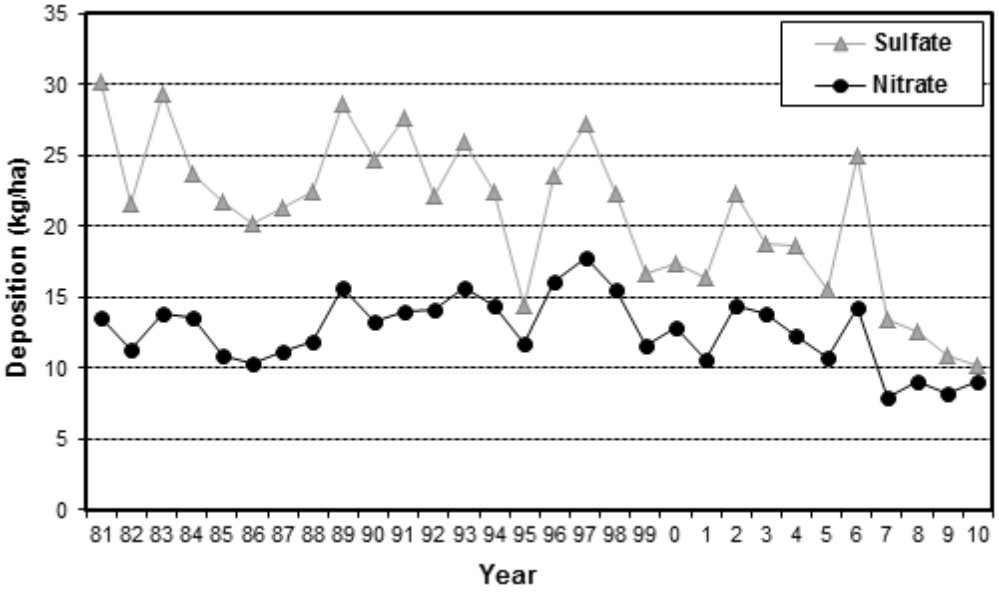


Figure 14. Annual wet sulfate and nitrate deposition at Elkmont, GRSM.

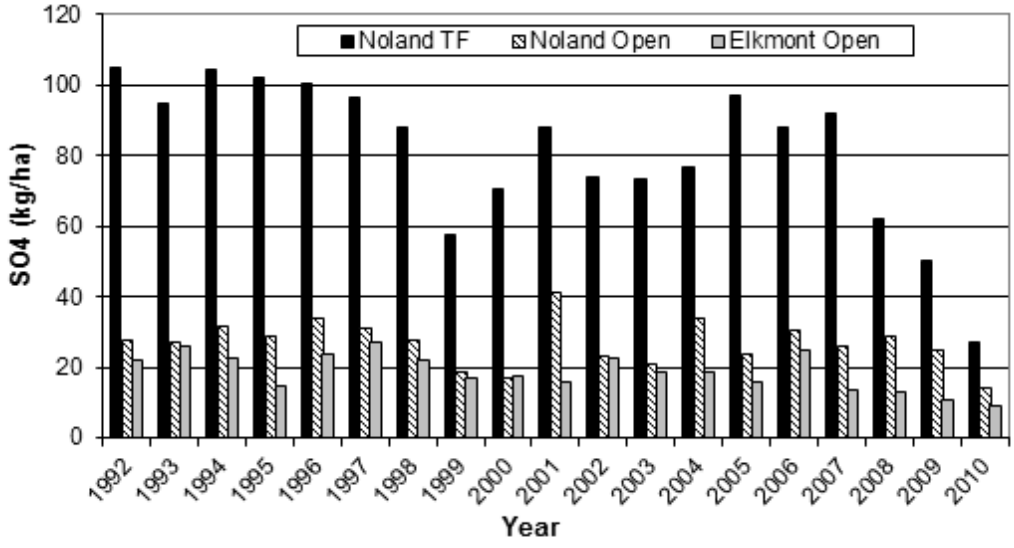


Figure 15. Sulfate deposition at Noland Divide and Elkmont, GRSM, over time. (open = wet-only, TF = through-fall).

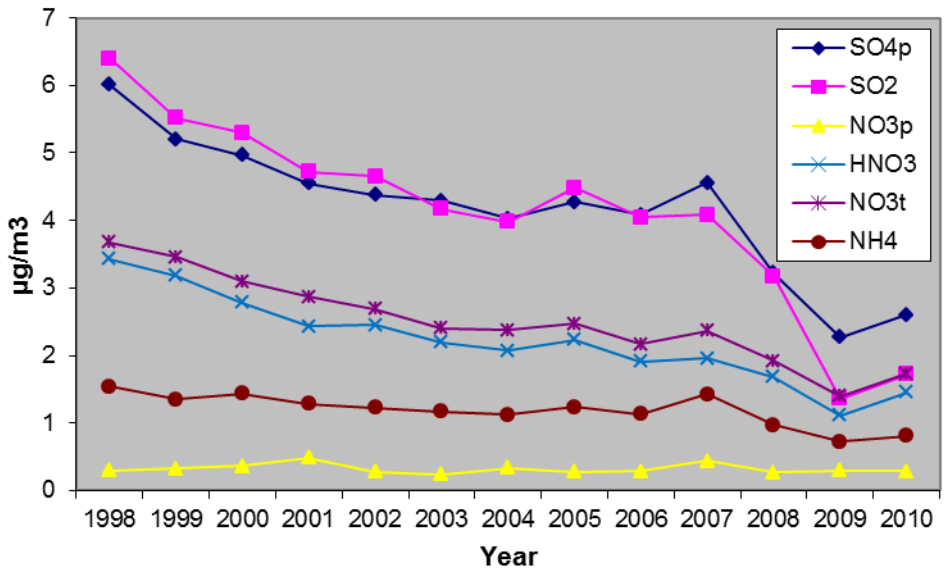


Figure 16. Annual dry deposition chemistry at Look Rock, GRSM.

The park also maintains a high resolution GIS map of total nitrogen and sulfur deposition for the entire park (Fig. 7). Together, these databases provide the necessary data to estimate long-term trends and spatial patterns (30 m resolution) in total atmospheric deposition at the park and provide critical inputs to the water chemistry, freshwater communities, soil quality, and vegetation communities vital signs.

3.4.1.7 Linkages of Acid Deposition to Chemical and Biological Effects

Atmospheric deposition of nitrogen and sulfur can acidify sensitive aquatic and terrestrial resources, both chronically and episodically (Nodvin et al. 1995, Smoot et al. 2000). Research at GRSM has shown that some high-elevation soils in the park are receiving so much airborne nitrogen that it exceeds the assimilation capacity of ecosystems, a condition commonly known as nitrogen saturation (Flum and Nodvin 1995, Van Miegroet et al. 1992). This limits the availability of forest nutrients (mainly calcium) to plants and causes the mobilization of toxic ions such as aluminum that can harm vegetation and aquatic biota and impact forest growth and composition (Johnson et al. 1991, Eagar and Adams 1992). Ecological concerns include the leaching of nitrogen and depletion of calcium from ecosystems, which affects productivity, soil chemistry, water quality, and resistance/tolerance of biota to other stresses (Eager et al. 1996, Johnson and Lindberg 1992). (see Conceptual Model for Acid Deposition, Fig. 17)

Sensitive mountain streams and forest soils are being acidified to the point that the health of the park's high elevation ecosystems are in jeopardy (Flum and Nodvin 1995, SAMI 2002). Some high-elevation park streams have the highest nitrate levels of any systems in the US that drain undisturbed watersheds (Stoddard 1994), and these levels are approaching the public health standard for drinking water (NCDENR 2010). These acidification levels lead to declines in aquatic diversity, including for

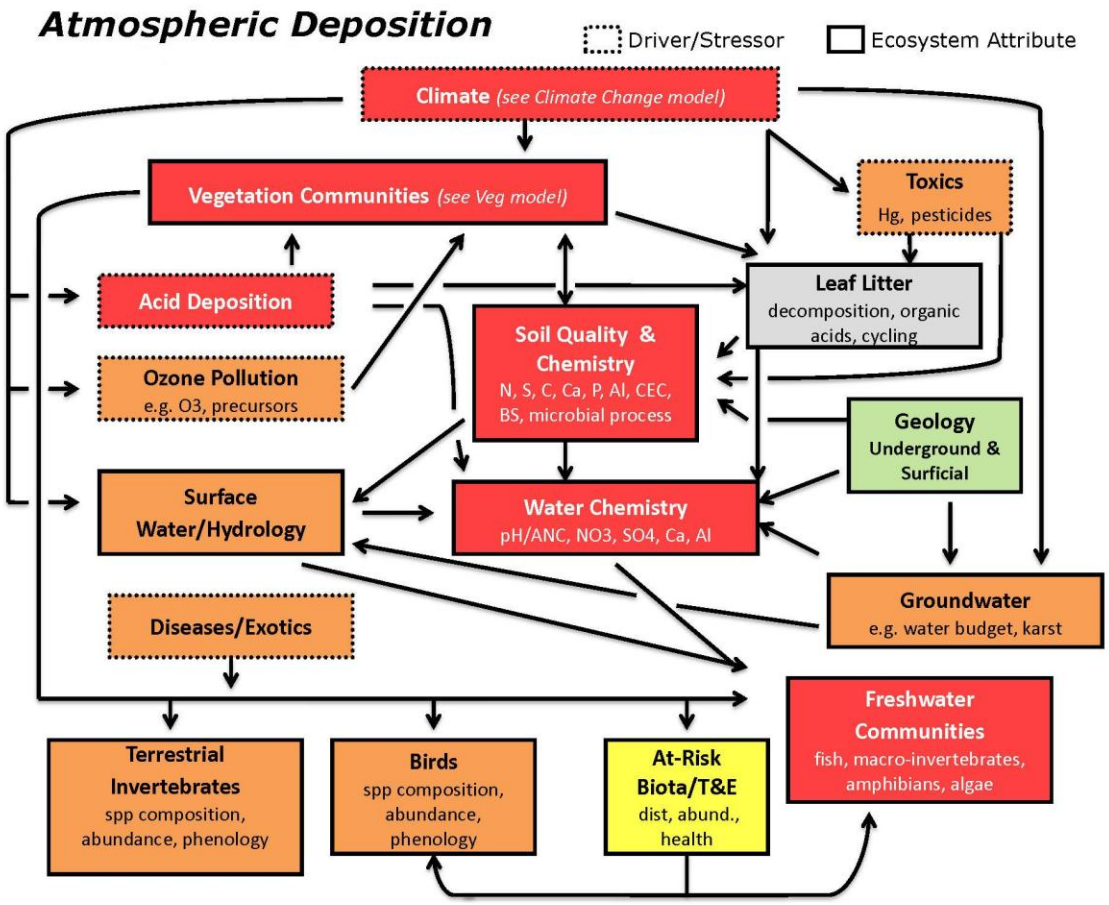


Figure 17. Conceptual model developed for acid deposition. Arrows refer to direct relationships and/or influences.

The native brook trout (Herlihy et al. 1996, SAMI 2002). In addition, naturally occurring organic acids are thought to play a key role and may confound the stream acidification issue (Cook et al. 1994).

Acid deposition affects various ecosystems in GRSM differently, depending primarily upon their buffering capacity. The higher elevation systems and those areas underlain by non-limestone geology are the most vulnerable to change (Smoot et al. 2000). Nitrate and sulfate concentrations increase with elevation, and pH and acid neutralizing capacity (ANC) decrease with elevation (Smoot et al. 2000); therefore, elevation, forest type and buffering capacities are important factors in risk assessment. Nearly 30 years of monitoring and research show that despite some recent improvements in air quality, the park's sensitive scenic, terrestrial, and aquatic resources remain degraded by human-made air pollution.

Because air and water systems are inextricably linked, poor air quality is also detrimental to the park's water quality and freshwater communities. For a full discussion of water quality threats from air pollution, see section 3.4.4 Critical Vital Sign: Water Chemistry.

3.4.1.8 Explanation of Indicators, Current Conditions, and Reference Conditions

Several types of reference conditions are used depending on the information available. They may be based on recovery or implementation plans (e.g., TMDLs/critical loads), federal or state standards (e.g., ozone and $PM_{2.5}$ NAAQS), recommendations from the scientific literature, studies, and empirical data (e.g., ozone W126), comparisons of current conditions to that of prior years (e.g., natural conditions), and in some cases, park managers have not determined them yet (e.g., aquatic TMDLs/critical loads). Each reference condition serves to inform park managers about whether a resource has significantly changed or is approaching or exceeding a threshold of concern.

3.4.2 Critical Vital Sign: Vegetation Communities

3.4.2.1 Background and Justification

GRSM is internationally renowned as a center of biological diversity within North America. In particular, complex ecological gradients combine to create a diverse mosaic of plant communities whose native species number over 1300. The biological importance of GRSM led to its designation as an International Biosphere Reserve in 1976, and supported its designation as a World Heritage Site in 1983.

GRSM has a history of vegetation monitoring; however, future monitoring will focus more on emerging threats that will allow park staff to detect incipient stressors, while assessing impacts and making predictions of future forest health. Despite its large size (>200,000 ha) and protected status, many biotic and abiotic factors have altered and continue to threaten plant communities within GRSM. Among biotic factors, exotic species have been the most destructive; these were discussed in Section 1.7.3.

Native ungulates also exert considerable influence on the composition and structure of native vegetation by selectively browsing certain species. In the woodlots in and around Cades Cove, white-tailed deer (*Odocoileus virginianus*) have altered the cover, diversity, and population demographics of forest herbs (Griggs et al. 2006, Webster et al. 2005a). In 2001, GRSM reintroduced elk (*Cervus elaphus*) to the park. This species may have considerable long-term effects on a wide range of vegetation communities throughout the park.

Atmospheric deposition of sulfur and nitrogen from wet, dry, and cloud processes may acidify soils in susceptible areas, resulting in greater aluminum toxicity (Cronan and Schofield 1990) and decreased soil nutrients that limit growth for many plants. In addition, high ozone exposures can stress plant populations at high elevations (Somers et al. 1998) in the park and cause visible foliar injury, growth reductions, and species composition changes to certain forest types (e.g., cove hardwood forests). (see Conceptual Model for Vegetation Communities and Soil Quality, Fig. 18)

In addition to these factors, alterations in the park's disturbance regimes have impacted vegetation communities. Throughout the park, plant communities continue to recover from past unregulated logging and agricultural use that occurred before the park was established (Pyle 1988, Webster et al. 2005b). Additionally, fire suppression has allowed for the succession of many pine stands to hardwood dominance, and pine mortality from the southern pine beetle (*Dendroctonus frontalis*) has

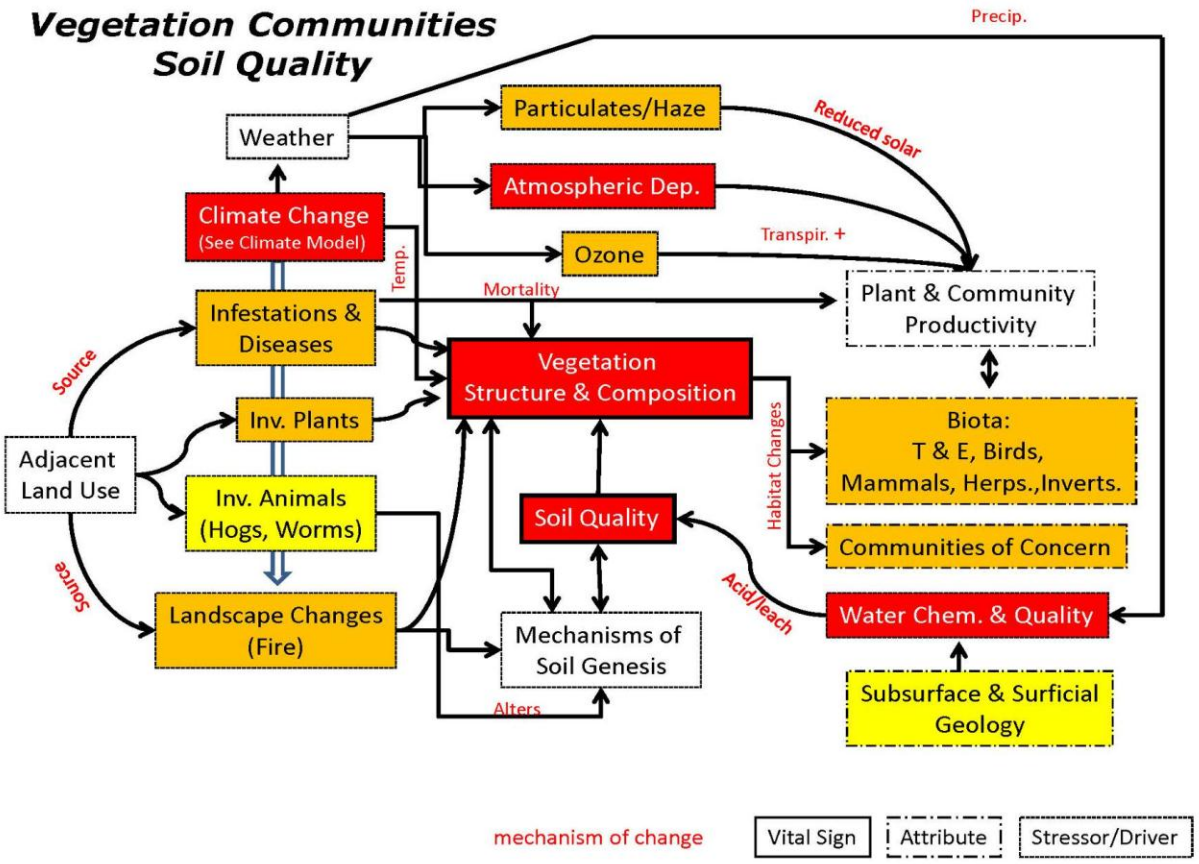


Figure 18. Conceptual model developed for vegetation communities and soil quality. Arrows refer to direct relationships and/or influences.

accelerated this succession (Coulson et al. 1999). Within hardwood stands, oak species on mesic sites will not regenerate under closed canopies without the reintroduction of fire at regular intervals.

3.4.2.2 History of Permanent Plots

Forest vegetation studies in GRSM involving plot sampling have been conducted since the 1930s. The most extensive study, which was completed in the late 1930s by F. H. Miller, was a park-wide survey of the vegetation types within the existing park boundary. More than 1100 plots were sampled, and a vegetation map was drawn from the data. This map has been recentlydigitized; however, the plots were not permanently marked in the field, and therefore cannot provide detailed information on vegetation dynamics (White and Busing 1993). During the late 1970s through the early 1980s, over 400 permanent vegetation plots were established and sampled in western GRSM, and between 1995 and 2001, graduate students from the University of North Carolina-Chapel Hill and GRSM staff re-located and sampled over 200 of these plots. Additional plots have since been established, and there currently are more than 1300 vegetation plots in GRSM (not including the Miller plots). Many of these plots were set up by researchers and have not been sampled on a regular basis, whereas others are permanently marked and have been revisited (Fig. 19).

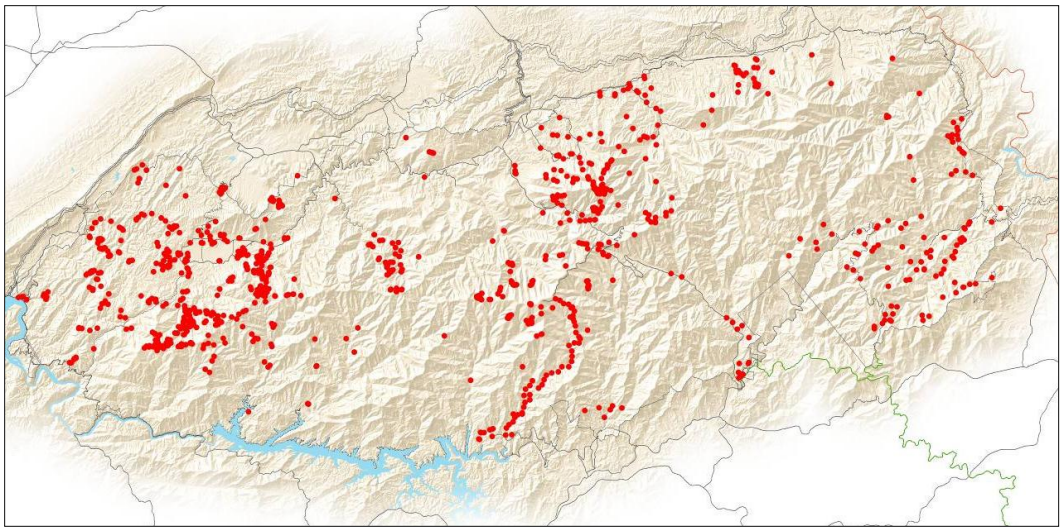


Figure 19. Permanently marked vegetation plots in GRSM, from various projects. This does not include the Miller plots.

3.4.2.3 Vegetation Communities in GRSM

According to NatureServe, GRSM has 79 unique vegetation communities (White et al. 2003) comprised of over 1650 vascular plant species (native and non-native). Jenkins (2007) grouped the 79 vegetation communities in GRSM into 11 major types of communities based on similarities in vegetation composition. Eight communities are forested types (montane alluvial forests, early successional forests, cove forests, hemlock forests, montane oak-hickory forests, xeric ridge forests, high-elevation hardwood forests, and spruce-fir forests) and three are non-forested types (heath balds, grassy balds, and grasslands). We modified the groupings to include wetlands and combined pine and oak forest types (Fig. 20). Below are the dominant vegetation communities (1-4) and their leading concerns, followed by additional vegetation communities of concern (5-10) and their leading stressors:

1. Oak-pine Forests (combination of Montane Oak-Hickory forests and Xeric Ridge forests): Oak-pine forests represent 47% of park area. Oaks (*Quercus* spp.) and pines (*Pinus* spp.) dominate these forest types, many of which have been highly altered by fire exclusion practices, southern pine beetle, and the loss of American chestnut (*Castanea dentata*). Oak mast is an important food source for mammals and invertebrates (Matschke 1964, Henry and Conley 1972, Scott and Pelton 1975, Wathen 1983, Pozzanghera 1990, Wentworth et al. 1992, Wolff 1996, Vaughn 2002).
2. High-elevation Hardwood Forests: High-elevation hardwood forests represent 17% of park area. Canopy dominants include yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*), and northern red oak (*Quercus rubra*). High-elevation beech gaps are one of the most threatened communities in the southern Appalachians due to beech bark disease and hog damage (Bratton 1975, Howe and Bratton 1976, Huff 1977, Howe et al. 1981, Lacki and Lancia 1986). Ozone has been shown to damage herbaceous species within this vegetation type (Somers et al. 1998).

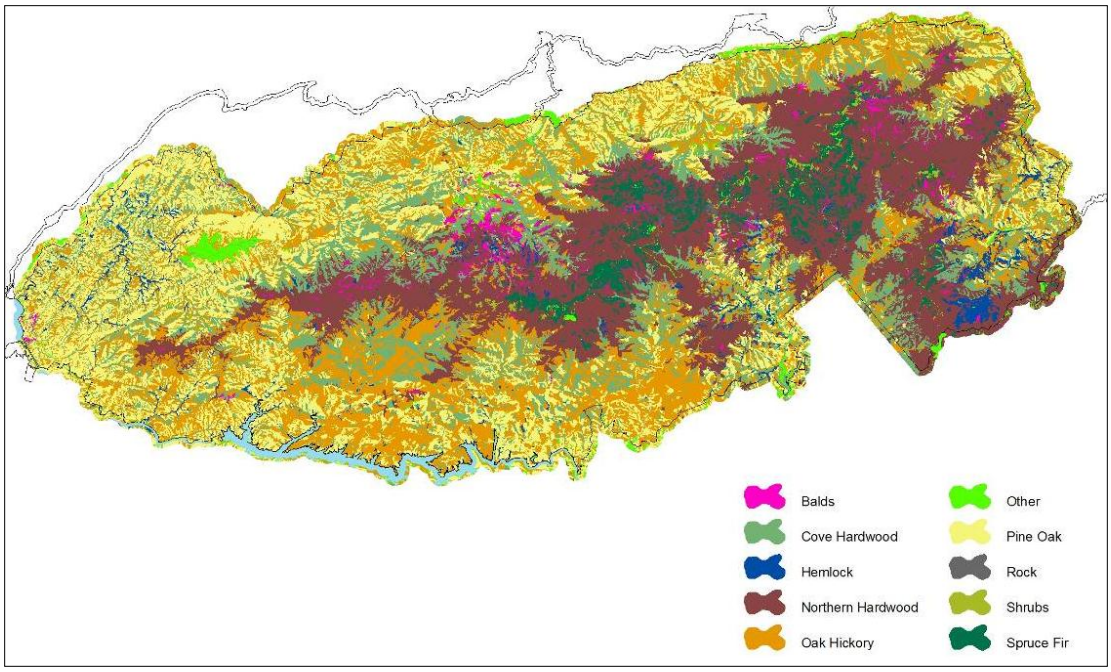


Figure 20. Major vegetation communities in GRSM.

3. Cove Hardwood Forests: Cove hardwood forests represent 12% of park area. Cove forests are the park's most floristically diverse hardwood community, with canopies dominated by sugar maple (*Acer saccharum*), yellow buckeye (*Aesculus flava*), American basswood (*Tilia americana* var. *heterophylla*), silverbell (*Halesia tetraptera* var. *monticola*), eastern hemlock (*Tsuga canadensis*), tulip poplar (*Liriodendron tulipifera*), sweet birch (*Betula lenta*), and red maple (*Acer rubrum*). Ozone has been shown to have a negative effect on growth in sensitive species and causes compositional shifts in this community (SAMI 2002).
4. High-elevation Spruce-fir Forests: Spruce-fir forests represent 8% of park area. Spruce-fir forests within the park represent 74% of all spruce-fir in the southern Appalachians (Dull 1988). These forests provide critical habitat for a number of endangered and endemic plants and animals (USFWS 1990). At least 90% of mature Fraser fir have been killed by balsam woolly adelgid since it was found within GRSM in 1960 (Dull 1988). Additional stressors include chronic acid deposition, ozone, and climatic stress (Johnson et al. 1986).
5. Early Successional Forests: Early successional forests represent 5% of park area. This forest type regenerated on abandoned agricultural land or heavily logged areas, and is transitional on the landscape. Species typically occurring in this forest type are tulip poplar (*L. tulipifera),* black locust (*Robinia pseudoacacia*), and Virginia pine (*Pinus virginiana*). Known stressors include ozone and southern pine beetle (*Dendroctonus frontalis*) (SAMI 2002).
6. Hemlock Forests: Although hemlock forests comprise only 2% of park area, it is one of the most common tree species in the park and occurs as a co-dominant or sub-canopy species across a broad range of forest community associations (Jenkins 2007). Hemlock forests in the

park have seen widespread mortality due to the hemlock woolly adelgid (*Adelges tsugae*), which was first found in GRSM in 2002.

7. Montane Alluvial Forests: Montane alluvial forests represent 1.3% of park area. This type is uncommon in GRSM because it occupies a very discrete landscape position. Species occurring in montane alluvial forests include American sycamore (*Platanus occidentalis*), tulip poplar (*L. tulipifera*), and white ash (*Fraxinus americana*). This community type has been impacted by development, and un-impacted areas may be susceptible to human disturbance. Ash species are vulnerable to emerald ash borer (*Agrilus planipennis*), a non-native beetle that just recently (2012) has been found within GRSM.
8. Heath Balds: Heath balds are a shrubland community type of unknown origins representing approximately 1% of park area. The vegetation consists of dense ericaceous shrubs such as catawba rhododendron (*Rhododendron catawbiense*). This community is thought to be stable, but can be impacted be landslides during significant rain events (Hales et al. 2009).
9. Grasslands/Grassy Balds: These communities are treeless areas with variable composition (Jenkins 2007). GRSM contains approximately 940 ha (less than 1% of park area) of this community type. Grassy balds are found at high elevations while grasslands occur at low elevations. Both types may be anthropogenic in construction. These communities can be significantly altered by invasive non-native plants and hogs.
10. Wetlands: Although not represented in Jenkins' (2007) vegetation communities, wetlands have a unique assemblage of plant species. White et al. (2003) addressed wetland communities in GRSM as non-alluvial areas "dominated by plants adapted to anaerobic conditions imposed by substrate saturation or inundation during 10% or more of the growing season." Many of the park's wetlands are impacted by non-native plants and hogs and are vulnerable to multiple other stressors.

3.4.2.4 Vegetation Community Monitoring Questions

- What are the park-wide statuses and trends of the aerial extent of forest/shrubland/grassland/herbaceous community types?
- How are vegetation communities changing with regard to abundance, productivity and/or composition of species?
- To what extent are changes in vegetation communities linked to other vital signs, such as climate change, acid deposition, soil quality, water chemistry, freshwater communities, and to other natural resources?

3.4.2.5 Monitoring Design Considerations for Vegetation Communities

GRSM vegetation communities are affected by many biotic and abiotic factors. In order to prioritize which factors to include in a long-term monitoring program, it is essential to analyze the severity, extent, and persistence of each. Some of the threats have short-term dramatic impacts on productivity, structure, and composition (e.g., hemlock woolly adelgid causes mortality in all age classes of hemlock trees), while others have a long-term, subtle impact (e.g., chronic ozone exposure changes species composition of cove hardwood forests over time). Several stressors can have a

synergistic effect. Some of these vegetation communities have already been impacted by historic land use (logging, fire, settlement), non-native diseases (chestnut blight, beech bark disease, butternut canker), non-native insects (balsam woolly adelgid, hemlock woolly adelgid), invasive plants (multiflora rose, tree of heaven, garlic mustard), or native and non-native animals (browsing by white-tailed deer in grasslands/woodlands, rooting by wild hogs in wetlands).

In addition, air pollution can impact forest communities, changing the soil and the plants themselves, resulting in community shifts over time. Park forests initially respond to the fertilizing effect of additional nitrogen deposition by increasing productivity, until they reach nitrogen saturation. Once a forest reaches nitrogen saturation, acidification from nitrogen deposition increases, nitrate leaching increases, and plant nutrient imbalances may occur. When there is excess available nitrogen, other nutrient elements such as calcium (Ca), magnesium, potassium, and phosphorus, become growth limiting. The resulting nutrient imbalances can lead to increased susceptibility to insect infestation and to disease and may ultimately lead to changes in plant species composition. The most broadly used chemical criterion is the aluminum (Al) to base cation (BC) ratio (Al:BC) or aluminum to calcium ratio (Al:Ca) in soil solution. These criteria are used because of research linking elevated Al availability in soils, relative to base cation (especially Ca) availability, to root toxicity. Because Al uptake by plants increases when Ca and other base cations become scarce, it is typically not the absolute value of Al concentration in soil that is biologically meaningful; rather, the ratio (Al:BC or Al:Ca) is linked to plant toxicity (Pardo et al. 2007). After completion of critical modeling of soil solution in forests at GRSM (Pardo et al. 2007), it was determined that nitrogen deposition of 4.5 kg/ha/yr would serve as a good reference condition and protect spruce-fir forest soil solutions from toxic aluminum effects and prevent Al:Ca ratios from exceeding 0.1.

Many studies have suggested that species may differ in their response to nitrogen saturation. For example, Lovett and Rueth (1999) examined nitrogen transformations (e.g., mineralization and nitrification) along a nitrogen deposition gradient and found strongly contrasting responses between beech (*Fagus grandifolia*) and maple (*Acer rubrum*) stands. McNulty et al. (1996) suggested a shift in community structure as deciduous trees regenerated much faster than spruce or fir following large scale declines of both due to nitrogen saturation. Overall, as soil nitrogen saturation continues, primary productivity decreases due to aluminum toxicity and nutrient imbalances resulting in tree mortality, either directly or due to increased susceptibility to stress (e.g., frost, pathogens) (Shortle and Smith 1988, McNulty et al. 1996).

Not all of the communities are affected by drivers and stressors to the same degree (Table 2). Some communities are affected by multiple stressors, but cover a relatively small portion of the park (e.g., wetlands). Other communities cover a large portion of the park and are relatively stable (e.g., xeric pine/oak forests). To effectively monitor the park's vegetation communities, both factors must be taken into account. In addition, some of the stressors have an acute effect while others are chronic in nature.

GRSM extends over 2000 km^2 of primarily mountainous terrain, which presents unique logistical challenges that need to be addressed in sampling designs. As the design is being set up, vegetation

Table 2. Perceived effects of key drivers and stressors on major vegetation communities in GRSM.

Vegetation Community Type (% Cover)	Sensitivity to Change: High: **H** Intermediate: **I** Low: **L**	Oak-pine Forests (47%)	High-elevation Hardwood (17%)	Cove Hardwood Forests (12%)	High-elevation Spruce-fir (8%)	Early Successional Forests (5%)	Hemlock Forests (2%)	Montane Alluvial Forests (1.3%)	Heath Balds (1%)	Grasslands/Grassy Balds (<1%)	Wetlands (<1%)
Chronic/Global Stressor	Particulates & Visibility	**I**	**H**	**I**	**H**	**L**	**L**	**L**	**L**	**L**	**L**
	Ozone Pollution	**L**	**H**	**H**	**H**	**H**	**L**	**I**	**I**	**L**	**L**
	Acid Deposition	**L**	**H**	**I**	**H**	**L**	**L**	**L**	**I**	**L**	**H**
	Toxics[1]	**L**	**L**	**L**	**L**	**L**	**L**	**L**	**I**	**L**	**H**
	Climate Changes[1]	**H**	**H**	**I**	**H**	**I**	**I**	**I**	**L**	**L**	**H**
Acute/Local Stressor	Invasive Plants	**L**	**L**	**L**	**L**	**H**	**I**	**I**	**L**	**H**	**H**
	Invasive Animals	**L**	**H**	**H**	**L**	**I**	**I**	**I**	**L**	**H**	**H**
	Infestations & Diseases	**H**	**H**	**I**	**H**	**L**	**H**	**I**	**I**	**L**	**L**
	Landscape-Park Changes (fire)	**H**	**L**	**L**	**L**	**I**	**I**	**L**	**L**	**H**	**L**
	Human Impacts	**L**	**L**	**L**	**I**	**L**	**L**	**H**	**L**	**I**	**I**
Drivers	Soil Quality	**L**	**H**	**L**	**H**	**L**	**I**	**L**	**I**	**L**	**I**
	Water Chemistry	**L**	**H**	**L**	**H**	**L**	**L**	**I**	**L**	**L**	**H**
	Groundwater	**L**	**L**	**I**	**L**	**L**	**I**	**I**	**L**	**L**	**H**
	Water/Hydrology	**L**	**L**	**I**	**L**	**L**	**I**	**I**	**L**	**L**	**H**

[1]Perceived effects based on incomplete or uncertain knowledge.

communities that may be monitored in the future, and perhaps co-located, need to be included. A substantial percentage of the permanent vegetation plots discussed below will be co-located with other vital signs wherever feasible. Co-location will reduce costs, time, and help identify community-level patterns.

Some traditional monitoring needs may be met by adding new protocols (e.g., evaluating balsam woolly adelgid densities while monitoring high-elevation vegetation plots), while others can be addressed through related extant programs (e.g., detecting invasive plants during regular fire effects monitoring). The extent and severity of some stressors, such as air and water pollution, are also measured through existing programs (see section 3.4.1 Critical Vital Sign: Acid Deposition and section 3.4.4 Critical Vital Sign: Water Chemistry).

Sampling designs to co-locate monitoring sites will need to take into account the nature of restricted communities, species of interest, high probability sites for non-native species invasion, site land-use history, geology/soils, and applicability of prescribed fire. Furthermore, for early detection of changes in vegetation types, plots should be randomized within each type. To target areas with impending changes due to acute stressors, a more intensive array of permanent plots might be warranted (e.g., a watershed approach).

3.4.2.6 Sampling Design/Approach

- focus on communities most likely to see changes due to identified stressors
- focus on communities that cover large portions of the park
- adjust sampling intervals to reflect the level of change expected to occur
- adjust plot intensity (plots per community type) to adequately and feasibly detect change.

3.4.2.7 Monitoring Measures

1. Existing long-term vegetation monitoring plots will be evaluated for vital signs applicability; if necessary, additional plots will be established. Plots will be used for multiple purposes, including for monitoring communities that are under the most threat from multiple stressors (see Table 2), communities that cover a majority of the park's landscape, and to a limited degree, communities that are critical to the understanding of other monitoring questions. Legacy vegetation monitoring plots will be evaluated and included into the current array where appropriate.
2. The aerial extent of vegetation communities will be mapped. All overstory and woody understory strata will be digitally mapped in GIS from aerial and satellite imagery according to NPS standards. A digital vegetation map was produced for the park in 2004. The park's communities will be re-mapped every 10 years to assess the shift in community dominance (e.g., hemlock forests).

3.4.2.8 Metrics to be Measured (in selected plots)

- species richness
- species composition/abundance

- growth rates (woody plants)
- tree mortality rates
- tree regeneration
- canopy recruitment
- canopy cover
- nativity
- foliar injury assessment for ozone (possibly)
- downed woody debris (possibly)
- invasive forest insects/diseases (possibly)

3.4.2.9 Thresholds

Thresholds are to be determined (TBD) and will be established by evaluating long-term growth and species richness trends, as well as reviewing available literature. Thresholds for some vegetation communities and stressors may be straightforward (i.e., the loss of a community type due to a forest insect or disease). Other thresholds may prove problematic or impossible due to naturally occurring vegetation community succession.

3.4.3 Critical Vital Sign: Soil Quality

3.4.3.1 Background and Justification

Soils in GRSM are highly weathered compared with many other regions of the eastern US. The underlying geology is dominated by Precambrian sandstone and includes several areas of exposed and unexposed acidic Anakeesta formations and a few small Ordovician limestone windows. The soil layers of GRSM tend to be rather shallow inceptisols consisting of a silty loam to a sandy loam texture, generally <1 m in thickness (Cai et al. 2009).

Like soil formation processes everywhere, pedogenesis in the Smoky Mountains is strongly influenced by climate, parent material, relief, vegetation, and other biotic factors over time. GRSM has strong climatic gradients (Fridley et al. 2006) and one of the most complex and deformed geologies in eastern North America (S. Southworth, pers. comm.). Little was known about what soils existed in the park until recently, when a mapping project began with NRCS. The park now has a general soils map (Fig. 21), and physical and chemical data analyses on soil profiles have been completed. Sixty-four soil series were identified, of which 17 were new to science and seven were found to be endemic to the park (NRCS 2009).

Soils within many of the watersheds in the southern Appalachians are inherently low in base cations such as calcium, magnesium, and potassium (Holzmueller et al. 2007). These base cations are essential to vegetation and animal growth, and regulate water chemistry by buffering acidic inputs. Soil calcium, in particular, is a limiting growth factor for animal species including endemic snails (Hotopp 2002) and for native tree species including dogwood, ash, and red cedar (Jenkins 2007).

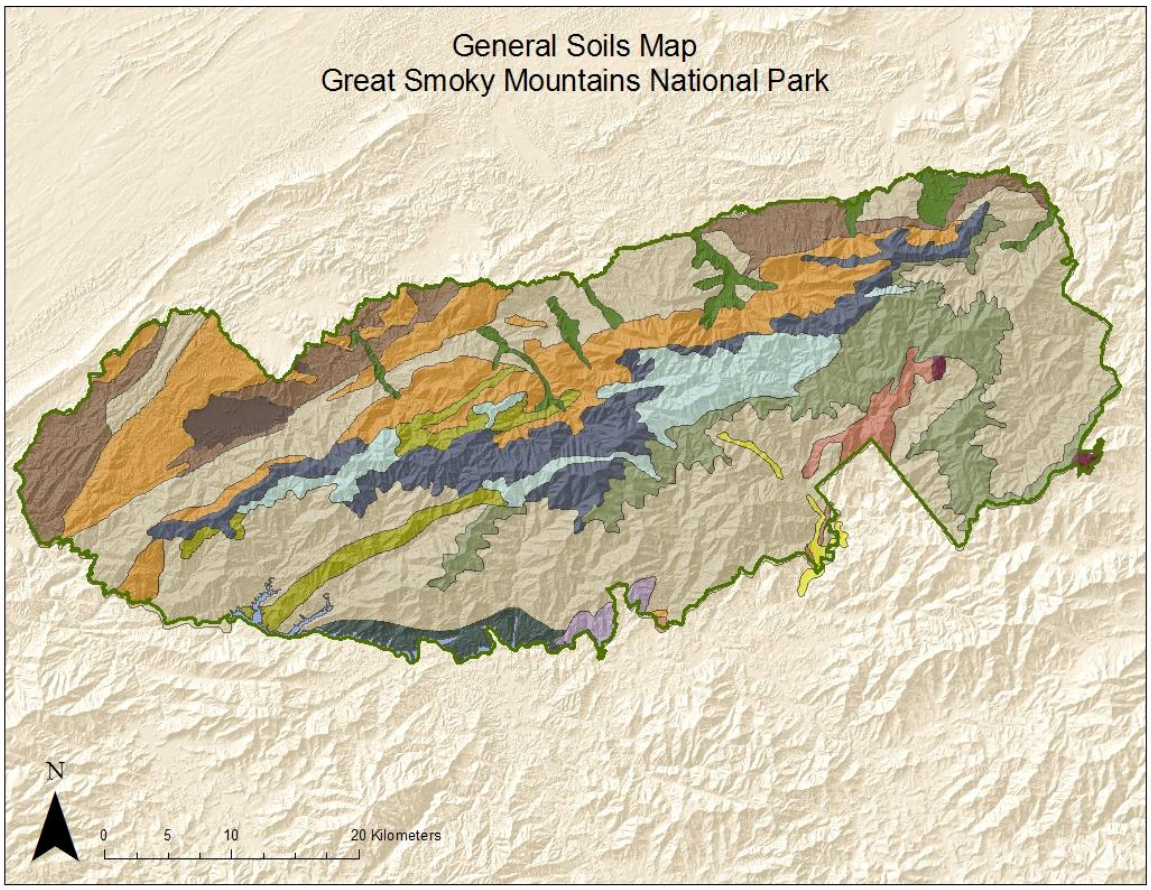


Figure 21. Draft general soils map of GRSM developed by USDA-NRCS. (Legend has been omitted for this scale).

Much has been learned in recent years as researchers have made collections of soil and sediments throughout the park to study, among other topics: carbon sequestration (Garten 2008), mercury contamination (Buchwalter et al. 2009), recreational impacts (Marion 1994), diversity and ecology of bacteria and archaea (O'Connell et al. 2007), impacts of invasive earthworms (Snyder 2008), diversity of algae (Johansen et al. 2007), diversity of soil arthropods (Bernard and Felderhoff 2007), soil fertility (Givnish, unpublished), soil charcoal record (Horn, unpublished), and wetland characterization and evolution (Young, unpublished). The ATBI has found that the greatest fraction of species documented thus far in the park are associated with the upper soil and forest floor layers, rather than forest canopies, grassland/shrublands, or aquatic environments (K. Langdon, pers. comm). In recent modeling of the distribution of individual species in various groups, soils and geology are nearly always a major determinant (B. Zank, pers. comm.). Other federal agencies, including the US Forest Service, have begun to recognize the importance of monitoring soil quality and modeling stream chemistry within the Blue Ridge Province of the

southern Appalachian Mountains (Sullivan et al. 2007a). The geographic scope of their research includes portions of North Carolina, eastern Tennessee, and upstate South Carolina - areas surrounding GRSM, but not equal in elevation or contiguous land area. Because the highest ridges

and watersheds in the southern Appalachians are within the park, comprehensively monitoring park soil quality will contribute to regional knowledge about acidic deposition, soil quality, and resulting water chemistry.

3.4.3.2 Threats to Soil Quality

Anthropogenic disturbances have affected soils in the region even before the park was established. Every relatively flat valley was extensively cultivated (Pyle 1985) and over 50% of the park was corporately logged (Pyle 1985). Some of these areas were subsequently burned in intense logging slash fires, significantly altering soils due to extreme heat and/or erosion. For example, the 1925 post-logging fires in the headwaters of Forney Creek modified soils such that the nearby red spruce still have not re-established.

Exotic animals can severely alter soil layers and nutrient levels. Wild hog rooting can cause a 93% reduction in the depth of the humic layer, or 01 horizon, and the A1 and A2 horizons can become mixed and indistinguishable (Howe and Bratton 1976, Singer et al. 1984). Hog rooting also disrupts the nitrogen cycle, with increases in nitrates and ammonia in rooted soils. Introduced Asian and European earthworms have also altered natural soil horizons and removed organic duff, albeit on a local rather than park-wide scale (Snyder 2008).

The chemical composition of soils in GRSM is determined by a delicate balance of positively and negatively charged ions. This balance is interrupted by the addition of acid anions from atmospheric deposition, including sulfate and nitrate, which cause the release of calcium and other cations from the soil. Over time, a decrease in nutrient availability in park soils will threaten terrestrial and aquatic communities, particularly those at high elevations (>1066 m) where base cations are already scarce (Sullivan et al. 2007b, Cai et al. 2009). The loss of nutrients such as calcium can lead to declines in snail populations, which rely on available calcium in dogwood and other tree leaf litter for their shells, and subsequently on the birds that feed on snails who then use this calcium for egg shells (Graveland 1996). Studies have found snail and other environmental calcium sources to be crucial for avian egg shell production; lacking this food source in calcium-poor environments, bird populations were found to decline due to poor reproductive success (Graveland et al. 1994, Graveland 1996). One study found fewer wood thrushes in areas of high acid precipitation, and hypothesized that this could be due to decreasing available calcium throughout the food chain as a result of soil base cation depletion (Hames et al. 2002). In GRSM, calcium was found to decline in junco eggs as acid deposition increased across the landscape (Simons and Keller 2010).

In addition to depleting cations, acid precipitation and throughfall with pH values as low as 2.0-4.0, overwhelm the acid neutralizing capacity (ANC) of soils and bedrock, causing soil water pH to permanently drop over time. A decline in ANC could result in acute mortality in freshwater life due to pulses of toxic metals, such as aluminum, and chronic reproductive and health stress on sensitive native fish, such as brook trout (Neff et al. 2008; see section 3.4.4 Critical Vital Sign: Water Chemistry).

To better understand the role that soils play in storing deposited acid and releasing it to waterways, a recently published study analyzed 1991-2006 data collected from lysimeters at Noland Divide in the

park (Neff et al. 2008, Cai et al. 2009). Results showed that while soil adsorbed over half (61%) of the sulfate deposited through precipitation and throughfall, during large precipitation events sulfate flushed directly through the soil into streams. This results in dramatic declines of pH and ANC. Streams are buffered somewhat by an outflow of cations from soil, although once these are continually flushed and depleted, stream water quality has limited potential to recover from very low pH and ANC levels (Cai et al. 2009). If there is a reduction in power plant emissions (i.e., a sudden reduction in sulfur deposition), this could lead to an increase in soil pH, which will cause soil desorption of stored sulfate, thereby causing a temporary increase in stream water pH.

Unlike sulfur, much of the deposited nitrogen does not flow directly into streams due to vegetation uptake, which accounts for a third of deposited nitrogen, and storage in the uppermost soil layer by both biotic and abiotic adsorption. Soils in many parts of the park are now considered nitrogen saturated because sources such as acid deposition, and organic mineralization and nitrification processes, exceed the rate of forest uptake; therefore, nitrate is leached into streams.

Other impacts to soil quality in GRSM include aluminum and climate change. The greatest impact of acid deposition on plants is due to the mobilization of aluminum and cation availability (Fenn et al. 2006) in the root zone of soils. Monomeric aluminum is toxic to plants (Reuss 1983), and Johnson et al. (1991) found it to be the dominant form in the soils of two spruce forests in GRSM. The effects of climate changes on different soils are not well understood; however, work by the Oak Ridge National Lab (Garten et al. 2000) in the park showed that temperature of the soil plays a large part in determining rates of carbon sequestration in forests.

Soils are a critical resource in the park environment. Natural biodiversity, plant productivity, carbon sequestration, the ability to buffer and store incoming acid and toxins, and many other ecological processes are heavily dependent on the physical and chemical properties of soils. Park soils are believed to suffer from acute local and more widespread deterioration emanating from historical land use and current stressors. Restoration of many resource groups will depend on the quality of GRSM soils; therefore, monitoring of water chemistry, climate, and other factors that can change soil quality is essential.

3.4.3.3 Soil Quality Monitoring Design Considerations

- To the greatest degree practical, co-locate actual sampling sites with other monitoring, especially water chemistry, vegetation communities, and acid deposition.
- Concentrate monitoring sites in ecologically connected watersheds in order to better understand soil quality changes. Collect samples preferably across different vegetation communities, soil parent materials, bedrock types, elevations, and disturbance types.

3.4.3.4 Soil Quality Monitoring Questions

- What are the park-wide statuses and trends in soil physical and chemical characteristics?
- To what extent are changes in soil quality linked to changes in other vital signs, such as climate change, acid deposition, vegetation communities, water chemistry, and freshwater communities, and to other natural resources?

- What are the trends in soil physical and chemical characteristics in areas with episodic or exotic species disturbances (e.g., Fraser fir, hemlock, and beech forests, wildland fire sites, exotic earthworm infestation sites)?

3.4.3.5 What Metrics do we Need to Answer these Questions?

- comprehensive soil chemistry, including but not limited to, base cations (Ca, Mg, K), sulfate, nitrogen, carbon (TOC/DOC), organic acids, phosphorus, aluminum, and pH
- trends in amount and chemical analyses of pore water
- correlations between soil carbon and vegetative biomass.

3.4.3.6 Soils Monitoring Measures

1. Collect bulk soil samples from all permanent vegetation monitoring plots (where appropriate). The park will establish an array of long-term 0.1 ha vegetation monitoring plots, which will be co-located with other critical monitoring sites so that researchers can analyze multiple impacts from known stressors (e.g., soils collected from high-elevation vegetation plots will provide metrics to assess the impacts of acid deposition).
2. Collect soil water from a subset of permanent monitoring plots. Lysimeters will be used to categorize pore water characteristics. Wetlands and other special sites will be monitored on a regular basis.

3.4.3.7 Thresholds

Thresholds are to be determined (TBD), and will be established based on results of current research being conducted park-wide, and on literature review of regional research.

3.4.4 Critical Vital Sign: Water Chemistry

3.4.4.1 Background and Justification

GRSM contains over 3300 km of streams (Parker and Pipes 1990), almost all of which originate within the boundaries of the park. There are 45 major watersheds (>5 km^2) encompassing these streams, as well as hundreds of riverine, forest/shrub, and emergent wetlands, and ponds (Parker and Pipes 1990). Streams range in size from 1^{st}-6^{th} order (Fig. 3), with gradients typically ranging from 2-20%, and daily discharge ranging from 0.03-1.13 m^3/sec. Stream temperatures normally are 0-18^oC; however, temperatures occasionally reach critical limits for salmonids (~25^oC) during drought periods in some lower elevation stream segments (5^{th}-6^{th} order). Soils (see above) are often acidic or have low buffering capacity, which contributes to water acidification.

GRSM is unique because it has almost no direct adverse water quality impacts coming from human development or siltation upriver, as is often the case in other parks across the country where headwaters are outside the park. Five GRSM streams are recognized as pristine by the Tennessee Department of Environment and Conservation (TDEC) and designated as Outstanding Natural Resource Waters (ONRW). The ONRW designation provides additional evidence of the pristine nature of water quality in GRSM; however, the park receives some of the highest rates of atmospheric deposition of acid pollutants in the US (Silsbee and Larson 1983, Nodvin et al. 1995,

Shubzda et al. 1995, Smoot et al. 2000, NADP 2006, Sullivan et al. 2007b), which has been linked to emissions from regional coal-fired power plants and automobile emissions (Chestnut and Mills 2005). Given the poor buffering capacity of underlying soil and geology formations, and high acid deposition rates, GRSM stream and surface water pH typically ranges from <5.0 to 6.5 throughout much of the park, and stream conductivity is typically <30 μS/cm (Robinson et al. 2001). Most GRSM streams are low in ANC and exhibit chronic and episodic acidification (Robinson et al. 2005, 2008, Deyton et al. 2009).

An important issue regarding the response of streams to long-term increases in nitrogen loading is how denitrification rates will respond (e.g., saturated soils) (Mulholland et al. 2009a). While there currently is no acid deposition standard for nitrogen or sulfur in the Clean Air Act aimed at protecting the park's aquatic or terrestrial resources, evidence of reduced buffering capacity became evident in 2006 when the state of Tennessee, using park water quality monitoring data, added 65.6 km of 12 GRSM streams to the state's 303(d) list of impaired waters (Fig. 9).

Continued efforts by the EPA and state regulatory agencies to reduce sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions in the eastern US have reduced sulfate and nitrate deposition in the park since the late 1990s. Despite these deposition reductions, stream pH continues to decline at elevations below 914 m (3000 ft). Based on water chemistry data gathered from the mid-1990s to mid-2000s, forecasting models suggest that 30% of the stream sample sites will reach pH values <6.0 in 10 years, 63.3% in 25 years, and 96.7% in 50 years.

The water resources of GRSM serve as important habitat for fish and other aquatic biota, a water source for wildlife, and as a recreational resource for visitors. The water quality of streams, caves, and wetlands are influenced by an intricate network of GRSM ecosystems which determine the chemistry of these waters. In many cases, stressors in one ecosystem can manifest throughout all of the subsequent ecosystems in the park, at the community and population level (see Water Quality Links to Biological Effects section below, and Conceptual Model for Acid Deposition, Fig. 17). Monitoring the park's surface water chemistry (Fig. 22) will clarify the links between major ecosystem stressors (e.g., climate, acid deposition, ozone) and park resources (e.g., terrestrial communities and processes, and freshwater communities). This is critical for identifying potential problems within and among ecosystems, determining long-term water quality trends, and maintaining the park's aquatic and terrestrial fauna.

3.4.4.2 Current Sampling Design and Approach

The current water quality program consists of two primary components: 1) detailed hydrologic and water quality monitoring at Noland Divide, a small high-elevation catchment site; and 2) park-wide stream surveys during baseflow water quality conditions.

Noland Divide Watershed: The Noland Divide watershed (NDW) was selected for long-term monitoring because of its high-elevation location (1600 m [5249 ft]). In the eastern US, high-elevation watersheds with poor buffering capacity tend to be vulnerable to stream acidification from acid deposition (Hyer et al. 1995, Driscoll et al. 2001). NDW provided a good site to record stream

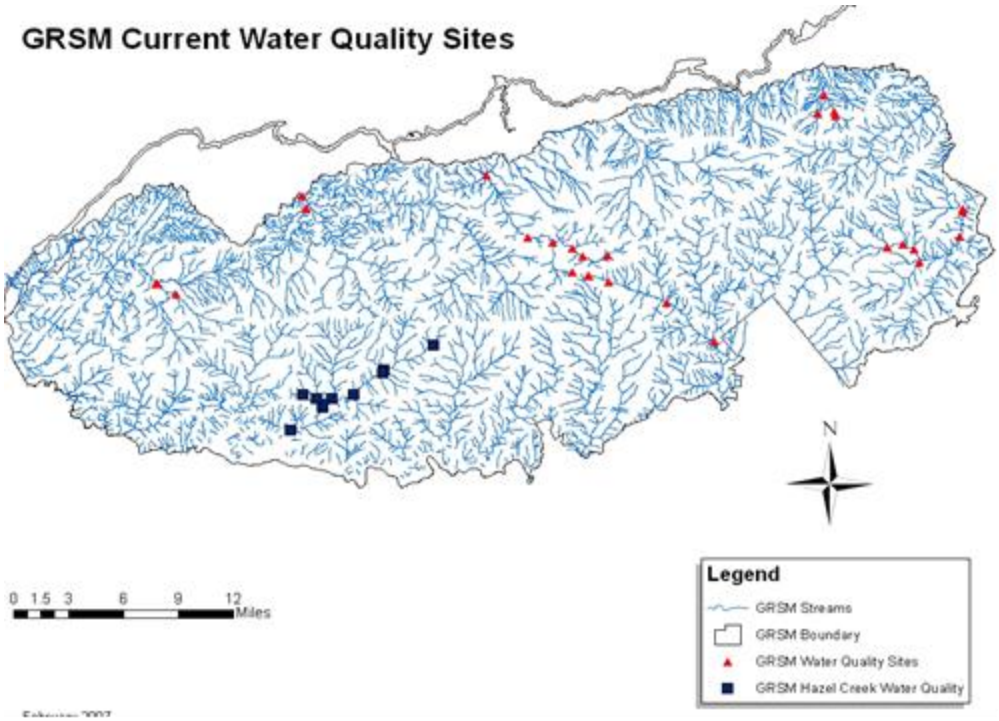


Figure 22. Map of GRSM water quality monitoring sites.

acidification responses due to acidic deposition; five monitoring sites were installed to monitor the potential effects of long-term acid deposition.

Park-wide Stream Survey for Baseflow Water Quality Monitoring: A park-wide stream survey began in October 1993 to identify potential impacts of acid deposition on GRSM streams and to monitor long-term changes in stream acidification. Sites were selected to assess the spatial variability of water quality within GRSM across a range of elevations, geology types, and disturbance histories. From 1993 to 1995, samples were collected at 367 sites semi-annually. In 1995, the number of sites was reduced to 160 (in order to reduce costs) and samples were collected on a monthly basis. In 1997, the number of sites was reduced to 90 and samples were collected quarterly. Based upon the results of multivariate optimization techniques (which provided a spatial recommendation) and temporal analysis (which provided a frequency recommendation) of park water quality data from 1993-2002, Odom (2003) classified GRSM into seven water quality districts and recommended reducing the number of sites collected and increasing the sampling frequency. The analysis removed sites in watersheds with duplicate geology, forest types and chemistry data while favoring sites with co-located fish and benthic sites, easier access, and representative baseflow chemistry data. Based on his recommendation, the number of sites was reduced to 32, sampled bi-monthly, and 11 Hazel Creek sites sampled bi-annually. The sites selected within these seven watersheds and collection frequencies provide the ability to use baseflow chemistry to characterize the health of most park surface waters, and the statistical confidence to detect changes and trends over time.

3.4.4.3 Results of Current Monitoring Program

GRSM receives some of the highest sulfate (2029 eq/ha/yr) and nitrate (1191 eq/ha/yr) loadings in North America (Robinson et al. 2005) (Figs. 23-24). These heavy loadings have resulted in nitrogen saturated soils, which export more than half of the nitrogen inputs to streams (Van Miegroet et al. 2001). Recent data suggest that sulfate deposition is decreasing at a rate of -0.83 to -1.3 eq/l/yr, comparable to declines observed at Hubbard Brook in New Hampshire (Robinson et al. 2008). Despite these improvements, base cations such as calcium, sodium, and magnesium continue to be exported to streams from soils faster than they are weathered or deposited from the atmosphere (Fig. 25). Continued reduction of the base cation pool may result in an acceleration of stream acidification (Cai et al. 2009). The lower pH streams on the 303(d) list are believed to have been acidified primarily due to deposition of anthropogenic air pollutants (nitrate and sulfate) over time.

Given the heavy loading of both nitrate and sulfate into nitrate saturated soils, baseflow stream pH has not yet shown an upward trend (Robinson et al. 2008). In general, stream pH is declining 0.2 units per year at low to mid-elevations (approximately 310 to 1080 m), but no declines in pH have been detected in streams above 1080 m elevation. In addition, 77% of the GRSM sites measured had median pH values <6.5; levels which can have adverse effects on aquatic organisms (Robinson et al. 2005).

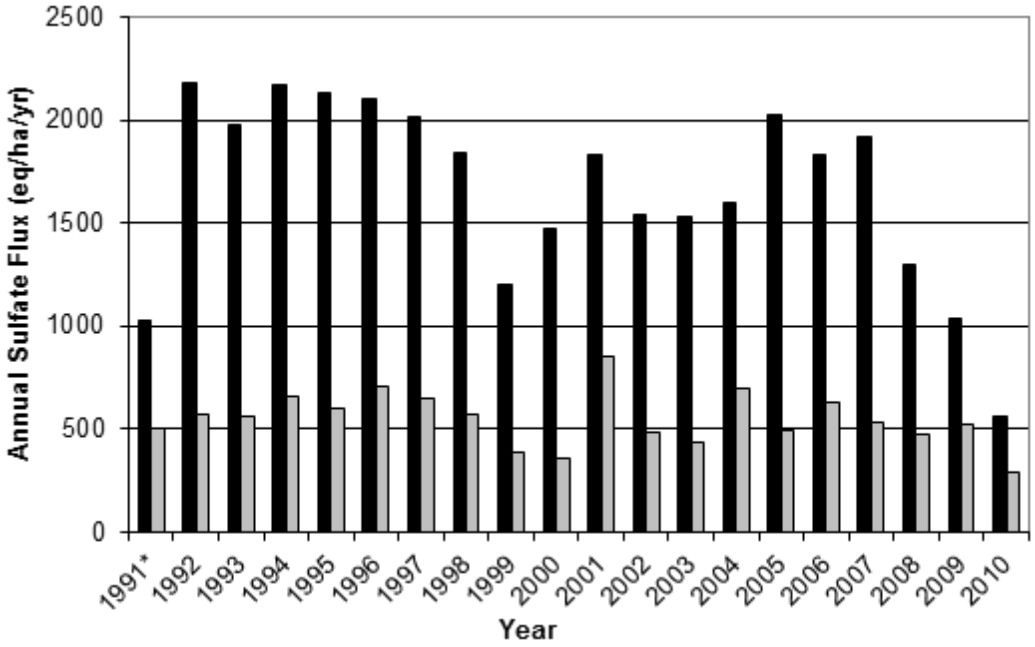


Figure 23. Total sulfate entering the NDW as throughfall (black bars) and wet-only (white bars) precipitation.

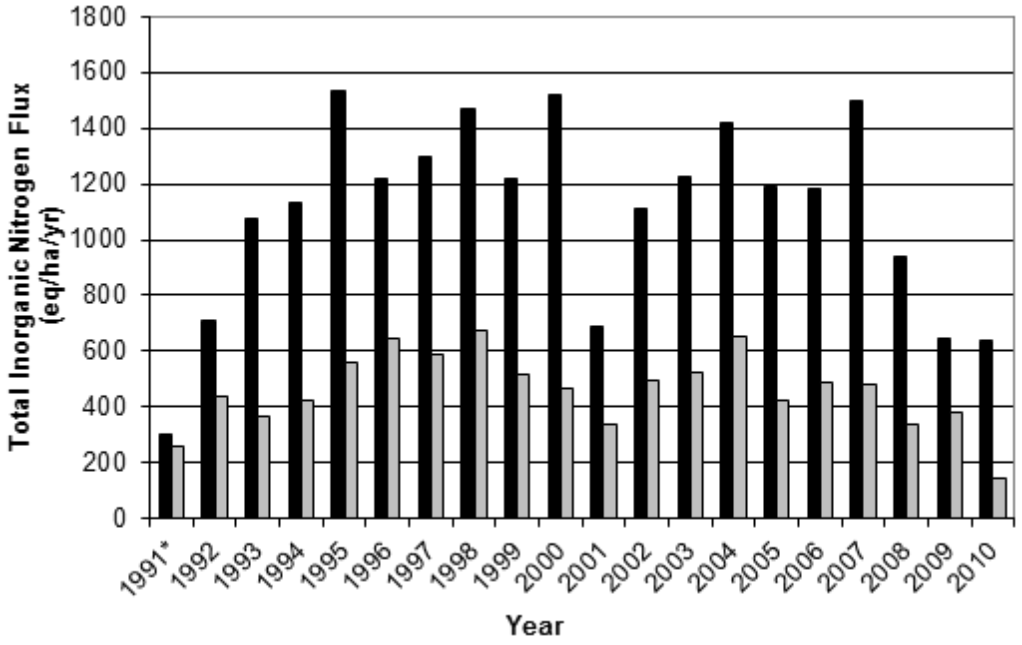


Figure 24. Total nitrate, including NH4-N, entering the NDW as throughfall and wet-only precipitation.

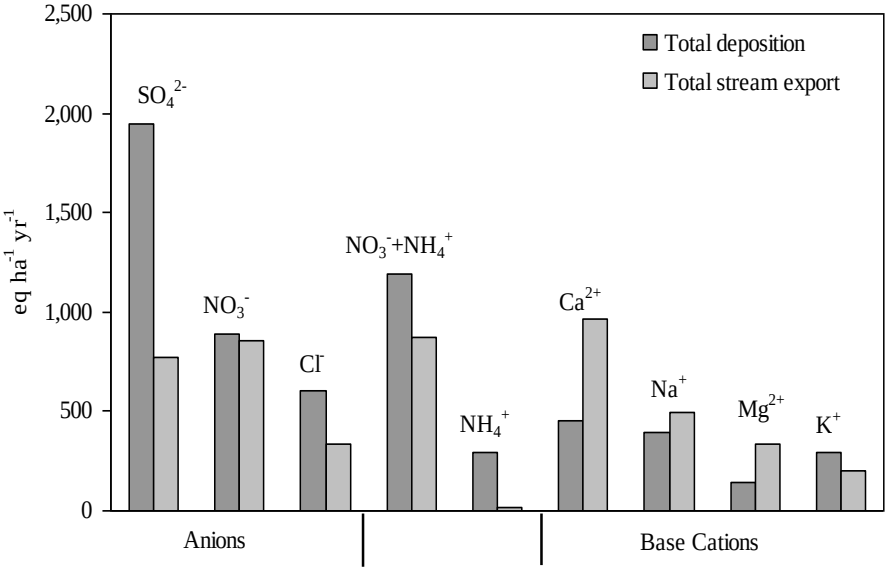


Figure 25. Mean annual fluxes in anions and base cations (eq/ha/yr) in throughfall and stream net export at NDW from 1991 to 2006 (Cai et al. 2009).

3.4.4.4 Water Quality Links to Biological Effects

The biological effects of acid deposition manifest themselves through a variety of mechanisms both among and within ecosystems. For a variety of water quality parameters, biological effects differ among life history stages. The following are some examples of how excessive acid deposition constituents affect various communities and the species that live within them.

Threats to the chemical composition of park streams include acidic deposition from polluted air, which lowers rainfall and cloud pH and changes ionic and anionic composition of soil and stream water. Acid deposition reduces ANC and base cation concentrations, and increases the acidity of soils and streams in some forested watersheds in the park. Acidic deposition has reduced the ability of some aquatic organisms, including brook trout, to survive or maintain stable populations in affected streams. Stream ANC and pH are good indicators of the suitability of a stream to support fish and reflects the combined impact of sulfate and nitrate anions, organic acids, base cations, aluminum, and hydrogen ions in stream water.

Many aquatic species have an ability to detect the pH of their environment and will avoid areas with low pH (Havas and Rosseland 1995). Gagen and Sharpe (1987a) documented significant downstream movement of brook trout to avoid low pH conditions during storm events. In some cases, lower surface water pH may initiate secondary effects, such as increasing the lethal effects of ultraviolet-B radiation on amphibians (Pahkala et al. 2002). Even acute exposures (<24 hr) to low stream pH (<5.0) can result in abnormal development of various fish organs such as gills, brain, and heart (Peterson et al. 1982). Additionally, Mathews and Larson (1980) found that 19-fold reductions in surface water pH over 25 years resulted in pH near toxic levels to endemic shovelnose salamanders. Amphibian and salmonid egg production typically declines when stream pH is below 7.0 (Sadinski and Dunson 1992, Barnett 2003), and survival diminishes rapidly after stream pH falls below 5.1 (Kwain 1975, Menendez 1976, Alabaster and Lloyd 1980, Sadinski and Dunson 1992, Marschall and Crowder 1996). Although Alabaster and Lloyd (1980) demonstrated that brook trout can survive short term exposure (<24 hr) to low pH (<4.5), chronic exposure can lead to death through primary (e.g., system failures) or secondary causes (e.g., disease) (Heath 1995). More than 90% of the parks brook trout populations live in streams >762 m in elevation (Fig. 26). Current trends indicate that if the rate of stream acidification continues, all streams above 762 m will be at an average pH of 6.0 in 32 years (Robinson et al. 2008).

Total nitrogen and sulfur deposition are appropriate air quality indicators and parameters to measure when assessing impacts of acidic deposition to park forests and streams. Current modeling efforts (Driscoll, unpublished) will determine the critical loads of sulfur and nitrogen deposition and TMDLs to achieve water quality standards for pH of 6.0. Currently there is no integrated plan in place with the EPA, states, or Congress to begin to address and solve this problem. After modeling, the park will work with the state of Tennessee to develop an implementation plan for the TMDLs for stream water pH restoration.

Episodic events such as storms and spring snow runoff can cause major loading of acid materials into streams, especially after long dry periods when accumulated dry particles wash from leaves and soil

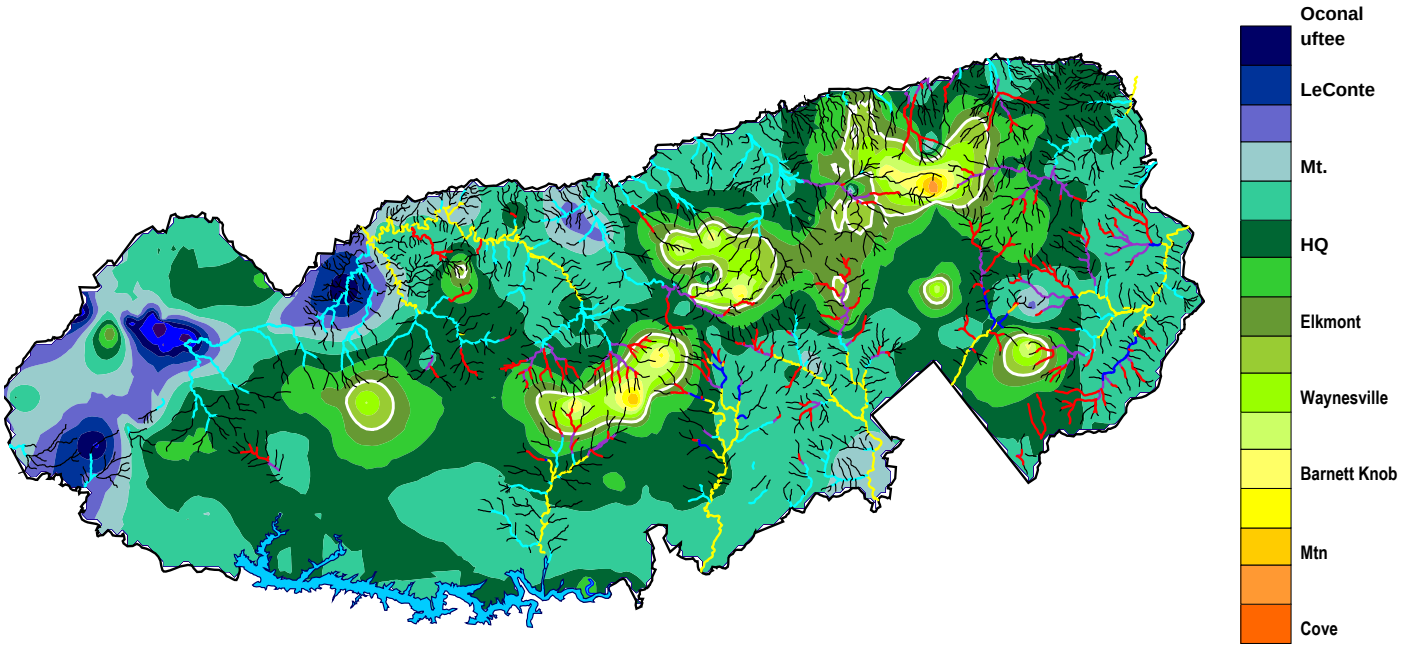


Figure 26. Map of GRSM depicting salmonid distribution overlaid on top of the average maximum stream pH isopleths from 1993-1995. Allopatric brook trout are depicted by the red lines, sympatric brook and rainbow trout by the purple lines, allopatric rainbow trout by the blue lines, and sympatric brown and rainbow trout by the yellow lines. Note the pH 6.0 isopleths depicted by the white circles with decreasing pH values towards the center.

(Deyton et al. 2009). Significant drops in pH due to episodic events causes a major increase in ion efflux from fish gills, eventually leading to ion regulatory failure and eventually death due to low blood pressure (Packer and Dunson 1970, Heath 1995). Neff et al. (2008) demonstrated regular whole net sodium reductions of 10-20% (>20% is typically fatal) in brook trout in three streams suffering from chronic episodic stream acidification (pH drops of 1-2 units per event). Total dissolved aluminum levels during these same events ranged from 202-210 µg/l, also exceeding levels that are typically fatal for salmonids and other fish groups (Neff et al. 2008). Stress associated with whole-body sodium and chloride loss results in a lack of feeding and subsequent smaller body sizes and lower egg production (Barnett 2003). Over the last 20 years, at least six headwater brook trout populations have been lost in GRSM due to stream acidification.

Another result of acid deposition is the increased solubility of aluminum and other metals from soil to water as pH decreases (van Dijk and Roelofs 1988). Once mobilized into water, aluminum can form a complex with organic and inorganic species or remain as free aluminum, depending upon stream pH (Barnett 2003). Gagen and Sharpe (1987b) found that free aluminum ions and inorganic monomeric aluminum are most toxic to fish and other aquatic groups such as invertebrates. Both forms of aluminum can kill aquatic organisms in several ways: 1) via aluminum binding to the gill lamellae resulting in excessive mucous secretion which inhibits oxygen uptake, 2) by disrupting the permeability of the gill membrane causing fatal lesions, and 3) causing major organ dysfunction leading to the failure of body systems (Barnett 2003). During periods of high runoff of acidic water into comparably alkaline waters, aluminum can precipitate as aluminum hydroxide, which gathers on gills and the filtering apparatus of aquatic organisms causing acute toxicity (Havas and Rosseland 1995). Herrmann and Frick (1995) found that benthic shredders and animals that inhabit and/or consume benthic detritus had higher aluminum concentrations than other animals. In the early 1970s, Huckabee et al. (1975) documented stress and mortality of numerous fish in Beech Flats Prong (GRSM) and attributed the losses to gill hyperplasia associated with zinc and aluminum poisoning. Recently, Furey et al. (2009) reported persistent deformities in the diatom genus *Enotia* at several permanent springs along the crest of the main Great Smokies ridge. Deformities in diatoms are unusual, and have been associated with mining operations where waste waters have high levels of dissolved metals. Preliminary water chemistry analysis showed higher aluminum concentrations in the springs where diatom deformities were observed.

As soils become increasingly nitrogen saturated due to acid deposition, the soil not only loses its ability to ameliorate acidic inputs, but also sets the stage for major changes in terrestrial and freshwater ecosystems that depend upon water chemistry. For more description on the impacts of soil nitrogen saturation on vegetation, see above section: 3.4.2. Critical Vital Sign: Vegetation Communities.

3.4.4.5 Water Chemistry Monitoring Questions

- What are the park-wide status and trends of water quality/chemistry?
- How are water quality/chemistry [e.g., base cations, sulfate, nitrogen, carbon (TOC/DOC), organic acids] changes linked to changes in other vital signs, such as climate change, acid deposition, vegetation communities, soil quality and freshwater communities?

3.4.4.6 Metrics Needed to Answer these Questions

- base-flow and storm-flow water chemistry from select park watersheds
- episodic event samplers placed at a representative subset of baseflow water chemistry sites (e.g., high/low elevations, Anakeesta watersheds)
- high elevation watershed chemistry input/output budget (i.e., continue sampling at fully implemented Noland Divide watershed).

3.4.4.7 Design Considerations

- number and distribution of current sites is based on statistical analysis of historic data; also include any streams listed as impaired [303(d)]
- co-location with other monitoring sites (freshwater communities, vegetation communities, soil quality, acid deposition)
- monitoring samples should be across an elevation gradient within representative watersheds
- include habitats with known species changes (e.g., hemlocks, beech, fire, etc.)
- monitor in designated watersheds, then sample other areas on longer rotations to more representatively sample park diversity
- other considerations: elevation, climate (e.g., temperature, precipitation), geochemistry.

3.4.4.8 Recommended Sampling Design

In order to provide the metrics needed to answer the primary water chemistry monitoring question, we recommend utilizing the sampling design outlined by the results of Odom (2003). The design is a result of a detailed analysis of park water quality data from 1993-2002 using principal components and discriminant function analysis, which resulted in a recommendation for the number of samples sites and sampling frequency. This sampling scheme would include bi-monthly grab samples at 32 sites across seven key watersheds, and 11 grab samples collected in one key watershed bi-annually. In addition, a set of episodic samplers would be placed at a sample site within each of the seven key watersheds. Finally, we recommend continued operation of the Noland Divide watershed monitoring station in order to collect high elevation chemistry input/output data. The recommended design provides the ability to detect long-term trends, a means of relating air inputs to soil/stream water imports/exports, and identifies natural variation of baseflow chemistry.

3.4.4.9 Thresholds

TBD.

3.4.5 Critical Vital Sign: Freshwater Communities

3.4.5.1 Background and Justification

In addition to streams, other aquatic resources within the park include small wetlands, ponds, springs, seeps, cave pools, and two large reservoirs along the southern and western park boundary. Aquatic communities within these habitats are diverse, and include fish, insects, algae, mollusks, crustaceans, and amphibians.

Tennessee boasts the richest freshwater fish fauna (over 300 native species) of anywhere in the U.S. (Etnier and Starnes 1993) and roughly 25% of these species are found within the streams of GRSM (i.e., 77 species of fish represented by 15 families). The lack of impacts from glaciation, coupled with the geologic, elevational, and hydrographic diversity represented in an array of cold, cool, and warm-water streams provide a wide variety of habitat for these freshwater organisms (Etnier and Starnes 1993). Four species of fish in the park are listed by the USFWS as Federally Threatened or Endangered. Efforts to restore these native species to their former ranges have been successful for three of the four species to date. Although brook trout (*Salvelinus fontinalis)* are the only salmonid native to GRSM, rainbow trout (*Oncorhynchus mykiss)* were well established in nearly every watershed of GRSM by 1934 and are the most frequently encountered species due to widespread stocking since the turn of the century (Burrows 1935, King 1937, 1938). Stocking continued throughout GRSM until 1975 when it was discontinued to comply with NPS policies.

There are also 43 species of amphibians in the park, including at least 31 species of salamanders, making GRSM one of the most species-rich reserves of this size in the world. Several of these species are endemic or near-endemic to the park. The breeding habitats of amphibians vary from vernal pools, rivers and larger creeks, springs and seeps, to shallow subterranean sites and caves.

Macroinvertebrates are abundant in all types of aquatic systems in GRSM. This diverse group of organisms is intricately involved in ecological processes, such as the breakdown and cycling of organic matter and nutrients (e.g., algae, detritus) (Voshell 2002), while also providing food for a number of other organisms, such as fish and amphibians. Within GRSM, samples have been taken at approximately 150 different sites, with 27 sites receiving nearly 10 years of annual sampling. Over 900 species of macroinvertebrates, including insects, crustaceans, and mollusks, currently are known.

Benthic algae are ubiquitous in most aquatic habitats in the park, with well over 1000 species currently known (Johansen et al. 2007). These photosynthetic organisms are of fundamental importance to stream ecosystems. Through the process of photosynthesis, they provide fixed carbon (i.e., carbohydrates) as food for algivores, and oxygen for all benthic aerobic organisms (Lowe and LaLiberte 2006).

3.4.5.2 Current Sampling Design and Approach

The original intent of the Inventory and Monitoring program was to co-locate water quality, aquatic macroinvertebrate, and fish community monitoring sites (Figs. 27-28) along streams or within a watershed to observe the impacts of acid deposition, climate change, and other factors on all of these systems. To date, only a small number of monitoring sites have been co-located. Further efforts will

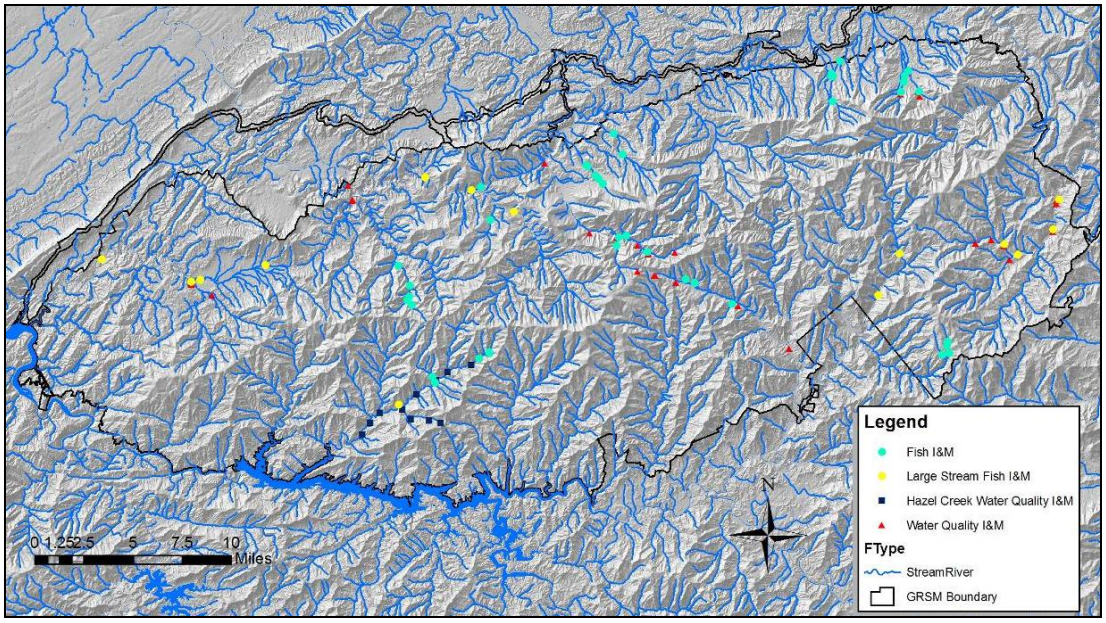


Figure 27. Current fish and water quality monitoring sites in GRSM.

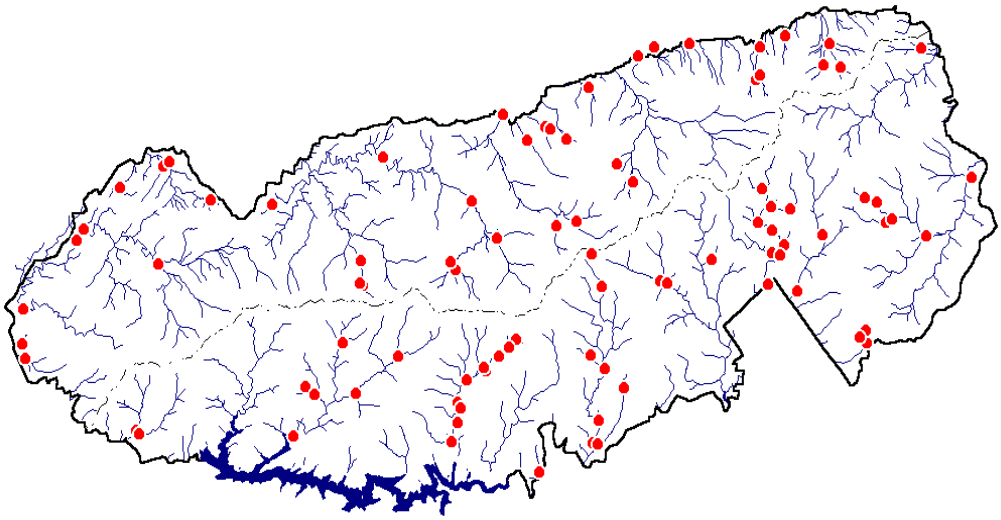


Figure 28. Permanent and rotating benthic macroinvertebrate sites in GRSM.

be made to co-locate monitoring sites for water quality and freshwater communities, and additional components where appropriate.

3.4.5.3 Impacts on Freshwater Communities

Many factors, including climatic and hydrologic conditions, atmospheric inputs, vegetation community type and condition, and soil chemistry within watersheds impact freshwater communities in each of the park's aquatic systems (see Conceptual Model for Acid Deposition, Fig. 17). More specific impacts could include the following: changes in flow regime, stream temperature, and input due to riparian zone disturbance; community structure changes due to invasive species; and severe habitat alteration/acid deposition and/or other pollutant inputs.

Some streams and aquatic systems in GRSM are naturally acidic, and due to the poor buffering capacity of underlying geology and some of the greatest atmospheric acid deposition in North America (Powers 1929, Silsbee and Larson 1983, Nodvin et al. 1995, Smoot et al. 2000), GRSM streams range in pH from <5.0 to 6.5, and stream conductivities generally are <30 μS/cm (Robinson et al. 2001). Park waters are therefore considered sensitive or very sensitive to anthropogenic acidification. The Water Chemistry section of this document provides some detailed information on the effects of water chemistry and climate change on aquatic communities (see Water Quality Links to Biological Effects, above).

Aquatic macroinvertebrates play a central role in most aquatic habitats and act as integrators of environmental conditions (Ward 1984). They are subjected directly to changes in the physical and chemical conditions of the water and exhibit responses to a wide array of stressors. Certain species, primarily in the EPT [Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)] groups, are very sensitive to stressors, such as low pH, high concentrations of toxic metals, increased temperature, and high turbidity. All of these are stressors that exist in some GRSM streams. Benthic algae communities also exhibit sensitivities to changes in the aquatic system, and they respond rapidly to ecosystem shifts (Lowe and LaLiberte 2006). Both of these groups (i.e., macroinvertebrates, algae) have been routinely used as biological indicators (Bonada et al. 2006, Lowe and LaLiberte 2006).

Infectious diseases such as chytrid fungus (*Batrachochytrium dendrobatidis*), and *Ranavirus* (a genus in the virus family Iridoviridae) appear to threaten amphibians worldwide (Dodd 2004, Rothermel et al. 2008). Research has shown that these two diseases are present in the park (Rothermel et al. 2008), but the level of the threat to park amphibians is unknown. In addition, climate change could exacerbate the effects of these disease organisms on park amphibians. For example, increased temperatures could result in drying and subsequent loss of amphibian wetland habitat. This stress could lead to greater susceptibility of amphibians to disease and subsequent die-offs. Because wetlands are a crucial habitat for our amphibian biodiversity, it is vital that we understand them as intact communities as well as consider threats to individual species.

Anthropogenic impacts and non-native species have the potential to impact the park's aquatic ecosystems and adversely affect native fish, plant, and invertebrate species by depriving them of habitat, competing for limited resources, and altering the ecosystem and life histories of other park

species. For example, the introduction of non-native rainbow trout in the park displaced native brook trout from roughly 70% of their former range (S. Moore, pers. comm.). Given the amount of recreational fishing use and close proximity to many vectors of infestation (e.g., reservoirs, tail water fisheries, boundary water fish stocking, etc.), there is great potential for future invasion by other non-native aquatic species into GRSM. The following are examples of aquatic invasive species and potential impacts of these factors on GRSM aquatic species.

- Didymo *(Didymosphenia geminata*) is an invasive freshwater diatom, probably originally from Canada and the northwestern US that can form massive blooms. This species is able to dominate stream surfaces by covering up to 100% of the substrate with thicknesses of greater than 20 cm, greatly altering physical, biological, and ecological properties of the stream (e.g., species diversity, population sizes, nutrient pools) (Larned et al. 2006). Invertebrate, fish, and native algal species diversity and population sizes may be altered. In addition, high growth rates and extensive mats of didymo may impact ecological processes such as ecosystem metabolism and nutrient cycling. This is a very adaptive diatom, and it has been documented in many locations worldwide that did not appear to have ideal conditions for growth and establishment. It has been found in tail water rivers and streams close to the boundary of the park, but not in the park.
- Bd (*Batrachochytrium dendrobatidis*) is a chytrid fungus (Division Chytridiomycota) that often causes a fatal disease in amphibians referred to as chytridiomycosis. This fungus has been identified in association with amphibian population declines on every amphibian-inhabited continent (Speare and Berger 2000). It is thought to have originated in South Africa (Weldon et al. 2004). Bd has been found within the park at various locations but has not been implicated in amphibian die-offs (Rothermel et al. 2008).
- *Ranavirus* (Family Iridoviridae) infections can cause catastrophic mortality of pond-breeding amphibians. This virus has been determined to be the cause of episodic amphibian mass die-offs in the park, including eastern red-spotted newts (*Notophthalmus v. viridescens*), spotted salamanders (*Ambystoma maculatum*), marbled salamanders (*Ambystoma opacum*), and wood frogs (*Rana sylvatica*) (Rothermel et al. 2008).
- Other aquatic invasive non-native species expected in the park area, with the potential for long term impact, include the zebra mussel (*Dreissena polymorpha*), the New Zealand mud snail (*Potamopyrgus antipodarum*), and whirling disease (*Myxobolus cerebralis*), which affects salmonid fish.

3.4.5.4 Freshwater Community Monitoring Approaches

To the degree practical, the approach is to co-sample for the different species groups that make up freshwater communities at the same sites. This location of sites will be part of an overall stratification that includes consideration of the permanent terrestrial monitoring sites. This is to ensure the major portions of the vital signs program are mutually informative over time. Some sites may be selected due to their known/future risk of significant impact to one or more stressor.

3.4.5.5 Monitoring Questions

1. What are the park-wide status and trends of macroinvertebrates and fish?

2. To what extent do changes in other vital signs, such as acid deposition, vegetation communities, soil quality, water chemistry, and climate changes, affect freshwater communities?
3. What are the status and trends of freshwater communities (including algae, amphibians, aquatic vascular plants) impacted by site-specific biological threats, such as non-native fish, chytrid fungus, *Ranavirus*, *Didymosphenia*?

3.4.5.6 Metrics

- species richness, condition, distribution, and relative abundance of native/non-native fish
- biotic indices for macroinvertebrates
- species composition and abundance of algae at selected sites; presence/absence of malformed diatoms at springs
- presence/absence of new aquatic invasives in select areas of the park, based on known habitat preferences
- presence/absence of diseases in populations of amphibians.

3.4.5.7 Design Considerations

- comprehensive sampling of all freshwater community species groups at representative sites, as practical
- site selection based predominantly on coordination with other ecologically related monitoring, especially water chemistry, and in watersheds with terrestrial, permanent monitoring plots (e.g., vegetation communities, soil chemistry, temperature, etc.)
- sample additional areas with known stressors such as development (in-park, or along boundary), impacts from exotic forest diseases, wildland fires, acidification, etc.
- conduct population health checks at selected sub-sample sites for diseases in amphibians and fish, and malformations in diatoms, chironomids, and others.

3.4.5.8 Freshwater Community Monitoring Measures

1. Fish: Measure the species richness, condition, distribution, and relative abundance of native/non-native fish species. Fish species will be collected from the permanent aquatic monitoring sites and analyzed using the Index of Biotic Integrity (IBI) methodology (Karr 1981). A different set of sites will be visited each year, resulting in a visit to each stream once every three years. The IBI methodology uses a series of metrics to score the health of the aquatic ecosystem based upon the number, types, and condition of species collected from various habitat types. Other sampling sites will provide distribution data and will inform managers of species composition changes. In select headwater brook trout monitoring sites, depletion estimates will be used in order to evaluate long-term trends and detect composition and species assemblage changes in relation to historic data.
2. Macroinvertebrates: Benthic macroinvertebrates will be collected from permanent aquatic monitoring sites. Monitoring protocols for benthic macroinvertebrates typically involve the

calculation of indices, which include abundance and pollution tolerance values of each taxon. The North Carolina state protocols have been used in GRSM in the past (NCDENR 2006), with modifications for use in the generally higher elevation areas of western North Carolina and east Tennessee. Trends will be calculated using the biotic indices calculated from each stream, giving an indication of overall stream condition over time. Timely identification of species, many of which will be in larval form, will be accomplished by park staff using local reference collections, and as necessary, identification to the generic (or higher) level.

3. Diatom Malformations: Measure the community composition and percentage of diatom malformations over time in springs and seeps. Significant numbers of malformed diatom species have been documented in several high elevation springs (Furey et al. 2009). Water chemistry results indicate the potential for metal contamination. The diatom community will be used as an early indicator of harmful pollutants; human health concerns are also a consideration as these springs are a drinking source for Appalachian Trail hikers. Water samples will be collected and diatom samples processed periodically; chemical parameters and deformity percent will be analyzed for correlations and trends.
4. Non-native Invasives: A suite of aquatic sites throughout the park (springs, streams, and managed sections of reservoirs) will be selected and sampled on a rotational basis (e.g., every 3-5 years) in order to detect the presence of new aquatic invasive species. Sampling will consist of presence/absence tabulations. Non-native species will be identified and the locations used to focus monitoring efforts to determine relative abundance, potential future distribution, and whether management actions are warranted.
5. Amphibians: Amphibian species encountered in sub-samples of permanent aquatic monitoring sites will be tallied and examined for infections of Bd, *Ranavirus*, and any other disease presentation. The appropriate sampling interval will be determined in consultation with USGS, whose scientists have been actively studying these infections/diseases in the park. Other sites with known infections or at risk to infections may be included as well. Most of these locations are mass breeding sites with larger populations of vernal breeding amphibians (e.g., Cades Cove, Cataloochee, cave sinks); therefore, sampling effort will be focused in these areas. Water, sediment, and tissue samples will be collected and analyzed for presence of disease organisms.

3.4.5.9 Thresholds

TBD.

3.4.6 Critical Vital Sign: Climate Changes

3.4.6.1 Background and Justification

The climate has always changed naturally, in annual, decadal and much longer cycles. These cycles are driven by a complex set of factors involving solar cycles, planetary mechanics, the uneven heating of the planet's atmosphere, oceans, and land masses, and the subsequent delayed transfer of that energy around the earth's surface. Climate operates as a strong driver in every ecosystem in the park (see Conceptual Model for Climate Change, Fig. 29). It drives general patterns of species

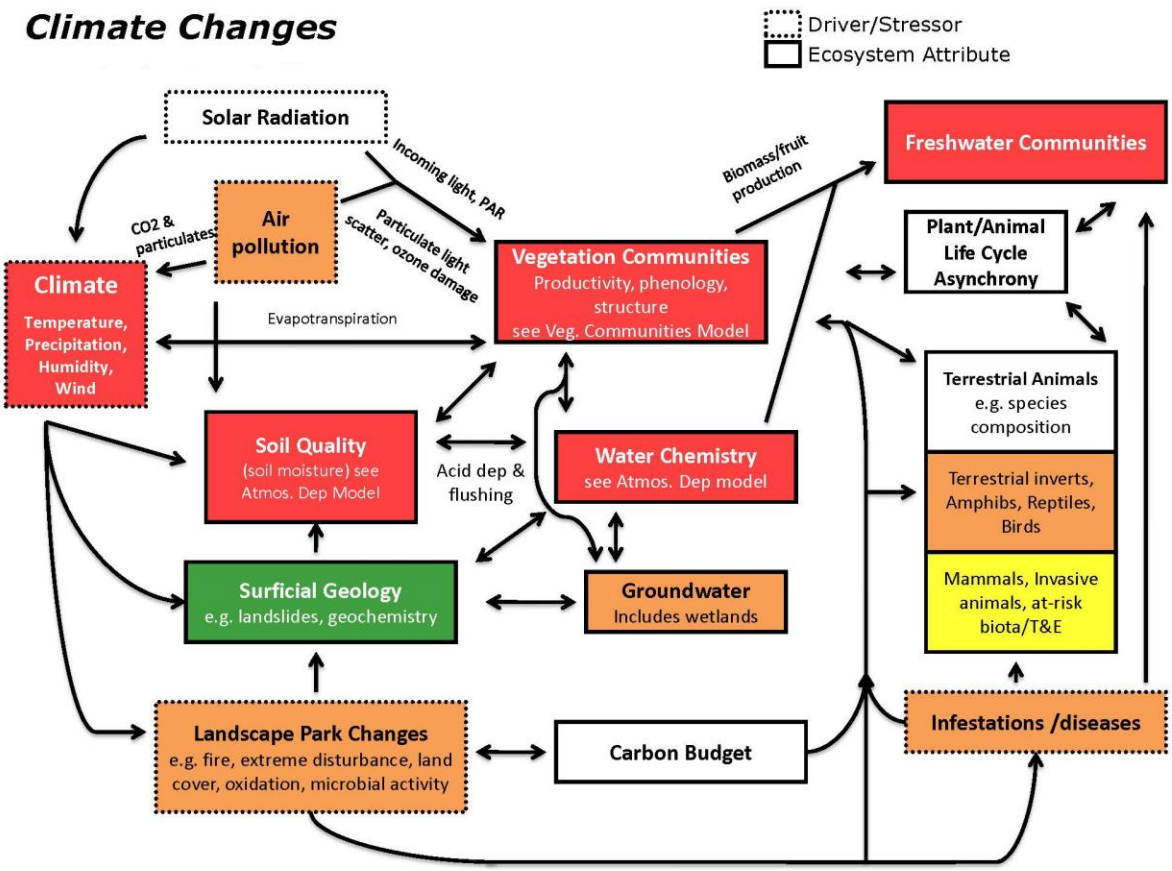


Figure 29. Conceptual model developed for climate changes. Arrows refer to direct relationships and/or influences.

composition and distribution and also affects ecosystems at various geographic scales including sites (microclimates), landscapes (topographic position), and regional physiography (e.g., mountainous terrain) (Stohlgren et al. 1997). The southern Appalachians, like many mountainous areas, are distinguished by steep moisture and temperature gradients resulting in substantially different environments over relatively short distances. In GRSM, cool and moist forests of spruce and fir grow on mountaintops within sight of much hotter, drier ridge and valley forests, each of which has a significantly different species composition. This region is characterized by exceptionally high precipitation, second in North America only to the Pacific Northwest in annual precipitation.

Like many areas in the US, GRSM is subject to strong environmental changes on an annual, multi-year, or decadal scale. There are many overlapping influences, indirect effects, and cycles, making the assignment of what is a natural driver and what is a human-induced stressor very difficult and controversial. Anthropogenic changes may also amplify or dampen natural cycles, obscuring what may be an important influence (Diffenbaugh et al. 2005).

Sources of anthropogenic climate change include increased atmospheric concentrations of greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and carbon monoxide. These come primarily from burning fossil fuels and changing landscapes such as clearing forests. These activities

change atmospheric chemistry and air quality by altering particulate concentrations, cloud cover, and atmospheric moisture levels (Burkett et al. 2001, US Global Change Research Program 2000). Their combined effect globally is theorized to produce global warming: gases trap heat in the earth's lower atmosphere, reduced forest cover is not able to absorb excess CO_2, a changing land surface (increased pavement, reduced ice cover) absorbs more heat, and increasingly acidified oceans release CO_2 (IPCC 2007).

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At the local level, these changes could alter many park ecosystem functions and natural attributes, including plant primary productivity, air quality, soil and water chemistry, vernalization, animal migration, sensitive habitat types, dates of first and last frost, increased drought occurrences, and increased storm/flooding severity and frequency. These changes may also alter natural ecosystem disturbance regimes (including fire and landslides), and can facilitate exotic species invasions, among many other potential impacts (Dale et al. 2001). In addition, changing climate attributes may cause indirect stresses on resources. For example, a plant with high moisture requirements may continue to receive the same amount of precipitation in its habitat, but if it warms, additional moisture will be required to compensate for increased evapotranspiration rates (Ibanez et al. 2007).

All attributes of climate sustain and profoundly influence the biotic communities of the park. We recognize four primary attributes of climate: 1) moisture as water vapor, frozen, and liquid precipitation; 2) temperature; 3) solar energy inputs; and 4) wind as average velocities and events. All of these occur in somewhat predictable natural fluctuations but also as higher magnitude, less predictable events. They are discussed in more detail below:

1. Precipitation is a major driver in both terrestrial and aquatic systems, influencing soil and plant moisture, primary production, stream flow, pollutant concentrations (see Acid Deposition section), and oxygen carrying capacity in stream systems. Extended drought profoundly affects succession patterns in wetlands, all aquatic species populations, and forest composition on sites that are prone to desiccation. Relative humidity is a by-product of precipitation that affects resource attributes as diverse as plant transpiration rates, amphibian activity, wildland fire rates-of-spread, and deposition of acidic fog.
2. Temperature changes through the seasons create a natural synchrony that most natural communities and species depend on, often in complex inter-relationships. Extremes in temperature and prolonged periods at certain temperature ranges which are unseasonable have direct impacts in terms of survival for species and natural communities, but they also affect moisture availability, fire occurrences, plant primary productivity, fruiting, and many other effects park-wide (Mulholland et al. 2009b). Temperatures in GRSM appear to be strongly modified not just by the physical factors of elevation and slope direction relative to sunlight, but by the cooling effect of evapotranspiration (Fridley 2009).
3. Solar energy drives temperature and the plant photosynthesis upon which ultimately all species in the park depend. Incoming solar energy to the park is currently measured at three stations, with one station's records going back nearly 20 years. Solar energy totals can vary as much as 30% between the stations during the same growing season. Additionally, daily differences in regional haze can cut incoming solar energy by ~15%, and dense stratus clouds by 70%. These cumulative changes can result in an annual total fluctuation of at least 8% in solar energy received by park plants (NPS data, J. Renfro, pers. comm.). Any changes in regional/global climatic circulation patterns may change cloud persistence, thickness, and elevational and geographic distribution, with possible impacts to ground-level moisture, temperature, and park-wide photosynthetic uptake.
4. Wind events on the Tennessee side of the park have been increasing in recent decades (NPS data, J. Renfro, pers. comm.). These winds can occur without precipitation and have velocities in excess of 160 kph. Increased wind events may be caused by gradient winds associated with low pressure centers. The winds traverse the Great Smoky Mountains from south to north, then rush down the mountain faces on the Tennessee side of the park. Extensive forest canopy destruction and property damage has occurred in these short (a few hours) events. The National Weather Service has investigated and their analyses indicate a possible change in where intense low pressure cells are tracking; now, they appear to be tracking more to the north than in past decades, which has resulted in more extreme wind events on the lee (TN) side of GRSM (Gaffin 2009).

Climatic factors also strongly control/sustain ecological services, including plant sexual reproduction (pollination, fruiting), ground water and surface water recharge, phenological synchrony of ecological processes/events, migration, decomposition, and others. At GRSM, increased temperatures would probably have a disproportionate impact on the biota at higher elevations; with a shift of natural communities upslope, there is less area available for occupation (Fridley 2009). For example, elevations in GRSM range from about 300 m to over 2000 m. From the 400 m altitudinal

band from 1200 to 1600 m, there are 57,370 ha of available habitat. But in the next higher band of 1600 to 2000 m, there are only 9300 ha; an 84% reduction in habitat (B. Zank, pers. comm.). As one proceeds upslope, a greater percent of the flora and fauna are made up of endemic species and relict boreal communities; therefore, we expect a greater loss in these endemic-rich communities than in communities at lower elevations in the park. This is significant because the entire southern Appalachian area including GRSM has been recognized as one of six national biodiversity hot spots by NatureServe (Stein et al. 2000; see Fig. 4). The park is developing high resolution distribution models of many of its species to track long-term changes (Fig. 30).

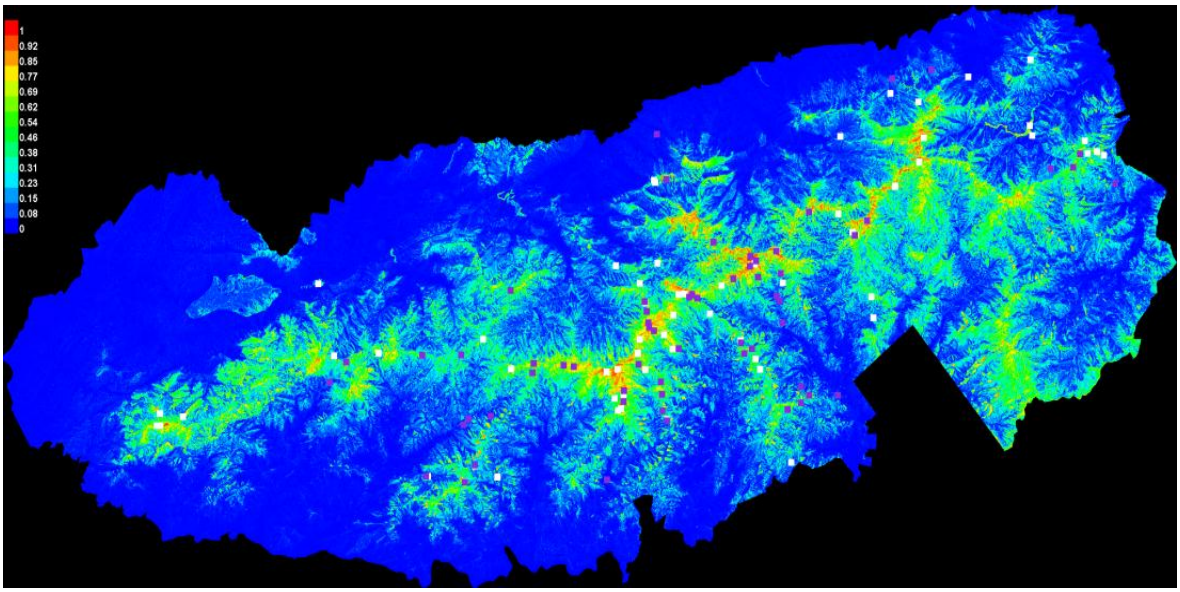


Figure 30. Example of a high elevation species distribution in the park, the red-cheeked salamander (*Plethodon jordani*), which is endemic to the park. Prepared by B. Zank, GRSM GIS Specialist, using MaxEnt (freeware, Princeton University) 2009. Lower densities are represented by blue, and higher densities by red.

Preliminary analyses of ATBI Pilot Study data, collected from 2000-2003, indicate an unconformity for invertebrate elevational distributions (N. Sanders, pers. comm.). Plants and animal groups generally decrease in species richness with elevation gain in the park, but invertebrate species richness only decreases until about 1300 m elevation, then increases in species richness as elevation increases (Fig. 31). Invertebrates make up over 50% of the park's 17,000 documented species. Alarmingly, this would mean a greater fraction of the park's overall fauna will have to squeeze into the much more area-restricted upper elevations than would be supposed in a uniform displacement upslope for all natural communities (Fridley 2009). Other potential resource impacts related to climatic changes include reduced avian nesting success, increased incidence of native and exotic forest insects and diseases, perturbations to plant pollination and fruiting cycles, changes in forest humidity/temperature, growing season changes, and increased tropical storms and adiabatic wind events that alter natural communities and cause changes in species/habitat distributions (Melillo et al. 2001; Burkett et al. 2001). Many other secondary effects of climate change remain unknown.

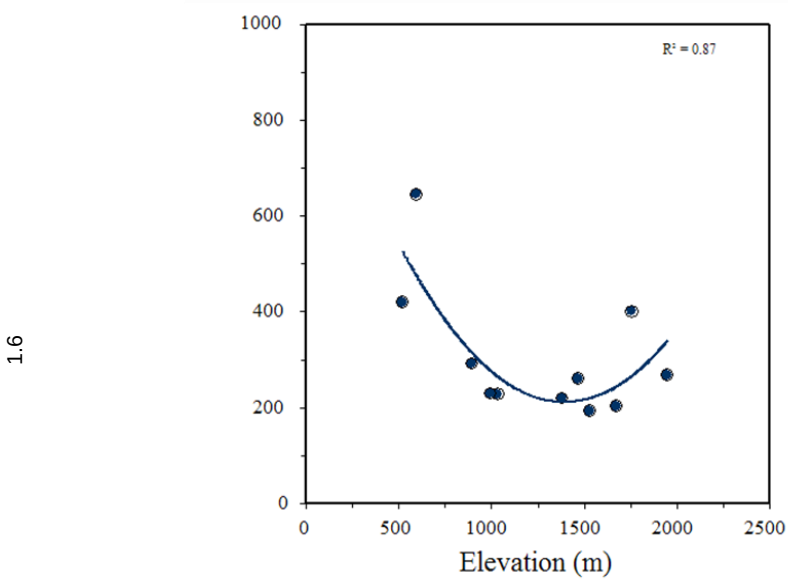


Figure 31. Arthropod species (insects and spiders) at 11 structured sampling sites. Data from Parker and Bernard (2006); interpretation from Sanders (pers. comm.). These relationships also showed up in traditionally collected sampling.

Whether natural or human influenced, climate change is a major driver of regional, continental and global ecosystem change. As indicators of overall ecosystem condition, climate metrics are critically important because 1) they have direct implications for the condition of the broadest array of park and regional biota, 2) we need to know how much variation is due to climate cycles before we can estimate the impact of non-climatic drivers and stressors, and 3), there is some element of predictability in climate cycles that can be related to park resources.

3.4.6.2 Climate Monitoring Approaches

A basic approach will be to develop more extensive monitoring of a few climatic measures across the park as part of co-location with, and support of, other monitoring: water quality sites, hydrology sites, forest vegetation/soil/community sites, and selected at-risk communities such as wetlands and cave sites. Since climate is not just a local stressor, this design must allow for scaling up from data points throughout the park, to inform park-wide models, and scale up again from the park to regional and even larger geographic scales, allowing analyses at multiple geographic resolutions.

A key focus of design will be to continue collection of climate data from established stations in the park, thereby preserving unbroken monitoring records at these stations going back 20-90 years. These stations will be high-confidence baseline points, which will serve to synchronize larger arrays of instrument packages, some of which will be temporary and only deployed for specific purposes. These purposes include developing models of park-wide temperature, precipitation, soil moisture, relative humidity, and phenology of biological resources, as inputs into other monitoring. Linking climate variables collected in new arrays in the park, to the decades-old climatic stations has allowed the development of modeled backcast data for Phenology is important to include since earlier vernalization dates over the longer term will cause changes in forest carbon sequestration, soil

moisture, stream levels, forest humidity and other ecological processes (White et al. 2009). With the exception of phenology, most data for effects on biological/ecological resources will be collected by other portions of the monitoring program (i.e., plant biomass, aquatic populations, species composition changes, etc.). Only selected at-risk resources that are not monitored elsewhere in the program, and phenological events, will receive new climate related monitoring protocols.

3.4.6.3 Monitoring Questions

- What are the park-wide trends of climate, as indicated by changes in: temperature, precipitation, winds, humidity, solar energy input, and phenology of species?
- How do measured trends compare to historic regional and in-park averages and trends?
- How are changes in climate metrics correlated with: disturbance regimes, forest productivity, carbon storage and cycles, special status resources, and biodiversity?
- There is a need to continue climate related data collections at sites that maintain the continuity of a long monitoring record. As an example, the park is fortunate to have historic climate stations with temperature and precipitation records going back ~90 years, as well as more than 20 years of air quality monitoring data at seven sites with much more comprehensive instrumentation.
- In total, measurement sites must be representative of the range of climatic variation in the park, since there are so many unknown factors related to direct and indirect impacts in this complex issue. Due to its topography, the park has one of the steepest gradients for temperature and moisture in eastern North America, making sensor-based data collection across gradients attractive from an efficiency, access, safety, and precision standpoint. These data will inform geographic models of climatic variables.
- General co-location of measurements with permanent monitoring sites is essential in order to compare changes seen in other natural resources with climate data at those sites.
- Over the decades, valuable climate related data sets have been collected intermittently. These legacy data need to be assessed for quality and linked at an appropriate scale in the park. For instance, some of the same species had vernalization dates recorded in the 1940s to 1960s, and then again in the 1990s, but they have not been spatially related. This may now be possible using backcasted temperature models synchronized to climate stations operating for most of a century. The park also has data from former stream gauge sites that could possibly prove useful with future precipitation models.
- Moisture and temperature both need to be monitored and modeled in order to understand changes in natural systems (Whittaker1956). The amount of moisture available for evapotranspiration may be the key to understanding how warm or cool the upper elevations become with climate change (Fridley 2009). Incoming precipitation, soil moisture, and stream discharge all need to be measured and included in a hydrological model of the park. This model needs to be utilized to explain observations, estimate near-term changes, and with regional/global models, forecast longer scale changes in GRSM.

3.4.6.5 Climate Monitoring Measures, Metrics, and Thresholds

1. The park will maintain extant permanent stations that collect climate data. Currently five historic National Weather Service climate stations, two NPS remote fire weather stations, seven NPS air quality sites, and 11 flood warning precipitation gauges exist in the park (Fig. 32). The park has a number of climatic data assets, some of which extend for 90 years (Fig. 33).

   Metrics Collected:

   - precipitation; increment varies but at least daily
   - daily maximum/minimum temperature at all stations
   - solar energy (watts/m^2) at three stations

   Many other measurements are collected at the air quality stations, including solar radiation, visibility, ozone, and various other air pollutants. Staff will evaluate each sampling methodology of each array for compatibility across systems as appropriate, so as to evaluate trend information. All data will be captured in a single relational database to facilitate analyses. Climate data also will be used in analyses of changes in most other monitored resources.

   Thresholds will be the annual averages for precipitation and temperature that exceed one standard deviation from long-term trend data for those metrics. These values are established as initial thresholds pending comparison of impacts to sensitive resources at various precipitation and temperature values.

2. Remote sensors will be used at selected permanent monitoring plots. Small, remotely deployed recording instruments (e.g., Hobo, I-Button) are inexpensive and have been used in the park to efficiently collect air, water and soil temperature, soil moisture, and relative humidity. Data can be downloaded from the sensors at variable frequencies, including annually or less often. These devices were used to create a park-wide temperature model for the park (Fig. 34).

   Data collected at permanent monitoring plots will be used to inform the park-wide climate model and also to support other monitoring protocols and management programs, including biomass, productivity, vegetation species composition, forest structure, exotic insect/fungal/vertebrate species, ozone injury, soil water quality, carbon storage, drought severity indices, acorn/fruit production, and others. Data from these sites will be synchronized to the existing climate stations. The park will also measure selected climatological attributes in areas known to be climate-sensitive, such as caves or wetlands. These will supplement park-wide data and allow backcasting for temperature and other climate attributes at these sensitive or special management protection sites (see Fig. 35).

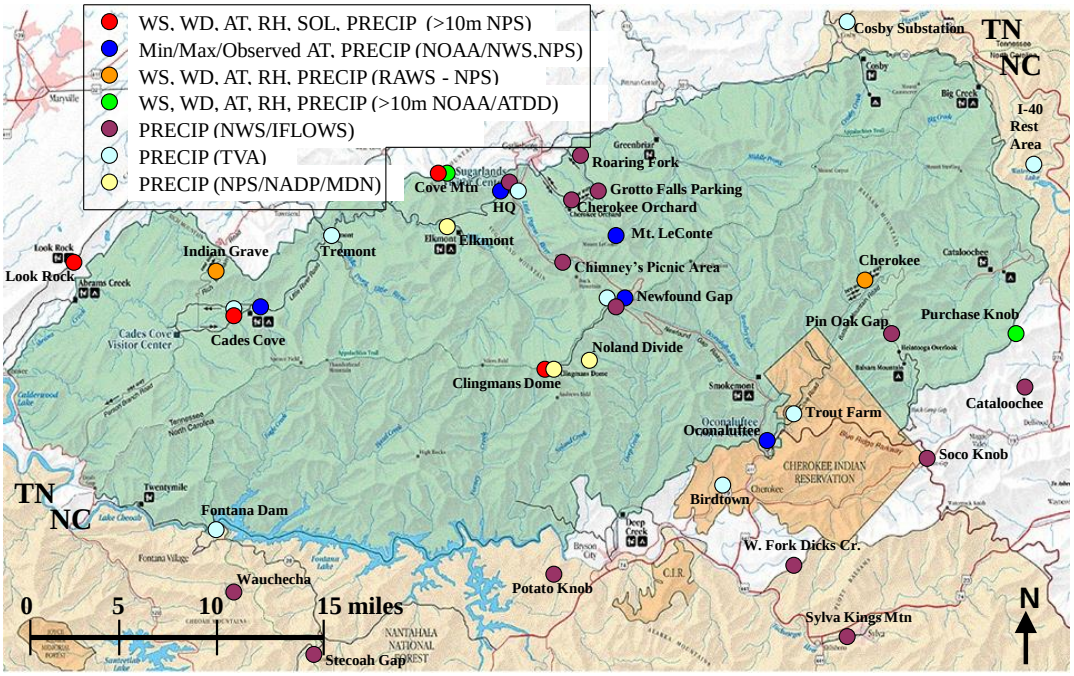


Figure 32. Climate, meteorological, and air quality stations in GRSM.

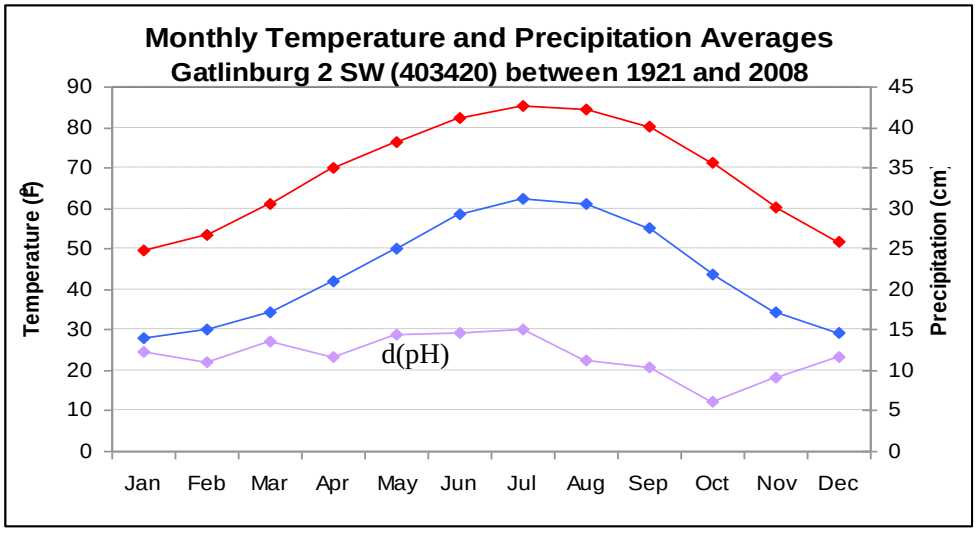


Figure 33. Average monthly maximum (red), minimum (blue) temperature, and precipitation averages for Gatlinburg, TN, 1921-2008. (National Weather Service)

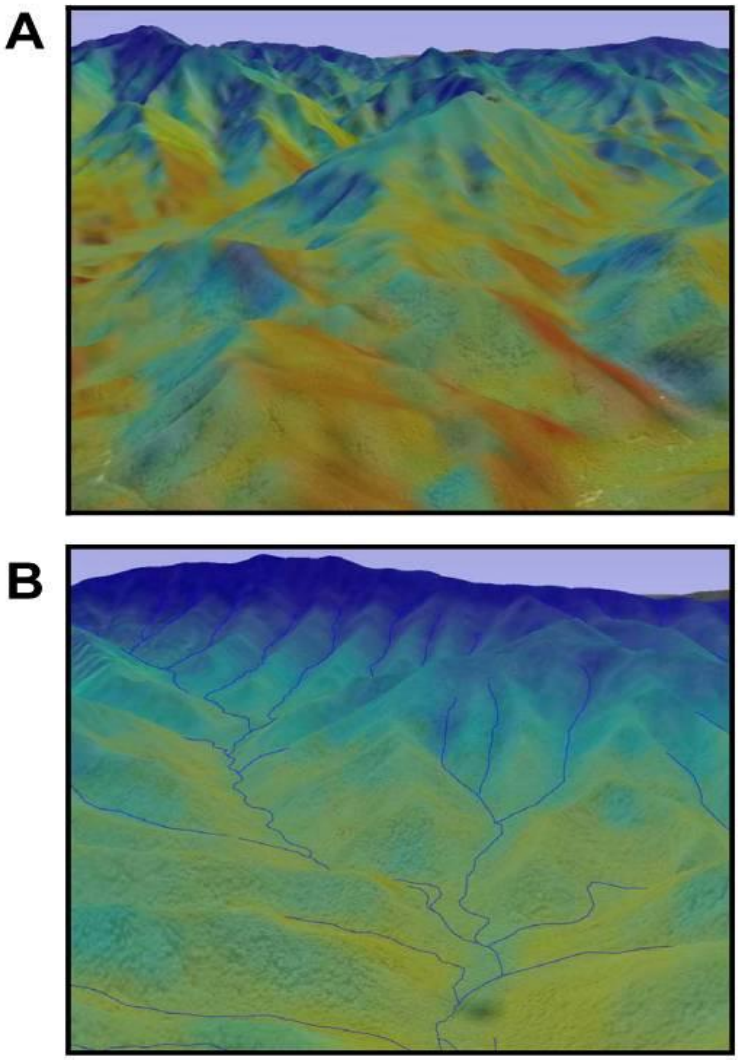


Figure 34. Examples of fine-scale spatial structure of minimum and maximum temperature maps. A) Maximum July temperature from a location looking southeast over Sugarland Mountain with Mt. LeConte at upper left. This view highlights the extreme fine-scale variance of day-time temperatures caused by radiation differences. B) Minimum January temperature from a location looking south from Elkmont across Little River to Clingmans Dome. This view highlights warmer streamside locations in winter. Graphics courtesy of Dr. Jason Fridley, Syracuse University.

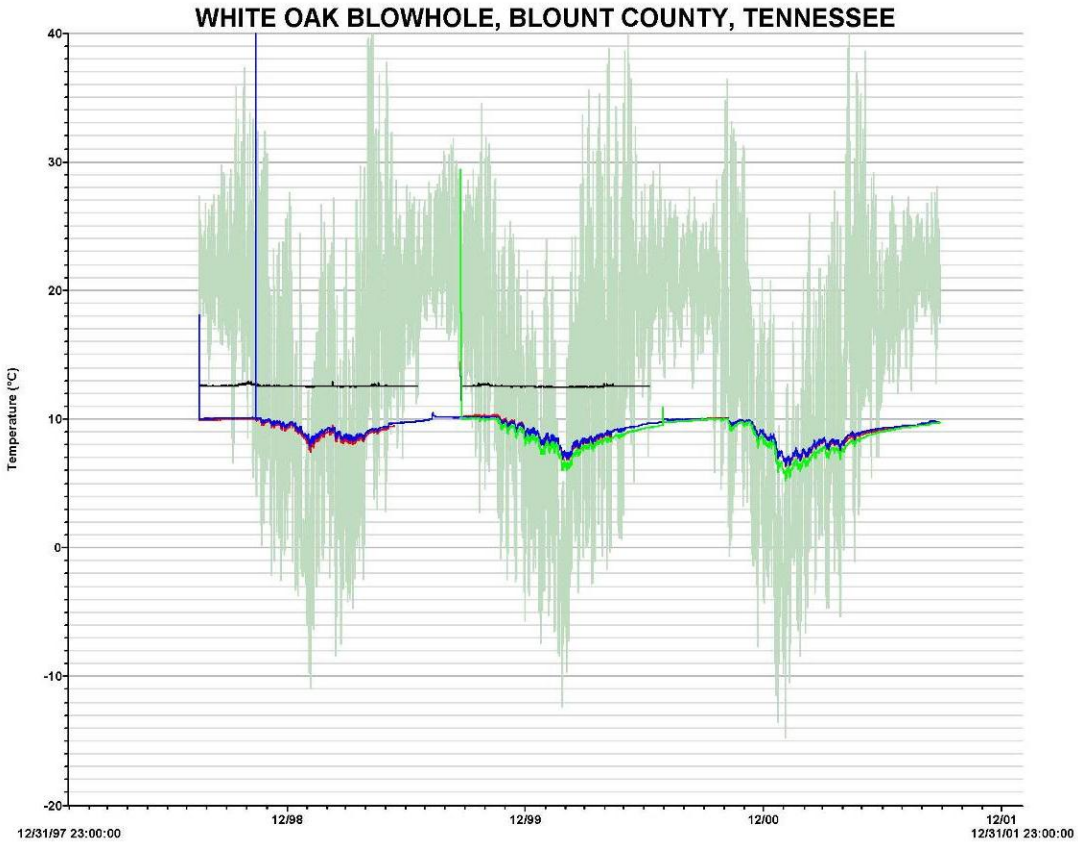


Figure 35. Temperature at four locations inside Blowhole Cave and on the nearby surface (pale green), 1998-2000. The black line is temperature in an isolated room; note that it is quite stable.

Metrics that may be collected at permanent monitoring plots:

- air temperature, at 2-hr increments
- relative humidity
- soil temperature, multiple times/day
- soil moisture, at least daily
- stream water temperature

Initially, data from the U.S. Forest Service's Coweeta Hydrological Lab, and recommendations from Fridley (2009) and other researchers will be used to set extreme values that will initiate investigations of undetected effects on sensitive resource groups. These thresholds will be based on metrics from statistical analyses from models, and can be expected to change as more data are accumulated.

3. The park will develop/implement a model for park-wide precipitation. National Weather Service Doppler radar will soon have upgraded capabilities (NOAA 2010). These upgrades will allow improved typing of precipitation, better estimation of amounts, and better performance in mountainous areas. These data will be used to carry out the following:

    - Summary maps of rainfall and snowfall amounts will be produced for watersheds or other sub-divisions of the park. These data will in turn be used as important model inputs for watershed and park-wide measurements of trends in: hydrology, ground-water recharge, soil chemistry, water quality, contaminant deposition, influences on aquatic invertebrate and vertebrate populations, and many other ecological systems.
    - Several permanent and many temporary stream gauges will be maintained/installed in selected major catchments of the park. These will be used to construct a hydrological model of selected watersheds, to evaluate and challenge the radar derived precipitation model, and to derive transpiration.

    Metrics collected:

    - download of NOAA-National Weather Service dual polarity radar imagery
    - soil moisture, collected in permanent plots as part of soil quality monitoring
    - data from permanent/temporary stream gauges in selected watersheds.

    Statistical thresholds are available for short term precipitation events likely to create localized disturbance to park resources from specific storms at any point in the park. However, thresholds for seasonal or longer accumulations will have to be established.

4. Phenological monitoring in the park will be re-organized. Measurements of plant and animal phenology events have been recorded for several different projects at the Great Smoky Mountains Institute at Tremont (GSMIT) for ~20 years (Mathis 2008). The combined first-bloom dates for 25 native plants preliminarily show that over 23 years (1985-2007), plant bloom date has shifted to >22 days earlier. Neo-tropical bird first-arrival dates also are earlier in some species. Additional discreet and systematic phenological observations are available from earlier decades. All such data need to be uniformly included in backcast temperature modeling for analysis. Aspects of the re-organized phenological monitoring program in the park include the following:

    - Permanent plots will be established in several natural areas near cooperator, partner, and park-staffed facilities to permit regular monitoring during targeted phenological windows. Several less-intensely monitored sites may be utilized to provide stratification by elevation or solar aspect. Within plots, several attributes for each of the targeted species will be measured, including vernalization and first reproduction benchmarks, peak reproduction dates, and cessation of growth/occurrence, as appropriate. Target species would include plants, neo-tropical and resident birds, insect, and amphibian species. Audio observations will be recorded using standard protocols,

and perhaps with remote recording instrumentation. Other within-plot recording sensors may include air temperature and soil temperature.

- Cultivars derived from native tree species, which are part of the continent-wide phenological monitoring system of the National Phenological Network, will be planted in several developed-zones in the park. Vernal measurements of the genetic standard will be analyzed with data collected from native species to measure variability of impact to park resources.
- Currently, remote sensing from regular satellite passes can measure and model the degree of forest canopy vernalization, calculate estimates of when forest canopies reach full vernalization, autumn abscission of canopy foliage, and annual duration of the canopy in 250 m pixels. However, performance differs among satellite based methods (White et al. 2009). An evaluation will be undertaken to select the best method.
- Park-wide temperature modeling will be continued and compared with plot and satellite data.
- Park-wide phenological changes will be estimated by synchronizing plot data with park-wide, regional, and global phenological remote sensing and climatic data.
- Potential locations for phenological monitoring include GSMIT, Purchase Knob Research Learning Center, visitor centers, Twin Creeks Science and Education Center, selected sites adjacent to more accessible permanent monitoring plots, and schools outside of the park. These measurements will be collected by GRSM Resource Education Division staff, as part of the education curriculum, and also by RMS staff, citizen scientists, teacher naturalists from GSMIT, and other agencies.

Metrics collected:

- in-park measurements of vernalization of genetically standard plants provided by the National Phenological Network (see above)
- leaf expansion/shoot growth, first flowering, and peak flowering dates for all plants at selected plots, stratified by access, elevation, and solar aspect
- first dates and/or peak dates for neo-tropical bird arrival, amphibian calls, reproduction, and other measures
- air and soil temperatures in plots and park-wide
- remote sensing calculation of forest vernalization and leaf abscission from satellite imagery [this calculation has been automated for forest phenology, canopy foliation curves, and effective growing season in 250 m pixels (J. Fox, pers. comm.)].

In addition to the 20 years of phenological data collected by GSMIT, there also are 28 years of phenological records from park biologist Arthur Stupka (1935-1963). These data will be used to calculate annual variations and to establish thresholds of deviation. Growing degree-day statistics will be calculated from the park's climatic stations and remote temperature

sensors. Canopy vernalization data will have thresholds calculated from previously collected data. Acute changes of one standard deviation or more will initiate investigation of effects on sensitive resources. The USGS is submitting a research proposal to assist the park in organizing these data (G. Kish, pers. comm.).

5. The park will utilize remote sensing data, using appropriate imagery/sensors and seasons, to detect landscape changes. In addition to satellite phenology measurements, periodic remote sensing will measure changes in several categories of disturbance related to climate change: wind-damaged forest canopy, landslides, detection of forest insect and disease occurrences, defoliation/mortality areas, and conversion of natural areas outside the park boundary. Depending on the type of sensors chosen (conventional aerial photography, LiDAR, satellite multi-spectral scans, etc.), forest productivity and snow pack may eventually be assessed using satellite or other remote sensing platforms. Results from the park's wind, precipitation, temperature, and other climate data will be evaluated for their ability to explain the changes documented.

   Changes in land use from wildlands to agriculture or urban outside of the park will affect the park's climate and other systems. In a very recent study, GRSM had the largest rate of increase (1133%) in surrounding home density from 1940-2000 of 10 national park units surveyed nationally (A. Hansen, pers. comm.). Using remote sensing and analyses from national datasets available in the new NPScape program (Fig. 36) changes between natural, agricultural, and urban area outside of the park to a distance of ~30 km will be summarized over time (NPScape 2009).

   Metrics collected:

   - High resolution (~1 m) aerial photography (Fig. 37), or a technological equivalent, will be collected park-wide approximately every 10 years, or more frequently if deemed necessary and/or if collaborative opportunities occur.
   - Land use outside the park will be downloaded from national or regional databases. Summary categorical data will be tracked for wildlands, urban, and agricultural areas.

   The park has some aerial surveillance data on insect and disease occurrences, and there are remotely sensed legacy data that need to be evaluated for use in tracking landslides, wind damage, and urbanization. Once sufficient new and/or legacy data has been acquired and analyzed, thresholds for each disturbance type will be set using statistical parameters. For neighboring land use, data are available through the NPScape program.

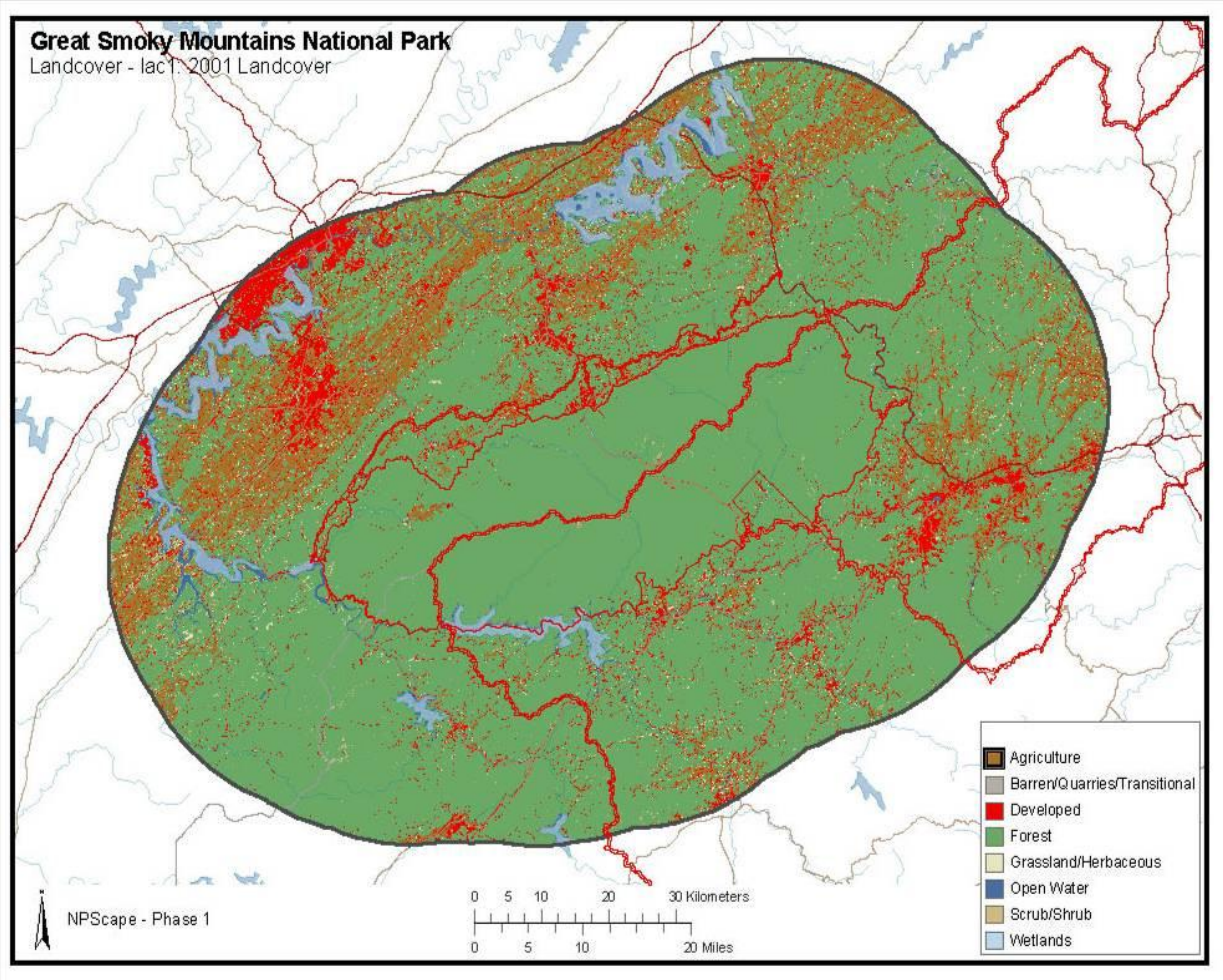


Figure 36. 2001 land cover for GRSM and surrounding areas. Urbanized areas are depicted in red. This image is an analysis from the NPScape program.



Figure 37. LiDAR data for the Cataloochee area, GRSM. The gray patches are open hayfields, and the light green areas, including those indicated by arrows, have thinned canopies, and in this case are believed to be sites with loss of eastern hemlock (*Tsuga canadensis*) overstory due to the exotic hemlock woolly adelgid.

4. Sampling Design

Sampling design is the physical approach to obtaining the repetitive measurements needed to detect change in a monitoring program. The park is large and ecologically complex, and cannot practically be monitored at the intensity desired. Therefore, critical monitoring questions were integrated at different geographic scales. Proposed is a nested hierarchy of measurement sizes, to answer questions at each geographic resolution, and to support the scaling-up of measurements to park-wide. All aspects of sampling design will be based on statistically valid sampling with the goal of detecting and measuring trends over time.

4.1 Monitoring Ecological Linkages

The critical vital signs are arrayed on an ecological axis that figuratively (and in some cases literally) flows downslope from incoming acidification at higher elevations to vegetation and soils, to water chemistry and freshwater communities. At each next lower component the geographic scale of concern usually widens. Climate change is seen as ubiquitous. In order to monitor across as many drivers and stressors as possible, yet scale the new program so that it is practical and economical, the team has decided on a hierarchical approach that shifts from intensive field plots to whole park/landscape scales (Fig. 38).

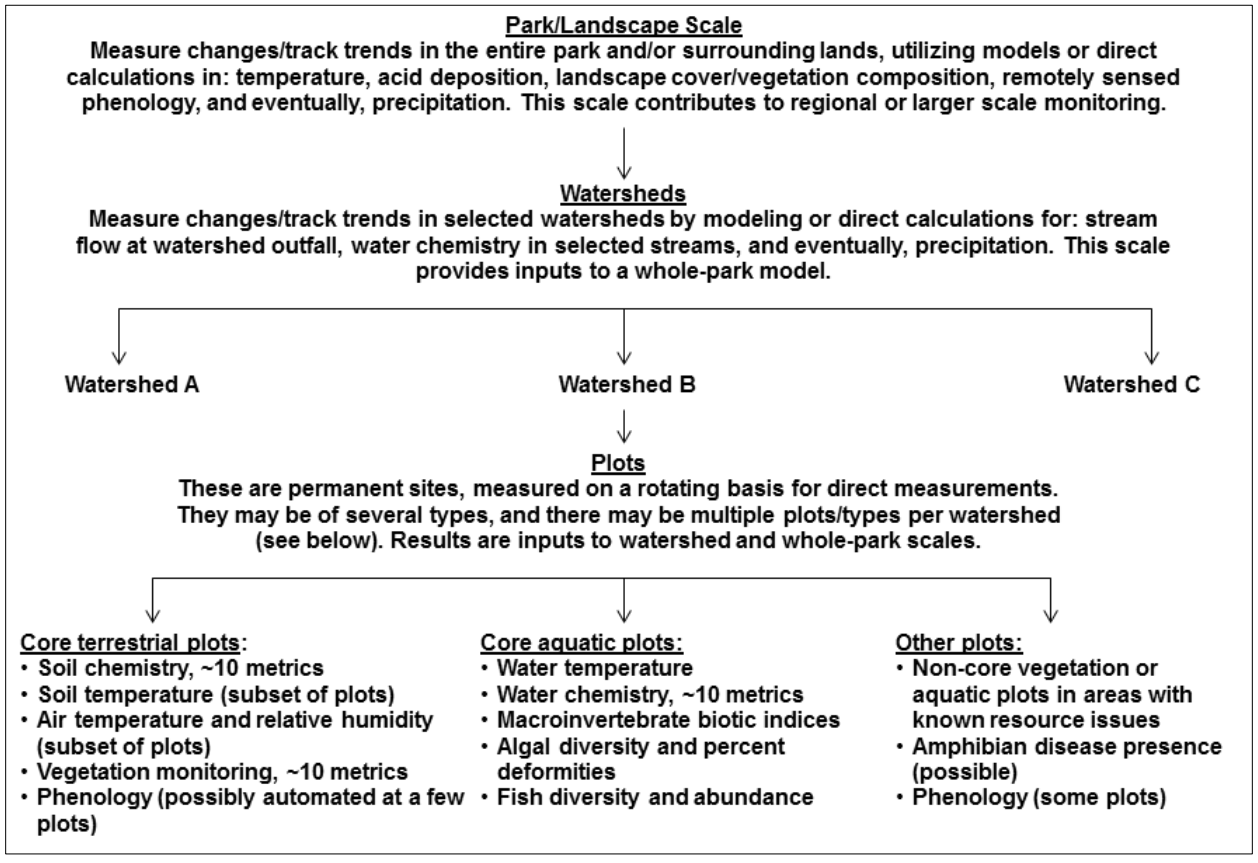


Figure 38. Preliminary scales of Vital Sign metrics.

4.1.1 Permanent Monitoring Plots

Permanent monitoring plots are intensively monitored sites, maximized so that park staff can collect measurements of several vital signs at the same sites. The core monitoring foci for these plots may be terrestrial (vegetation, soils, soil water chemistry, air temperature, etc.) or aquatic (water chemistry, algae, benthic macroinvertebrates, fish, etc.). Secondary monitoring, for example on breeding birds, amphibians, biodiversity, phenology, and others, could be added over time, if appropriate and as partners and resources allow. Any monitoring that would disturb the original plot or monitoring goals would be planned for an adjacent site. Aspects of these permanent plots include the following:

- Plot density will be higher in selected watersheds, and the number of plots will be determined by ecological variability in each watershed.
- Scheduled terrestrial monitoring includes vegetation, soils, and air/soil temperature; subsamples may include amphibians, birds, and other metrics on longer rotations.
- Scheduled aquatic monitoring includes water chemistry and temperature, algae, macroinvertebrates, and fish. Subsamples may include contaminants, salamanders, and other metrics on longer rotations. Site selection may be based on specific criteria rather than chosen randomly.
- Legacy plots may be utilized if they meet certain statistical thresholds; however, most terrestrial plots will be randomized within a stratification based on geography, ecological classifications, and accessibility.
- A lesser number of non-random plots will be selected at index sites known or thought to be highly likely to experience acute or chronic stress in the future. These may not be statistically valid for inclusion in watershed or park-wide analyses, but will allow measurement of worst-case scenarios for some stressors.
- Outside of selected watersheds, plots will be randomly selected in otherwise unmonitored ecological units. These plots will be at a lower level of surveillance than in the selected watersheds, and are intended to detect unforeseen park-wide changes. Data will be included in park-wide analyses.

4.1.2 Watersheds

Several representative watersheds will be selected for more intensive monitoring within the 26 major watersheds in the park. These watersheds will receive more intensive monitoring, and will be targeted for additional watershed-scale measurements, such as catchment hydrology, biogeochemical modeling, and additional air and water temperature modeling. Understanding watershed-level dynamics is the focus at this scale, and certain resources may be monitored along the watershed's entire longitudinal/ecological pathway. For example, analysis begins with water chemistry as it enters the park ecosystem in airborne pollutants, falls through forest canopies and filters through soils becoming soil water, flows into springs and first order streams, and continues downslope to larger streams and different forest types with complex terrestrial and aquatic communities. Measurements would be taken at each ecological stage/transition. The goal is to understand interactions, track trends, and make predictions at the watershed level, which generally involves several or more natural communities. The following are considerations for watershed monitoring:

- Staff will choose one watershed on each side of the mountain divide as a pilot, then expand to approximately 3-5 total watersheds from different major drainages and geology, as practical. Selection will be based on 1) efficacy in answering a broad array of monitoring questions, 2) capturing optimal ecological variability of the park while utilizing appropriate statistical inferences, and 3) ease of access.
- All selected watersheds will have a higher density of randomized terrestrial and aquatic plots to track all metrics downslope/downstream within the watershed unit. The number of plots in each watershed will be determined by the ecological variability in that watershed.
- All watersheds will have hydrologic gauging stations in lower reaches, and precipitation inputs calculated from remotely sensed data (weather radar), calibrated with precipitation gauges (part of research needs for monitoring).
- All metrics from each watershed's terrestrial and aquatic plots will be analyzed at the watershed level of resolution, summarized, and compared across similar environmental gradients to data from the other watersheds.
- All incoming acid deposition will be modeled annually for each watershed using the model developed by Weathers et al. (2006).
- Temperature and selected phenological metrics will be tracked/modeled over the watershed using remote sensing (see below) and limited ground observation points.

4.1.3 Park/Landscape

Watershed data will be scaled up to park-wide models, providing a synthesis of vital signs such as acidic deposition, forest health, species diversity, soil chemistry and carbon status, and water budget status and trends in selected aquatic groups. Additional remotely sensed data will be collected regularly and will include disturbance types (e.g., geologic, defoliations, wind throws), precipitation inputs, and phenological trends. The landscape level extends beyond park boundaries with periodic updating of land use by the NPScape program. The following are considerations for park/landscape monitoring:

- Trends in temperature, precipitation, and incoming acidity will be summarized park-wide.
- Water amount and chemistry, and soil water chemistry from watersheds will be extrapolated across the park, as appropriate.
- Other metrics from watersheds (e.g., forest biomass, species richness, water chemistry, etc.) will be compared/modeled across the park, and may be appropriate for valid comparisons at certain scales for particular metrics.
- Remote sensing will be used periodically to measure perturbations due to natural and anthropogenic causes (e.g., defoliations, landslides, wind-thrown canopies, fires, etc.) across the park and for some distance outside of the boundary, using NPScape criteria.
- Satellite remote sensing data (NASA –MODIS) will be used to track forest canopy vernalization and growing season duration (250 m pixels, park-wide) for seasonal and annual

variances. These will be used with ecologically selected phenology plots that include both native species and continent-wide standardized analogs (NPN 2009).

4.2 The Rest of the Park – Surveillance for Large Changes

Outside of the intensive watersheds, the rest of the park will be monitored using a less dense array of permanent monitoring plots. These representative sites will not be grouped or constrained by watershed boundaries, but stratified by geology/soils, elevation, under-sampled major forest communities, and/or other ecological categories represented park-wide. The objective is to detect large scale or intense perturbations in geographic areas and within ecologic components of the park that are not within the intensively-sampled watersheds. These plots may be less intensive or on a longer measurement rotation than those in the more intensive watersheds. If we do detect significant changes, we can then direct short-term studies to investigate and evaluate the changes detected.

Permanent plots will be placed according to one of two criteria: 1) stratified randomly within ecological associations not well represented in the intensive watersheds, or 2) located at sites of known management concern for the future. This last group of plots will be few in number and probably not be valid for use in park-wide statistical integration.

4.3 Other Monitoring in the Park

In addition to the six critical vital signs, the park identified 18 other important vital signs. These include: hydrology, terrestrial biodiversity, amphibians, toxins, rare species, ozone, breeding birds, invasive plants, sub-surface geology, and others. These groups need to be monitored at some level; suggested pathways towards establishing monitoring of these 18 priorities are listed below:

- Some monitoring can be focused as a result of base-funded management actions or park programs.
- Project funding in the same topical areas could allow for re-measurement of plots, or set up baseline measurements for future comparisons.
- The approximately 170 research permits/projects issued each year in GRSM offer an opportunity to involve other scientists in the collection of data valuable to monitoring. This could include re-measurement of existing sampling arrays or setting up new sampling that the park ensures (through the permit system) is repeatable for future use.
- Some monitoring can be accomplished by supporting and encouraging other agencies or entities that are interested in those groups or topics. Several USGS offices in the southeast have expressed interest in being involved in different monitoring programs in GRSM, and the National Ecological Observatory Network (NEON) will have a relocatable terrestrial and aquatic site installed in the park in late 2012. State agencies may also be able to collaboratively assist on some of the 18 important monitoring topics.
- Environmental education centers may be able to train and nurture citizen science groups that could undertake some of these activities on a longer term, periodic, or limited basis. Coordination and support of other agency and citizen science efforts should be a high priority for the park and program.

It also is possible that some limited monitoring of these important monitoring issues may eventually be appended to the critical vital signs protocols once the new program is operational.

5. Sampling Protocols

Pending receipt and review of comments on this conceptual plan, the park will finalize selection and modification of protocols. All protocols will follow guidelines for long-term monitoring protocols in Oakley et al. (2003). There will be a transition to the new program as resources become available to undertake the monitoring, and to conduct research to scope the monitoring effort. Also, the number of protocols implemented will depend on the resources that become available. The WASO I&M database of monitoring protocols will be used as a first source for use and or modification of protocols needed. (see http://science.nature.nps.gov/im/monitor/VitalSigns/BrowseProtocol.aspx).

To the greatest degree practical, we will develop protocols as interdependent components of the same program, which seeks to answer a unified set of critical questions about park resources. No protocol will be approved if it has not been planned to maximize scientific linkages in data analyses with other data being collected. Standard data analyses will be a section in each new protocol, and will not only include analysis of that particular set of data addressed in field collection, but will also articulate how other data sets will be analyzed in conjunction with it. Desired changes in any protocol must first receive concurrence from the other protocol leaders.

6. Data Management and Archiving

Data management in the park Vital Signs program will follow the detailed guidance of the park's recently updated draft Data Management Plan (2012). The objective of the data management system is to provide timely and useable scientific information about the status and trends of park resources. The success of the program hinges upon our ability to produce, manage, and deliver this information to its intended audience. Specifically, the objective is to develop and maintain a system for producing value-added park resources data.

A set of data, whether collected during the previous year or 20 years ago, must be accompanied by sufficient context of how and why it was collected so as to maintain its value beyond the lifetimes of those who collected it. A data management strategy cannot simply include the tables, fields, and values that make up a data set; there must also be a process for developing, preserving, and integrating the context that makes it interpretable and valuable. Following are highlights of the GRSM Data Management Plan.

6.1 GRSM Data Management Goals

The park data management goals establish the foundation for building a sound, responsive data management program; namely, that data collected by the park are of high quality, are readily available, can be easily interpreted, and are secure for the long-term. Specifically, the goals are:

1. To ensure that data managed by the park are of high quality and include standardized data entry, importation, and handling procedures which effectively screen for bad data, and minimize transcription errors.
2. To make certain that park data are readily available by implementing standard procedures for distributing data, while protecting sensitive data, and designing a standardized filing system for organizing Vital Signs information.
3. To ensure that park data can be easily interpreted, by considering the users' needs as the primary factor driving the design of summary reports and analyses; establishing rigorous data documentation standards; integrating common data tables and fields into the Natural Resource Database Template (NRDT) format; and making summary information available in formats tailored to the variety of audiences interested in Vital Signs program results.
4. To make certain that data are secure for the long term, including instituting standard procedures for versioning, data storage and archiving, and maintaining the necessary hardware and software configurations to support park data management needs.
5. To achieve the seamless integration of spatial and non-spatial data, eliminating barriers to use of data in a decision-support framework.

6.2 Data Management Roles and Responsibilities

Meeting the park's data management goals requires the participation of everyone on the GRSM staff, from field crews who collect data, to project managers who validate, analyze and summarize data, to the park data manager, who ensures that master data sets are of high quality, and that proper data management standards and practices are adhered to. Because good data stewardship is so central to

the mission of the park Vital Signs monitoring program, significant staff time at all levels is devoted to that effort (Table 3).

Table 3. GRSM staff resources directed toward data management.

Title	# of Staff Positions	% of Time	Data Management Activities	Total FTE
Coordinator	1	30%	data analysis, summary, and reporting; data validation and verification	0.3
Data Manager	1	80%	data archiving and dissemination, database development, overall QA/QC	0.8
GIS Specialist	1	20%	Spatial data archiving and dissemination, geodatabase development	0.2
Project Managers	6	35%	data analysis, summary and reporting; data validation and verification	0.7
Biological Technicians	1	30%	data entry and verification	1.2

6.2.1 Project Management

Project managers and the data manager play key roles in every park Vital Signs project. In GRSM, the project manager is normally the subject matter specialist and is responsible for data quality during all phases of the project, including data collection, quality assurance/quality control (QA/QC), analysis, and reporting. Developing project documentation and metadata are crucial elements of this function. The project manager's data management responsibilities include:

- Developing basic project metadata documentation.
- Documenting and implementing standard procedures for data collection and data handling, including deviations from those procedures.
- Developing quality control measures, including certification of field operations, equipment calibration, species identification, data entry, and data verification and validation.
- Maintaining hard copies of data forms and archiving original forms.
- Scheduling regular project milestones, including data collection periods, data processing target dates, and reporting deadlines.
- Acting as the main point of contact concerning data content.
- Ensuring that database schemas are compatible with linkages to geospatial datasets.

The project manager will work closely with the data manager to:

- Develop QA/QC procedures.
- Identify training needs for staff related to data handling procedures, quality control measures, and database software use.
- Coordinate the design of field data forms and the user interface for the project database.

- Document and maintain master data.
- Identify sensitive information that requires special consideration prior to distribution.
- Ensure regular archiving of project documentation, original field data, database reports and summaries, and other products related to the project.
- Create data summary procedures to automate the process of transforming raw data into meaningful information.
- Identify and prioritize legacy data for conversion to desired formats.
- Increase the accessibility and interpretability of existing natural resources information.

The park data manager has a central role in designing project databases, disseminating data, ensuring long-term data integrity, security, and availability, and ensuring that project data conforms to program standards. The data manager maintains standards for this data and the associated metadata, and develops procedures for sharing and disseminating data to the park and partners. The data manager's responsibilities include:

- Developing and maintaining the infrastructure of metadata creation, project documentation, and project data management.
- Creating and maintaining project databases in accordance with the best practices and current program standards.
- Providing training in the theory and practice of data management tailored to the needs of project personnel.
- Developing ways to improve the accessibility and transparency of digital data.
- Establishing and implementing procedures to protect sensitive data according to project needs.
- Establishing procedures for data dissemination.
- Integrating tabular data with geospatial data in a GIS.

The data manager will work closely with the project manager to:

- Define the scope of the project data, and create a data structure that meets project needs.
- Become familiar with how project data are collected, handled and used.
- Identify elements that can be built into the database structure to facilitate quality control, such as required fields, range limits, pick-lists and validation rules.
- Create a user interface that streamlines the process of data entry, review, validation, and reporting.
- Ensure that project documentation is complete, complies with metadata requirements, and enhances the interpretability and longevity of project data.
- Ensure proper archiving of project materials.
- Identify and prioritize legacy data for conversion to desired formats.

6.2.2 Data Management Coordination

The GRSM data manager works with national NPS I&M data management staff and regional resource information management personnel to maintain a high level of involvement in service-wide and regional databases and data management policy. The park data manager works with park personnel and cooperators to promote and develop workable standards and procedures for the purpose of integrating datasets and making them useful for a wider variety of applications. The park collaborates with other public agencies, universities and non-governmental organizations, either working together on inventory and monitoring projects, or sharing data and results from those projects. These relationships require coordination at all levels to ensure that data collected by NPS staff, cooperators, researchers, and others meet high quality standards, and that commonly accepted data management standards and procedures are adhered to.

The GIS specialist manages spatial data themes associated with park Vital Signs projects, as well as other spatial data related to the full range of park resources. The GIS specialist incorporates spatial data into the GIS, maintains standards for geographic data, and is responsible for sharing and disseminating GIS data throughout the park and the NPS community.

The GIS specialist will work in collaboration with project managers to:

- Determine the GIS data and analysis needs for a given project.
- Develop procedures for field collection of spatial data including the use of GPS and other spatial data collection techniques.
- Display, analyze, and create maps from spatial data to meet project objectives.
- Properly document data in compliance with spatial metadata standards.

The GIS specialist will also work directly with the data manager to:

- Design databases and other applications in support of Vital Signs protocols.
- Maintain relationships between GIS and non-spatial data through the use of a common primary key and create database and GIS applications to facilitate the integration and analysis of both spatial and non-spatial data.
- Establish and implement procedures to protect sensitive spatial data according to project needs.
- Develop and maintain an infrastructure for spatial metadata creation and maintenance.
- Ensure that project spatial metadata are created and comply with national and agency standards.

6.3 Project Work Flow and the Data Management Process

Both short-term and long-term projects share many work flow characteristics, and both generate data products needing management. Any Vital Signs project managed by GRSM is generally comprised of five primary stages: planning and approval, design and testing, implementation, product

integration and dissemination, and evaluation and closure. Each stage is characterized by a particular set of activities that are carried out by different people involved in the project:

1. Planning and approval: Establishing the project scope and objectives is the most important step in project development. It is crucial that park staff work together at this stage to establish why the data are needed, how they will be used, and what the data management requirements of the project will be.
2. Design and testing: At this stage, specifications are established for how data will be acquired, processed, analyzed, reported, and made available to others. The project manager and data manager work together to develop specific procedures (SOPs) related to data acquisition, processing, analysis, and quality control. Also, at this stage, the project manager and data manager collaborate to develop the data design and data dictionary, where the specific data parameters that will be collected are defined in detail. In addition, decisions should be made regarding integration and permanent storage of deliverables as they are produced.
3. Implementation: During the implementation phase, data are acquired, processed, error-checked and documented. Data collection and data processing requirements vary by project, but include all aspects of data entry and verification and validation. All aspects of data acquisition should be specified in project protocols and SOPs. Similarly, quality assurance measures should be documented as part of the project metadata.
4. Product integration and data dissemination: In this phase, data products and other deliverables are integrated into national and park databases, metadata records are finalized and posted in clearinghouses, and products are distributed, or otherwise made available to the project's intended audience. This is also when items that belong in collections, or archives, are accessioned and catalogued. Another aspect of integration is merging data from a working database to a corporate database maintained on the local park server. Certain projects may also have additional integration needs, such as when working jointly with other agencies, for a common database.
5. Evaluation and closure: For long-term monitoring and other cyclic projects, this phase occurs at the end of each field season, and leads to an annual review of the project. After products are catalogued and made available, program administrators, project managers, and data managers should work together to assess how well the project met its objectives, and to determine what might be done to improve various aspects of the project methodology, and the usefulness of the resulting information.

6.4 Data Management Resources

GRSM relies on park, regional, and national NPS offices to maintain database systems, applications, and software tools, as well as the computers which are the foundation of our information management system. Our park infrastructure works with three main components: park-based local area networks (LAN), a data server maintained by park staff, and servers maintained at the national level. These components each host different parts of our natural resource information system as follows:

- Park LAN:
    - Local applications – desktop versions of national applications such as NPSTORET.
    - Working project materials – working databases, draft geospatial themes, and draft copies of reports.
    - Park digital library – base spatial data, imagery, and finished versions of park project deliverables.
    - GIS files – base spatial data, imagery, and project-specific themes that are managed from a central location.
- Park data servers:
    - Master project databases – compiled data sets for monitoring projects and other multi-year efforts that have been certified for data quality.
    - Common lookup tables – park name, employees, species.
    - Project management application – used to track project status, contact information, and product due dates.
    - Park digital library – park repository for read-only finished versions of project deliverables for park projects (e.g., reports, methods documentation, data files, metadata, etc.).
- National servers:
    - Master applications – integrated client-server versions of IRMA Data Store, NPSpecies, NPSTORET.
    - Centralized repositories – IRMA Data Store, Protocol Clearinghouse, FEMP.
    - Public access sites – portals to IRMA Data Store, NPSpecies, NPSFocus, and websites for monitoring parks.

GRSM data design relies upon stand-alone project databases that share design standards and links to centralized data tables. Individual project databases are developed, maintained, and archived separately, rather than within a single, integrated database system. The advantage of this design is that it allows for greater flexibility in accommodating the needs of each project. Individual project databases and protocols can be developed at different rates without a significant cost to data integration. In addition, one project database can be modified without affecting the functionality of other project databases.

Project database standards are necessary for ensuring compatibility among data sets, which is vital given the often unpredictable ways in which data sets need to be aggregated and summarized. When well thought out, standards also help to encourage sound database design and facilitate interpretability of data sets. Databases that are developed for Vital Signs projects will contain the following main components (Fig. 39):

- Common lookup tables: Links to entire tables that reside in a centralized database, rather than storing redundant information in each database. These tables typically contain information that is not project-specific (e.g., lists of counties, personnel, and species).
- Core tables and fields based on park and national templates: These tables and fields are used to manage the information describing the "who, where, and when" of project data. Core tables are distinguished from common lookup tables in that they reside in each individual project database and are populated locally. These core tables contain critical data fields that are standardized with regard to data types, field names, and domain ranges.
- Project-specific fields and tables: The remainder of database objects can be considered project-specific, although there typically will be a large amount of overlap among projects.
- Enterprise architecture: Spatial and non-spatial data developed and stored in support of Vital Signs will be stored at the Denver Data Center on a blade server farm utilizing the most recent version of Microsoft SQL Server. Parallel to this data storage implementation is a web-based geospatial content delivery application which will provide query and display functionality.

The need for effective natural resource information management cuts across NPS divisional boundaries and management strategies must be defined at the highest level possible. The NPS Natural Resource Program Center (NRPC) and the I&M Program actively develop and implement a national-level, program-wide information management framework (Fig. 40). NRPC and I&M staff integrate desktop database applications with internet-based databases to serve both local and national-level data and information requirements.

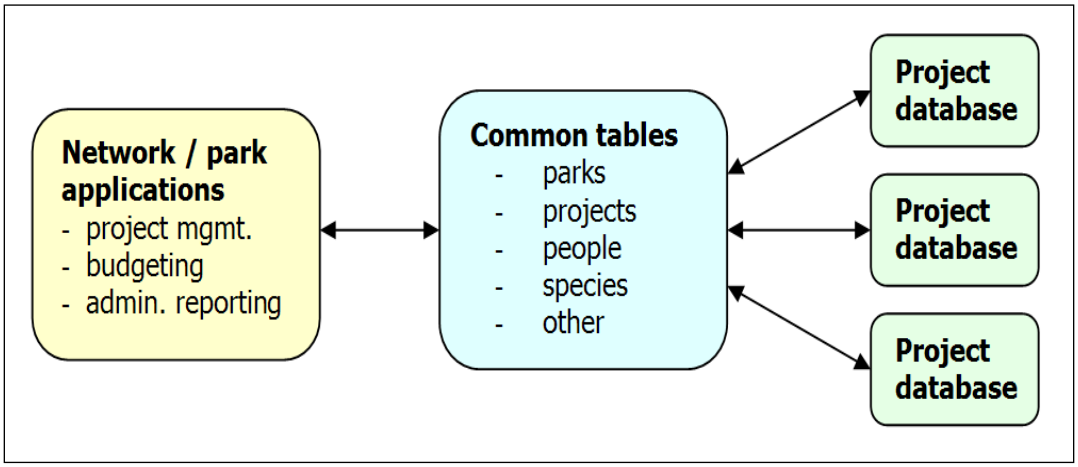


Figure 39. Linkage to common lookup tables.

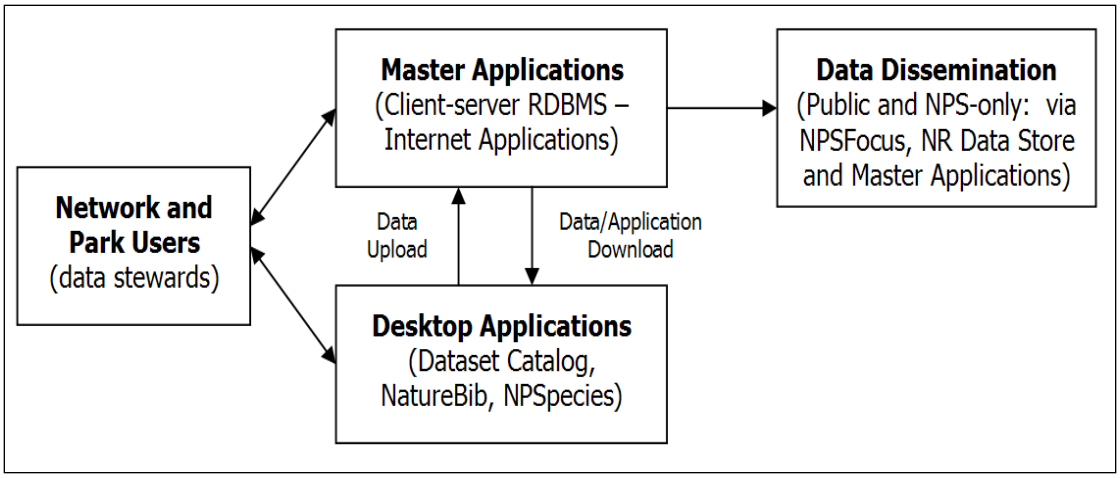


Figure 40. Model of the national-level application architecture.

NRPC staff members work with regional and support office staff to develop desktop GIS systems that integrate closely with the database systems. Centralized data archiving and distribution capabilities at the NRPC provide for long-term data security and storage. The NRPC sponsors training courses on data management, I&M techniques, and remote sensing to assist I&M data managers with developing and effectively utilizing natural resource information. To achieve this level of integration, GRSM has chosen to host its Vital Signs databases at the Denver Data Center. This allows real-time access to spatial and non-spatial data from most park locations, as well as centralized administration and supervision by NRPC staff.

6.5 Data Acquisition and Processing

The park handles two general types of data:

1. Programmatic data - data produced from projects that are initiated or funded by the I&M program.
2. Non-programmatic data - data collected from other NPS sources or produced by external non-NPS sources.

The value of the data from these two sources is determined by the quality and usefulness of the data for addressing management or scientific issues.

Programmatic Data: Projects initiated by the GRSM typically involve I&M personnel, park staff, or cooperators/contractors. These efforts may consist of gathering existing information or conducting field data collection. All information collected by the park is in either electronic or hard copy format, depending on how the data was collected. Electronic datasets are uploaded to the IRMA Data Store. Any geographic datasets obtained during data mining should be accompanied by FGDC (Federal Geographic Data Committee) compliant metadata. Information relating to the biodiversity of the park is entered into NPSpecies and linked to the associated reference, voucher, or observation. Hard copies of reports, data sheets, and field notes are copied and stored in file cabinets in GRSM offices. A filing system for these papers is being developed. The originals are archived in park collections.

All GRSM field studies will have a Microsoft Access database associated with them. The park has adopted the Natural Resources Database Template (NRDT) (http://science.nature.nps.gov/im/apps/template/index.htm) as the foundation for its database development program. The database template is highly flexible and can be modified and customized for each project to meet the needs and requirements of the researcher. Park databases will incorporate mechanisms such as pick lists and validation rules for quality assurance purposes.

Non-programmatic Data: These may be NPS projects outside of the I&M program, or they may originate outside the Park Service. If projects are conducted by Park Service staff, the resulting data often do not require a great deal of processing because the I&M Program shares many of the file standards with other parks and regional programs. Some basic processing steps include:

- Enter all new park biodiversity data into NPSpecies (this is especially important for park-based biological inventories) and enter all associated references into the IRMA Data Store.
- Ensure that all GIS data is in the proper projection and accompanied by compliant metadata.

GRSM will rely on external sources for data to support three Vital Signs: air quality, weather, and landscape change (remote sensing data). In these cases, the agencies or organizations that collect these data have the expertise to conduct the proper quality control procedures and the capability to function as a repository and clearinghouse for the validated data.

Unlike the data from NPS sources, much of the data collected from external sources must undergo some degree of processing to meet program standards; however, some of the basic processing steps are very similar.

- All GIS data obtained from other entities are to be stored in the proper format, have the correct spatial reference information, and FGDC compliant metadata.
- All biodiversity data received from other entities should be entered into NPSpecies. If the data was taken from a report or published document, the reference must be entered into the IRMA Data Store.

The level of data processing required for external data sets such as those used in the Vital Signs monitoring program depends on the desired output. Remote sensing datasets such as satellite imagery or aerial photography will require varying levels of processing depending on how they are received. These steps may include geospatial processing or spectral processing. Ideally, all spatial datasets will be received in a geo-referenced format and may only require geographic transformations to meet park standards. Varying degrees of spatial and spectral processing may be necessary to adequately answer the proposed questions. The individual protocols will outline the necessary processing steps.

6.6 Quality Assurance and Quality Control

Quality Assurance (QA) refers to a system of procedures which ensure that a process or product is of the quality needed or expected. Quality Control (QC) refers to the specific procedures employed to ensure that data products meet defined standards. QA procedures maintain quality throughout all stages of data development, whereas QC procedures monitor or evaluate resulting data products. The park will ensure that projects produce data of the right type, quality, and quantity to meet project

objectives and user needs. The most effective way of accomplishing this is to provide procedures and guidelines to assist the researcher with accurate data collection, entry, and validation. GRSM will initiate a comprehensive set of SOPs with data-collecting protocols for QC, field methodologies, field forms, and data entry applications with some built-in validation. Some important considerations in designing a comprehensive QA/QC program include:

- Data collection - Careful, accurate recording of field observations in the data collection phase of a project will help reduce the incidence of invalid data in the resulting data set. Before the data collection phase of a project begins, the data manager is responsible for providing the protocols/SOPs for data collection and storage to the project manager. The project manager, in turn, will ensure that field crews understand the procedures and closely follow them in the field. Field technicians are responsible for proofing raw data forms in the field, ensuring their readability and legibility, and verifying and explaining any unusual entries. They are expected to understand the data collection forms, know how to take measurements, and follow the protocols.
- Data entry - Transferring data from field projects into the computer seems like a fairly simple task, but the value of the data depends upon their accuracy, and we must feel confident about the overall data quality. The data manager, along with the project manager, will provide training in the use of the database to all data entry technicians and other users. Ideally, data entry occurs as soon as possible - immediately after data collection is completed, or as an on-going process during long projects - by a person who is familiar with the data. The primary goal of data entry is to transcribe the data from paper records into the computer with 100% accuracy. A few transcription errors are unavoidable; thus, all data should be checked and corrected during a data verification process. Geospatial databases will be developed with numerous built-in QA/QC controls which automate many redundant data entry tasks, primarily descriptive location information commonly used as explanatory habitat variables.
- Data verification - Data verification is a check to make sure that the digitized data match the source data. To minimize transcription errors, our policy is to verify 100% of records to their original source by permanent staff. In addition, 10% of records will be reviewed a second time by the project manager, and we will report the results of that comparison with the data. If the project manager finds errors in the review, then we verify the entire data set again.
- Data validation - Data validation is the process of reviewing data for range and logic errors. It can accompany data verification only if the operator has comprehensive knowledge about the data. More often, validation is a separate operation carried out after verification by a project specialist who can identify generic and specific errors in particular data types. Corrections or deletions of logical or range errors in a data set require notations in the original paper field records about how and why the data were changed. Modifications of the field data should be clear and concise while preserving the original data entries or notes (i.e., no erasing). Validation efforts should also include a check for the completeness of a data set since field sheets or other sources of data could easily be overlooked.

  General step-by-step instructions are not possible for data validation because each data set has unique measurement ranges, sampling precision, and accuracy. Nevertheless, validation

is a critically important step in the certification of the data. Invalid data commonly consist of slightly misspelled species names or site codes, the wrong date, or out-of-range errors in parameters with well-defined limits (e.g., elevation). But more interesting and often puzzling errors are detected as unreasonable metrics (e.g., stream temperature of 70°C) or impossible associations (e.g., a tree 2 ft in diameter and only 3 ft high). We call these types of erroneous data 'logic errors' because using them produces illogical (and incorrect) results. The discovery of logic errors provides important feedback to the methods and data forms used in the field.

- Version control - Version control is the process of documenting the temporal integrity of files as they are being changed or updated. Change includes any alteration in the structure or content of the files, and such changes should not be made without the ability to undo mistakes caused by incorrect manipulation of the data. Whenever we complete a set of data changes, the file is saved with a unique name. Prior to any major changes to a file, we store a copy of the file with the appropriate version number. This allows the tracking of changes over time. With proper controls and communication, versioning ensures that only the most current dataset is used in any analysis.
- Data quality review and communication - Quality assurance procedures may need revision to improve quality levels if random checks reveal an unacceptable level of data quality. Quality checks should not be performed with the sole objective of eliminating errors, as the results may also prove useful in improving the overall process. The GRSM data manager will use periodic data audits and quality control inspections to maintain and improve their data quality program. They will track and facilitate the correction of any deficiencies. These quality checks promote a cyclic process of continuous feedback and improvement of the both the data and quality planning process.

  The park will use data documentation and metadata to notify end users, project managers, and park management of data quality. A descriptive document for each data set/database will provide information on the specific QA/QC procedures applied and the results of the review.

6.7 Data Documentation

Metadata is information about the content, quality, condition, and other characteristics of data. While the importance of metadata is universally accepted within the data management community, there are many approaches to data documentation, involving varying levels of detail.

6.7.1 NPS Metadata System

The NRGIS Program has developed several applications to support NPS metadata creation and sharing as listed below:

IRMA Data Store: NPS Natural Resource GIS Program has developed the NPS Data Store, a service-wide repository for spatial and non-spatial NPS metadata and data. The Data Store contains records for both spatial and non-spatial data sets including documents, natural resource databases, GIS data sets, boundary data, base cartographic data, GIS layer standards, and images.

Posting data to the Data Store satisfies NPS data distribution requirements for data producers and provides access to a broad audience of data consumers both within and outside the NPS.

NPS Metadata Tools and Editor: This is a custom software application for authoring and editing NPS metadata. It extends the basic functionality of ESRI's ArcCatalog for managing geospatial metadata and also provides a stand-alone version for creating and manipulating non-spatial metadata outside of ArcCatalog. The Tools and Editor is intended to be the primary editor for NPS metadata that will be uploaded to the NPS Data Store. While not specifically designed for users external to NPS, Tools and Editor features a number of powerful metadata editing capabilities that any metadata author is likely to find useful.

A fact sheet can be found at the following website:
http://science.nature.nps.gov/im/units/sien/datamgmt/SIEN_DMP_Appendices_PDF/Appendix8-D_MetadataToosAndEditor_dmp_sien.pdf

6.7.2 Metadata Process and Workflow

Vital Signs monitoring datasets may originate from data mining efforts or from field data collections; and the sources may be internal or external. With data mining efforts, it is important to capture as much of the original metadata as possible. For new projects, metadata development will begin as early in the project design phase as possible. When project data are submitted, updates and revisions to the metadata will be kept in a revision log.

The park will develop a simple Dataset Catalog record for relevant spatial and non-spatial data. This approach provides brief metadata for all park data holdings in a searchable, centralized location. Managers can identify and prioritize datasets for which formal metadata will be developed. Prioritization of datasets for further documentation will be based upon current or anticipated future use. Datasets which will be used repeatedly in analysis or have a high probability for data sharing will be addressed first. All GIS layers will be documented with applicable FGDC metadata standards.

At a minimum, metadata and associated data will be submitted to IRMA. This will be accomplished using the recommended desktop applications. Additionally, information on data holdings will be conveyed in a meaningful manner for park resource managers, researchers, and others with a potential interest in park management and/or research endeavors. Geospatial metadata and associated datasets, when posted to IRMA, will be automatically "ingested" by web-based mapping applications for distribution within and outside of the NPS community.

6.8 Data Dissemination

6.8.1 Data Ownership

The National Park Service defines conditions for the ownership and sharing of collections, data, and results based on research funded by the US government. All cooperative and interagency agreements, as well as contracts, should include clear provisions for data ownership and sharing as defined by the National Park Service:

- All data and materials collected or generated using National Park Service personnel and funds become the property of the National Park.
- Any important findings from research and educational activities should be promptly submitted for publication. Authorship must accurately reflect the contributions of those involved.
- Investigators must share collections, data, results, and supporting materials with other researchers whenever possible. In exceptional cases, where collections or data are sensitive or fragile, access may be limited.

6.8.2 Data Distribution

One of the most important goals of the Inventory and Monitoring Program is to integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making. To accomplish this goal, procedures must be developed to ensure that relevant natural resource data collected by NPS staff, cooperators, researchers, and the public are entered, quality-checked, analyzed, documented, cataloged, archived, and made available for management decision-making, research, and education. Providing well-documented data in a timely manner to park managers is especially important to the success of the program. GRSM will make certain that:

- Data are easily discoverable and obtainable.
- Data that have not yet been subjected to full quality control will not be released by the park, unless necessary in response to a FOIA request.
- Distributed data are accompanied by complete metadata that clearly establishes the data as a product of the NPS I&M Program.
- Sensitive data are identified and protected from unauthorized access and inappropriate use.
- A complete record of data distribution/dissemination is maintained.

GRSM's main mechanism for distribution of the park's I&M data to the broader public will be the internet. As part of the NPS I&M Program, web-based applications and repositories have been developed to store a variety of park natural resource information. GRSM will use the following applications and repositories to distribute data, formal and informal reports, and publications:

- Integrated Resource Management Applications – an online repository for metadata and associated data products. (https://irma.nps.gov/App/Portal/Home)
- IRMA Data Store – a master web-based database housing both natural resource data sets and bibliographic data for I&M Program parks. (https://irma.nps.gov/App/Portal/Searches)
- NPSpecies – a master web-based database to store, manage, and disseminate scientific information on the biodiversity of all organisms in all National Park units. (https://irma.nps.gov/App/Portal/Searches)
- Biodiversity Data Store – This is work in progress.
- Federal Enterprise Management Program – Raw spatial and non-spatial data will be stored on a high-powered database and application server in a managed data center. These data will be

available to a variety of proprietary applications, including ArcGIS, Microsoft Office Suite, and R.

6.8.3 Handling Sensitive Data

In some cases, public access to data can be restricted. Under one Executive Order Director's Order 66 (FOIA and Protected Resource Information - draft), and four resource confidentiality laws (the National Parks Omnibus Management Act [16 U.S.C. 5937], the National Historic Preservation Act [16 U.S.C. 470w-3], the Federal Cave Resources Protection Act [16 U.S.C. 4304], and the Archaeological Resources Protection Act [16 U.S.C. 470hh]), the National Park Service is directed to protect information about the nature and location of sensitive park resources. Through these regulations, information that could result in harm to natural resources can be classified as 'protected' or 'sensitive' and withheld from public release.

Classification of sensitive I&M data is the responsibility of park superintendents. Park staff will work closely with park staff to identify sensitive data on a case by case basis. GRSM will work with investigators for each project to ensure that potentially sensitive park resources are identified, and that information about these resources is tracked throughout the project. The park staff is responsible for making principal investigators aware of sensitive resources. The investigators, whether park staff or partners, will develop procedures to flag all potentially sensitive resources in any products that come from the project, including documents, maps, databases, and metadata. Park staff will remove any sensitive information from public versions of documents or other media.

6.9 Data Maintenance, Storage, and Archiving

It is important to standardize procedures for the long-term management and maintenance of digital data, documents, and objects that result from GRSM projects and activities. This will help ensure that information is not lost over time, and that information can be easily obtained, shared, and interpreted by a broad range of users.

6.9.1 Digital Data Maintenance

Monitoring projects will have variable long-term data archiving requirements. Raw data sets that are later manipulated or synthesized will need archiving in the original form. Modifications to protocols will typically require complete data sets to be archived before modifications are implemented. With frequent changes to the monitoring project, it is necessary to preserve interim data sets (data "milestones") over the long term. Data archiving requirements for ongoing projects will be detailed in the data management SOPs for each monitoring project. At this time there is no practical way to save GIS data in a software or platform-independent format. Spatial data sets that are essential to GRSM (i.e., base layers) will be maintained in a format that remains fully-accessible by the current ArcGIS version. Both uncorrected and corrected GPS data (e.g., .ssf and .cor files) will be archived in their native format in addition to the corresponding GIS files that are created.

6.9.2 Digital Data Storage and Archiving Procedures

Digital data need to be stored in a repository that ensures both security and ready access to the data in perpetuity. The organization and naming of folders and files will follow well-established and

understood conventions already in place within GRSM. A standardized structure may not be practical; however, all project archives will include several to most of the following elements:

- Administrative documents such as agreements, correspondence, and research permits.
- Programmatic documents including protocols, procedures, and supporting documents.
- Interim data sets or "milestones."
- Data sets which have been reformatted or manipulated by GRSM.
- Data sets in their original form (ASCII).
- Conceptual or statistical models used for data interpretation.
- Final reports.
- Readme files–includes an explanation of directory contents, project metadata (including a dataset catalog report), and version documentation.

6.9.3 Document and Object Storage and Archiving Procedures

All paper documents managed or produced by GRSM will be housed in two locations: 1) GRSM central files, Gatlinburg, TN. These files contain project information, administrative documents, and non-record copies of documents that are archived at an off-site facility. Examples include meeting minutes, correspondence, memoranda of understanding, contracts and agreements, research permits, and interim and selected final reports produced by the program; 2) Park museums. Park archives will be the first option for original documents and associated materials produced by the park (e.g., photographs, field notes, permits) that are a high priority to maintain under archival conditions. Examples include original inventory reports and accompanying slides and maps, original vegetation mapping reports, and monitoring reports. Copies of these reports will be maintained in the GRSM central files, and all will have an electronic equivalent (e.g., .pdf) for distribution or reproduction.

For all materials submitted for archiving, GRSM will assist with cataloging and will provide essential cataloging information such as the scope of content, project purpose, and range of years, to facilitate ICMS record creation and accession. GRSM will also ensure that materials are presented using archival-quality materials (e.g., acid-free paper and folders, polypropylene or polyethylene slide pages).

Specimens collected under the direction of GRSM will be provided to the park natural history museum for curation. This data will be in comma-delimited format (.csv) format for automated uploading into ICMS. The GRSM curators are an ongoing source of expertise, advice, and guidance on archiving and curatorial issues. Project managers should involve park curators when projects are in the planning stage to ensure specimen curation and document archiving is considered, and that any associated expenses are included in project budgets.

7. Data Analysis and Reporting

A primary purpose of the Inventory and Monitoring Program is to develop, organize, and make available natural resource data and to contribute to the Service's institutional knowledge by transforming data into information through analysis, synthesis and modeling. The broad-based, scientifically sound information obtained through natural resource monitoring has multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

It is important that the data analysis Standard Operating Procedures (SOPs) for each Vital Sign ensure that the sampling designs and analysis methods meet park monitoring objectives. The primary audience for many of the products from the Vital Signs monitoring program is at the park level, where the key objective is to provide park managers and interpreters with the information they need to make and defend management decisions and to work with others for the benefit of park resources. However, other key audiences for monitoring results include park planners, interpreters, researchers and other scientific collaborators, the general public, Congress, and the President's Office of Management and Budget (OMB). To be most effective, monitoring data must be analyzed, interpreted, and provided at regular intervals to each of these key audiences in a format they can use. There must be several different scales of analysis, and the same information needs to be distributed in different formats to the key audiences.

The scientific data needed to better understand how park systems work and to better manage the parks will come from many sources. In addition to new field data collected through the Vital Signs monitoring program, data on status and trends in the condition of park resources will come from other park projects and programs, other agencies, and from the general scientific community. To the extent that staffing and funding is available, the park monitoring program will collaborate and coordinate with these other data collection and analysis efforts, and will promote the integration and synthesis of data across projects, programs, and disciplines.

7.1 Analysis of Monitoring Data

Appropriate analysis of monitoring data is directly linked to the monitoring objectives, the spatial and temporal aspects of the sampling design used, the intended audiences, and management uses of the data. Analysis methods need to be considered when the objectives are identified and the sampling design is selected, rather than after data are collected. Each monitoring protocol will contain detailed information on analytical tools and approaches for data analysis and interpretation, including the rationale for a particular approach, advantages and limitations of each procedure, and SOPs for each prescribed analysis.

Table 4 summarizes four general categories of analysis for GRSM Vital Signs, and the lead analyst responsible for each. The lead analyst will ensure that data are analyzed and interpreted within the guidelines of the protocol and program, but they may not actually perform the analyses or interpret the results in some cases.

Table 4. Analysis of monitoring data.

Level of Analysis	Description	Lead Analyst
Data Summarization/ Characterization	Basic statistics of interest including measures of location and dispersion. Forms the basis of more comprehensive analyses, and for communicating results in both graphical and tabular formats.	The Project Manager for each monitoring protocol, working with the data manager, will produce routine data summaries. Parameters and procedures are specified in the monitoring protocols.
Status Determination	Analysis and interpretation of the ecological status of a Vital Sign to address the following types of questions: • How do observed values for a Vital Sign compare with historical levels? • Do observed values exceed a regulatory standard, known or hypothesized ecological threshold? What is the level of confidence that the exceedance has actually occurred? • What is the spatial distribution of observed values for a given point in time? Do these patterns suggest directional relationships with other ecological factors?	The Project Manager for each monitoring protocol is the lead analyst for status determination, although the park coordinator, cooperators, partners, interns or other park staff may conduct analyses and assist with interpreting results. Consultation with regulatory and subject matter experts will support status determination.
Trends Evaluation	Evaluations of trends in Vital Signs will address: • Is there directional change in a Vital Sign over the period of measurement? • What is the rate of change (sudden vs. gradual), and how does this pattern compare with trends over broader spatial scales and known ecological relationships? • What is the level of confidence that an actual change (or lack thereof) has occurred?	The Project Manager for each monitoring protocol is lead analyst for status determination, although park coordinator, cooperators, partners, interns or other park staff may conduct analyses and assist with interpreting results. Comparison with relevant long-term experimental results will aid interpretation.
Synthesis and Modeling	Examination of patterns across Vital Signs and ecological factors to gain broad insights on ecosystem processes and integrity. Analyses may include: • Qualitative and quantitative comparisons of Vital Signs with known or hypothesized relationships. • Data exploration and confirmation (e.g., correlation, ordination, classification, multiple regression, structural equation modeling). • Development of predictive models.	The park coordinator is lead analyst for data synthesis and modeling, although Project Managers for various protocols, and cooperators, partners, interns or other park staff may conduct analyses and assist with interpreting results. Integration with researchers and experimental results is critical.

7.2 Communications and Reporting

GRSM is developing strategies for effectively sharing information with parks, scientists, cooperators, adjacent land managers, and other potential collaborators. The various approaches and products (Table 5) that will be used to disseminate results of the monitoring program and to make the data and information more available and useful to our key audiences are organized into the following seven categories and described in the following sections:

1. Annual reports for specific protocols and projects
2. Annual briefings to park managers
3. Analysis and synthesis reports
4. Protocol and program reviews
5. Scientific journal articles and book chapters, and presentations at scientific meetings
6. Internet and intranet websites
7. Interpretation and outreach

7.2.1 Annual Reports for Specific Protocols and Projects

The primary purposes of annual reports for specific protocols and projects are to:

- Summarize and archive annual data and document monitoring activities for the year.
- Describe current condition of the resource.
- Document changes in monitoring protocols.
- Increase communication within the park.

The primary audiences for these reports are park superintendents and resource managers, park staff, park-based scientists, and collaborating scientists. Most annual reports will receive peer review at the park level, although a few may require review by subject matter experts with universities or other agencies. Many of our monitoring protocols involve data collection each year, and those protocols will generate an annual report each year; however, some sampling regimes do not involve sampling every year - those projects will produce "annual" reports only when there are significant monitoring activities to document. Wherever possible, annual reports will be based on automated data summarization routines built into the MS Access database for each protocol. The automation of data summaries and annual reports will facilitate the park's ability to manage multiple projects and to produce reports with consistent content from year to year at timely intervals. For analyses beyond simple data summaries, data will first be exported to external statistical software.

7.2.2 Annual Briefings to Park Managers

Each year, in an effort to increase the availability and usefulness of monitoring results for park managers, the park coordinator will take the lead in organizing a 1-day "I&M Science briefing for park managers" (possibly in conjunction with a Board of Director's meeting) in which park staff, park scientists, USGS scientists, collaborators from academia, and others involved in monitoring the parks' natural resources will provide managers with a briefing on the highlights, key findings, and potential management action items for each particular protocol or discipline. These briefings may

include specialists from the air quality program, fire ecology program, Research Learning Center, and collaborators from other programs and agencies to provide managers with an overview of the status and trends in natural resources for their parks. The scientists will be encouraged to prepare a 1- or 2-page "briefing statement" that summarizes the key findings and recommendations for their protocol or project; these written briefing statements will then be compiled into an annual 'Status and Trends Report' for the park. In the process of briefing the managers, the various scientists involved with the monitoring program will learn about other protocols and projects, and the process will facilitate better coordination and communication and will promote integration and synthesis across disciplines.

7.2.3 Analysis and Synthesis Reports

The role of analysis and synthesis reports is to:

- determine patterns/trends in condition of resources being monitored
- discover new characteristics of resources and correlations among resources being monitored
- analyze data to determine amount of change that can be detected by this type and level of sampling
- provide context: interpret data for the park within a multi-park, regional or national context
- recommend changes to management of resources (feedback for adaptive management).

The primary audiences for these reports are park superintendents and other resource managers, park staff, park-based scientists, and collaborating scientists. These reports will receive external peer review by at least three subject-matter experts, including a statistician. Analysis and synthesis reports can provide critical insights into resource status and trends, which can then be used to inform resource management efforts and regional resource analyses. This type of analysis, more in depth than that of the annual report, requires several seasons of sampling data. Therefore, these reports are usually written at intervals of every three to five years for resources sampled annually, unless there is a pressing need for the information to address a particular issue. For resources sampled less frequently, or which have a particularly low rate of change, intervals between reports may be longer.

It is important that results from all monitoring projects within and across all parks be integrated across disciplines in order to interpret changes to park resources. This will be accomplished with a park synthesis report produced at no more than 10-year intervals.

7.2.4 Protocol and Program Reviews

Periodic formal reviews of individual protocols and the overall monitoring program are an important component of the overall quality assurance and peer review process. A review of each protocol will be conducted before the first 5-year Analysis and Synthesis Report and in conjunction with future Analysis and Synthesis Reports as needed, but at least at 10-year intervals. (Because protocols must be reviewed in light of the data they produce, it is most efficient to review protocols coincident with these synthesis reports). Features of these protocol reviews include:

- A USGS scientist, outside contractor or academic is enlisted to analyze data and evaluate results of the monitoring protocol (e.g., power analyses of the data) and report findings.

- Subject-matter experts/peers are invited to review the Analysis and Synthesis Report, power analysis, and protocol.
- Subject-matter experts/peers are invited to a workshop to discuss the protocol, results of the data analysis and evaluation, whether or not the protocol is meeting its specific objectives and is able to detect a level of change that is meaningful, and to recommend improvements to the protocol.
- The protocol PI, park coordinator, or contractor writes a report summarizing the workshop. The report is reviewed and edited by the participants, and then the final report is posted on the park's website. Copies of the report are sent to NPS regional and WASO program offices.

The park coordinator will initiate the park monitoring program review. The purpose of these reviews is to have the program evaluated by highly qualified professionals. Features include:

- Park staff and collaborators provide a summary of the program and activity to date including a summary of results and outcomes of any protocol reviews.
- Scientific review panel obtains input from Board of Directors, park staff, park scientists, and others. Panel holds a workshop to discuss the program and whether it is meeting its goals and expectations. Review Panel makes recommendations for improving the effectiveness and value of the monitoring program.
- Park coordinator develops a strategy with the GRSM Technical Committee and Board of Directors as to which of the review panel's recommendations to implement, how, and when.

Topics to be addressed during the program review include program efficacy, accountability, scientific rigor, contribution to adaptive park management and larger scientific endeavors, outreach, partnerships, data management procedures, and products. These reviews cover monitoring results over a longer period of time, as well as program structure and function to determine whether the program is achieving its objectives, and also whether the list of objectives is still relevant, realistic, and sufficient.

7.2.5 Scientific Journal Articles, Book Chapters, and Scientific Meetings

The publication of scientific journal articles and book chapters is done primarily to communicate advances in knowledge, and is an important and widely-acknowledged means of QA/QC. Putting a program's methods, analyses, and conclusions under the scrutiny of a scientific journal's peer-review process is basic to science and one of the best ways to ensure scientific rigor. Park staff, park scientists, and collaborators will also periodically present their findings at professional symposia, conferences, and workshops as a means of communicating the latest findings with peers, identifying emerging issues, and generating new ideas.

All journal articles, book chapters, and other written reports will be listed in the park's Annual Administrative Report and Work Plan that is provided to park staff, Technical Committee, Board of Directors, and regional and national offices each year. Additionally, all scientific journal articles, book chapters, and written reports will be entered into the IRMA Data Store.

7.2.6 Internet and Intranet Websites

Internet and intranet (restricted) websites are a key tool for promoting communication, coordination, and collaboration among the many people, programs, and agencies involved in the park monitoring program. All written products of the monitoring effort, unless they contain sensitive or commercially valuable information that needs to be restricted, will be posted to the main Park website: http://www1.nature.nps.gov/im/units/GRSM/index.html

Documents to be posted to the park website include this monitoring plan, all protocols, annual reports, analysis and synthesis reports, and other materials of interest to staff at the park, regional, and national levels, as well as our collaborators.

7.2.7 Interpretation and Outreach

The park will make a concerted effort, working with park interpreters and others, to ensure that the results of natural resource monitoring are made available to the interested public. In addition to providing scientific reports and briefings to managers for their protocols, each scientist involved with the park will be asked to contribute story ideas, photographs, and other materials to interpreters for use in newsletters, interpretive talks and exhibits, and other media for informing and entertaining the public. Park interpreters will be invited to participate in monitoring field efforts to increase communication and promote integration between the programs. Park staff may also speak at training sessions for seasonal employees and to special interest groups. We currently are working with the Southern Appalachian CESU, the Appalachian Highlands Science Learning Center, and park interpreters to more effectively interpret inventory and monitoring results to the parks and the public.

8. Administration/Implementation of the Monitoring Program

Long-term monitoring at GRSM will continue to be managed as a prototype Inventory and Monitoring program, associated with and part of the APHN. In this capacity, the program will entertain the testing of new and different types of inventories and monitoring for use and adaptation in other NPS units, especially in the APHN and other networks which are ecologically similar.

9. Schedule

This Plan will undergo internal review within the agency and by independent peer reviewers. Suggestions for improvement are sought and will be carefully considered for inclusion in the full Vital Signs Monitoring Plan prepared by the team. The final plan will include sections outlined in this plan, along with protocols. This will probably take the remainder of FY 2014 to complete. Implementation will be transitioned to the new plan as soon as practical; a substantial portion is expected to be in place by spring 2015.

10. Budget

The GRSM prototype long-term monitoring program was originally funded in the mid-1990s at about $500,000, which was supplemented with an additional $60,000 three years later for GIS support. These figures were added to the park base. Although the park also contributed four positions, the total I&M costs have exceeded what the original monitoring program contributed. Currently the monitoring account is about $584,000.

While the park will continue to seek out new funding opportunities, it is difficult to acquire new base funding. Therefore, most resources available to implement the new vital signs program are expected to come from:

1. changes in monitoring work assignments in the RMS Division (i.e., what is monitored, frequency, where, intensity, etc.)
2. efficiencies of field work resulting from integrated sampling designs and work teams
3. more automation in data collection, analyses, and portrayal
4. collaborations with partners.

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Appendix A. Monitoring Questions Developed in an Ecological Framework, July 2009

Note to Monitoring Questions: The following list of over 120 questions follows the format of WASO-I&M Ecological Framework. Its purpose was to elucidate a full spectrum of monitoring questions, from which to further prioritize. This is the product of several directed work groups of the park staff that systematically compiled questions that were deemed significant by the groups. Differing resolutions of resource issues resulted in slightly different formats occurring in different sections. In some cases, multiple questions are embedded in an overarching question, and in some cases the questions have been itemized to specific metrics. Some topics in the framework overlap ecologically; therefore, similar questions were posed from different perspectives. These similarities have been preserved as they may reflect different methods or metrics. Some questions have been flagged as research-oriented rather than monitoring-oriented.

Biological Integrity – Invasive Plants: What are the impacts on native species?

- Are incipient populations and new occurrences of target invasive plants invading prioritized areas (i.e., areas of high management significance)?
- Are there significant shifts in community composition, structure, distribution, and areal extent of native vegetation where target invasive exotic populations are established?
- Are there significant shifts in animal abundance, distribution, and species composition in areas where target invasive exotic plants are established?

Biological Integrity – Invasive Animals: What are the impacts on native species?

- Are incipient populations and new occurrences of target invasive animals invading prioritized areas (i.e., areas of high management significance)?
- Are there significant shifts in community composition, structure, distribution, and areal extent of native vegetation where target invasive exotic populations are established?
- Are there significant shifts in animal abundance, distribution, and species composition in areas where target invasive exotic animals are established?

Biological Integrity – Infestations and Diseases: What are the impacts on native species?

- Are incipient populations and new occurrences of target invasive pests/diseases invading prioritized areas (i.e., areas of high management significance)?
- Are there significant shifts in community composition, structure, distribution, and areal extent of native vegetation where target invasive pests/disease populations are established?
- Are there significant shifts in animal abundance, distribution, and species composition in areas where target invasive pests/diseases are established?
- Are pests/diseases above established baseline, if known, or deviating from known trends?

Biological Integrity – Communities of Special Concern: Wetland Communities

- Are there changes in areal extent and species composition of plants and animals?
- If so, are the changes linked with changes in soil, wetland hydrology, and/or water quality?

Biological Integrity – Communities of Special Concern: Cave Communities

(Note: Service-wide planning for cave monitoring is not completed, but we will evaluate it for concordance with park issues/questions – See Sub-Surface Geologic Processes, below)

- Are cave communities being significantly changed beyond baseline due to key environmental parameters (i.e., temperature, moisture)?
- Are human activities (e.g., recreation, adjacent land use) significantly altering species abundance, composition, and distribution?

Biological Integrity – Communities of Special Concern: Riparian Communities

- What are the status and trends of species abundance, composition, and distribution in previously impacted riparian zones (e.g., previously channelized streams)?
- What are the status and trends of riparian community species abundance, species composition, and distribution related to human disturbance (e.g., invasive species, recreation, Elkmont restoration, Chilogatee reclamation, compaction, trampling) and natural disturbance regimes (e.g., floods, drought, rock slides)?

Biological Integrity – Freshwater Communities

- What are the status and trends of species composition and relative abundance of representative aquatic animal and plant communities (e.g., amphibians, algae, macroinvertebrates, fish) in representative park streams?
- What are the status and trends of freshwater communities impacted by emerging/incipient target invasive species/diseases (e.g., didymo, non-native fish, chytrid fungus, ranavirus, etc)?
- What are the status and trends of freshwater communities impacted by changes in water quality (e.g., acid deposition, septic discharge, mines, etc)?
- What are the responses of the aquatic communities in restored brook trout streams? (this may be a research question)
- What are the status and trends of brook trout and other native fishes in restored systems?
- What are the status and trends of amphibian species composition, abundance, reproductive success, phenology, and distribution?
- What are the status and trends of exotic aquatic macroinvertebrate species and algae?

Biological Integrity –Vegetative Communities: Forests/Woodlands

- What shifts in forest community types result from major forest disturbance/loss of native community types (e.g., biotic and abiotic factors including hemlock, chestnut, beech, fir, lack of fire, gypsy moth, disease, floods, air pollution, climate change, over-browse by ungulates)?
- What are the status and trends of the health and sustainability (biomass and reproduction) of the dominant forest types in the park?
- How are plant understory, herbaceous, and non-vascular forest/woodland species' abundance and composition changing in representative forest-types?
- How are animal and fungal communities of interest changing as forest/woodland communities change in composition?

Biological Integrity –Vegetative Communities: Grassland/Herbaceous Communities

- What are the status and trends of community structure, species composition, and reproductive productivity in managed grassland/herbaceous communities (Cades Cove, high-elevation grassy balds)?
- What are the status and trends of commensal grassland animal (elk, deer, birds, spiders, insects, rodents, etc) species composition, use patterns, and relative abundance?
- What is the areal extent of impacts to grassland/herbaceous communities due to human disturbance (e.g., mowing, prescribed fire, tractor use, high visitation and related trampling/noise/presence, channelization)?

Biological Integrity –Vegetative Communities: Shrublands

- How is the areal extent, trends in reproductive productivity (e.g., fruiting), and species composition of shrubland communities (rhododendron, laurel, heath, etc) changing due to disease, fire, climate changes, etc?
- How are animal communities of interest changing as shrubland communities increase, decrease, or shift in species composition?

Energy Flow - Primary Production

TBD. Can potentially be calculated from biomass measurements taken at vegetation and other plots. (Repeated below under Soils)

Biological Integrity – Terrestrial Invertebrates

- How much is biodiversity changing?
- What are the status and trends of species composition, phenology, and relative abundance of representative terrestrial invertebrate communities?
- How do changes in environmental conditions affect terrestrial invertebrate communities?

- What are the status and trends of terrestrial invertebrate communities impacted by incipient, invasive species?

Biological Integrity – Amphibians and Reptiles
(Also see Freshwater Communities)

- What are the status and trends of amphibian species composition, abundance, reproductive success, phenology, and distribution?
- What is the link between fire and reptile distribution and abundance? (This may be a research question)
- How do changes in environmental conditions affect amphibian and reptile communities? (this may be a research question)
- Does poaching and other animal collection affect amphibian and reptile populations, and if so, to what extent does it alter abundance, reproduction, and distribution? (this may be a research question)

Biological Integrity – Birds

- What are the status and trends of abundance, reproduction, phenology, and species composition of breeding birds in representative habitats (e.g., spruce-fir, hemlock, ash)?
- How do changes in environmental conditions affect breeding bird community phenology, abundance, and species composition?
- What are the status and trends of abundance, phenology, and species composition of overwintering species?
- What are the status and trends of abundance, phenology, and species composition of transient migratory birds in spring and fall?

Biological Integrity – Mammals

- How do mammal populations (including bats) fluctuate in relation to climate/disease/invasive-induced vegetation community changes?
- What role do mammals play in disease transmission? How do trends in mammal populations affect disease incidence/transmission? What are the status and trends of mammal populations serving as disease reservoirs?
- How are areal distribution and abundance of large mammal populations (e.g., via on-ground or aerial thermal/remote sensing surveys) changing?

Biological Integrity – At-risk biota, T & E Species

- What are the status and trends of the distribution, abundance, and health of listed species?
- What are the status and trends of the distribution, abundance, and health of globally imperiled taxa and/or communities?
- Of the above species, which are leading indicators of environmental change?

Human Impacts – Extent and Continuing Impact of Human Use in the Park

- How is soil quality impacted by point-sources (fertilizer applications, spills, concession waste)? (this may be a research question)
- How is soil quality impacted by non-point sources such as erosion, trampling (see also acid deposition)?

Human Impacts – Consumptive Use

- What are the status and trends of abundance, recruitment, and distribution of target poached species?
- What is the effectiveness of poached plant restoration?
- What are the status and trends of legal consumptive collecting in the park, and what (and where, in terms of concentrated use) are the impacts on the consumed species in the park?

Human Impacts – Visitor Use

- What are the status and trends of visitor use and its impact to target areas, including trampling, horse use (invasives introduction and physical erosion/damage to trail structures), rock dams, erosion at stream bank access points?
- Include measure of visitor satisfaction/carrying capacity? Ecological protection (i.e., in Cades Cove) could be protected in terms of visitor satisfaction (reducing overcrowding?)
- How are concession operations, including commercial/special use permits in the park affecting status and trends of natural communities?

Landscapes/Park-wide Changes – Trends in the Broader Ecosystem Pattern and Processes: Land Cover and Use

(Evaluating the NPScape approach for monitoring conversion/fragmentation of lands in and outside of the park, plus periodic remote sensing.)

- What are the quantitative and spatial trends in forest fragmentation at varying distances out from the park boundary?
- What are the quantitative and spatial trends between land uses at varying distances outside the park boundary: urbanized, residential, agriculture, wildlands, etc.

Landscapes/Park-wide Changes – Trends in the Broader Ecosystem Pattern and Processes: Fire and Fuel Dynamics

(The park has a Fire Effects monitoring program for pre- and post-conditions of sites that receive prescribed burns.)

- What are pre- and post-conditions of wildfire sites where possible using forest monitoring plots? [This may be a research question]
- What is the relationship between wildfire intensity/frequency and habitat change (i.e., vegetation composition, invasive plants and animals, soil alteration, native animal community composition)? [this may be a research question]

Soundscape/Noise Pollution

(Note: the park is awaiting a final report by the FAA on noise modeling by aircraft and vehicles)

- What are the trends in ambient sound levels and types at baseline points in the park?
- How is noise pollution impacting the visitor experience? (this may be a research question)
- How is noise pollution affecting biological resources (e.g., birds, bats, other wildlife)? (this may be a research question)

Night Sky/Light Pollution

- What are the baseline and trends in night sky light pollution in the park?
- How is light pollution impacting the visitor experience and biological resources? (this may be a research question)

Extreme Disturbance Events

(Note: the approach is to use remote sensing to measure extent and intensity of wildland fires, debris slides, windthrows, ice storms, and other disturbances)

- What are the changes in frequency and magnitude of significant disturbance events in the park on a decadal scale, relative to changes in climate, etc.? (Maintain a geographic database that documents significant events as they occur: blowdowns, ice storms, debris slides, floods, defoliation events, significant changes in land use disturbance regimes; fire events are recorded elsewhere)

Climate- Temperature and Wind

- What are the trends in physical effects of wind to forest structure, increased evapotranspiration, changes in relative humidity, and cloudwater inputs (excluding blowdowns which are listed in Extreme Disturbance Events, above)?

Human Impacts – Cultural Landscapes

- How is the maintenance and preservation of cultural landscapes in the park (i.e., mowing, fertilizer use, maintaining roads and vehicular backcountry access, fire suppression around structures, wetlands/stream diversion or channelization and ditching) affecting the status and trends of natural communities?

Air Quality – Ozone

- What are the trends of ground-level ozone pollution using data from park monitoring stations at Look Rock, Cove Mountain, Clingmans Dome, Cades Cove, and Purchase Knob?
    - What is the 3-year average of the 4th highest 8-hour average ozone concentration (e.g., relate to NAAQS/health standard/attainment, maintenance of standards)?
    - What are the number of annual exceedances of the ozone NAAQS?

- What are the cumulative seasonal (May-Sep) ozone exposure indices (using the W126 and SUM06 metrics), and what is the relationship of exposure thresholds to forest responses (foliar injury, growth, species composition)?

Air Quality – Acid and Mercury Deposition

(Related to critical loads on aquatic and terrestrial resources, TMDLs for park streams, and progress toward ecological restoration)

- What are the status and trends of wet and dry atmospheric deposition of sulfur, nitrogen, major cations, and mercury using data from park monitoring stations at Elkmont, Noland Divide, Look Rock, and Clingmans Dome?
- What are the annual precipitation-weighted means of sulfate, nitrate, ammonium, major cation concentrations and wet deposition; dry chemistry and deposition, and cloudwater/throughfall deposition? Are these exceeding critical loads?
- What are the status and trends in ecological indicators of acid deposition as measured by community structure of aquatic and terrestrial resources?
- What are the status and trends of soil chemistry as it relates to acid deposition and nutrient cycling?
- What are the annual wet mercury and methyl mercury concentrations and deposition?

Air Quality – Particulate Matter and Visibility

(Relate data toward achieving EPA Regional Haze Rule goals toward natural conditions on haziest days, and attaining air quality standards)

- What are the status and trends of particulate matter and its impact on visibility using data from the Look Rock air quality station?
- What is the 5-year rolling average of the 20% best and worst visibility days calculated as reconstructed light extinction (haze) from chemically-speciated particle filter data?
- What is the 3-year rolling average of $PM_{2.5}$ mass and chemical concentrations (SO^4, NO^3, NH^4, organic carbon, elemental carbon, soil, dust/PM10) from the IMPROVE monitor?
- What is the annual number of exceedances of the $PM_{2.5}$ NAAQS?
- What is the effect of aerosol concentrations (causing variable levels of solar radiation/light) on forest productivity? (measured at different scales with remote sensing, on-the-ground particulate sensors, etc.)
- What is the trend of the effect of in-park prescribed burning on airborne particulate matter (with variable levels of outside-park particulate matter)?
- What are the effects of particulate matter on animal populations (e.g., bats, bears, birds, etc)?

Climate – Status and Trends in Climate Change Indicators: Temperature, Precipitation, Winds, Humidity, Solar Radiation

- What are the status and trends in weather and climate using data from the park's historic climate stations and air monitoring stations (including frequency, duration, magnitude and intensity of measured parameters)?
- What are the annual and seasonal trends in temperature; how do they compare to historical regional (and in-park) averages and trends, and how will they deviate from predictive models (e.g., IPCC, Fridley 2009)?
- What are the annual and seasonal trends in precipitation; how do they compare to historical regional (and in-park) averages and trends, and how will they deviate from predictive models?
- What are the annual and seasonal trends in wind speed, humidity, solar radiation; how do they compare to recent regional (and in-park) averages and trends, and how will they deviate from predictive models?
- What are the trends in native and invasive plant productivity, distribution, and abundance (i.e., radial woody growth and cover in park-wide plots) as they relate to climate variability?
- What are trends in terrestrial and aquatic vertebrate/invertebrate distribution, abundance, and phenology (using park-wide stratification, monitoring in permanent plots, satellite imagery of park-wide vernalization, hard and soft mast monitoring, aquatic sampling) as they relate to climate variability?
- Are there changes in trends of wildland fire distribution, frequency, and severity as they relate to climate variability?

Surficial Geology

(Includes: geomorphology, hillslope features and processes, debris slides on shale/slate geologies [related to precipitation events]. See also Landscape -extreme disturbance events section).

- Are there changes in slide event frequency and magnitude on a decadal scale associated with climate and forest structure/composition changes?

Subsurface Geologic Processes - Environmental and Biological Attributes of Individual and Collective Caves in the Park

(Includes: cave/karst features and processes, karst hydrology for wet caves, and temperature [see also Water section and Air and Climate sections]. Note: service-wide planning for cave monitoring has not been completed, but will be consulted to align with those questions/targeted resources, as practical)

- What are the trends in temperature profiles of selected caves?
- What are the trends in relative humidity at baseline points in caves?

- What are the trends in water quantity and chemistry in wet caves?
- What are the trends in endemic and rare cave organism populations?
- What are the trends in organism populations that bring nutrients into the system and thereby drive energy availability (i.e., bats, and twilight species)?

Soil Quality - Soil Chemistry Changes in Response to Acid Deposition, Climate Change, and Forest Composition Changes

(Monitoring questions will be focused especially on base cations, SO^4, nitrogen, carbon [TOC/DOC], and organic acids over a 5-10 year time frame, linked with water chemistry)

Soil Function and Dynamics

(See also Air and Climate, and Biological Integrity sections)

- How is pore water changing relative to changes in precipitation/climate? What are the related changes in soil microbial communities, methylation, ground water, and soil chemistry?
- How is species composition and primary productivity changing in response to changes in soil chemistry?
- How and where did soil structure change in relation to legacy land-use practices and how is it recovering? (Research questions to identify previous conditions and identify mechanisms of change)
- How is soil structure changing in relation to invasive exotics (worms, pigs, etc.), fire (or lack thereof), current land-use, and forest change impacts? (Research questions to identify previous conditions and identify mechanisms of change)

Nutrient Dynamics

TBD. Possibly monitored as by-product of other biogeochemical monitoring; addressed elsewhere on watershed level, landscape level

- What are the status and trends of calcium and phosphorus cycling within the park, related to air quality, forest composition changes, etc.?

Energy Flow - Primary Production

TBD. Some metrics can potentially be calculated from biomass measurements taken at vegetation and other plots. See Nutrient Dynamics section above; most appropriate on a community-level scale, rather than a park-wide scale

Climate - Temperature

- What are the trends in soil chemistry associated with changing soil moisture, and carbon and nutrient cycling due to climate temperature variability?

Hydrology - Surface and Ground Water Dynamics

(Hydrology changes in response to forest change, climate change, and land-use in selected stream systems. Stream gauges will be placed in selected major streams, as part of intensified watershed monitoring. Also see Air and Climate – Precipitation section, above).

- What are the impacts of changes in stream water quantity and regime, especially in Abrams Creek, on targeted species?
- How does local geology affect trends in stream water quality, as related to disturbances and subsequent recovery? [measure changes in frequency, magnitude, and physical (temperature, silt) trends with watershed disturbance]
- How does the management of reservoirs affect the introduction of exotics?
- What are the changes to wetlands in association with changes in hydrology and climate change? (plant composition, area, other characteristics)

Groundwater Dynamics

(Groundwater hydrology alterations in response to forest change, climate change, and land-use surrounding and within the park, especially focused on karst areas. Also, water volume and water quality)

- As a watershed source area, what are the park-wide trends of precipitation inputs? (develop precipitation model using new weather radar data)
- How do the trends in park-wide precipitation (above) influence/explain surface out-flow, forest evapotranspiration, ground water flow? (see also Air and Climate –Precipitation section).
- What are the hydrologic trends of wet karst sites (e.g., wet caves and sinkhole ponds)? (sites with concentrations of extreme endemic spp.)
- What is the role of ground water in surface water features and how is this changing with climate change, etc.? (select watersheds and wetlands)
- What are the changes in ground water hydrology in relation to air quality? (this may be a research question)

Climate – Temperature

- What are the trends in hydrologic cycles and water quality of key park watersheds in relation to climate variability?

Air Quality- Ozone

(Note: recent work indicates that ozone events result in greater forest evaporation which can be seen in stream level measurements)

- What are the status and trends in ecological indicators of ozone response as measured by foliar injury, growth, and species composition in forest plots and alterations to hydrology in selected watersheds?

Water - Water Quality /Water Chemistry: Human Impacts – Non-point and Point Source
(See also Air and Climate-Acid Deposition section, above).

- How is water quality impacted by non-point sources (i.e., road runoff, fertilizer, de-icers, crush and fill, trampling, moving rocks, erosion, acid deposition)?
- How is water quality impacted by point-sources (i.e., waste-water treatment plant, sedimentation, concession waste, septic systems, mines)? (this may be a research question)
- Is the park meeting regulatory standards for water quality?
- What are the status and trends of water quality (related to acute water quality standards) at drinking water springs? (recurring inventory)

Water - Water Quality /Water Chemistry: Nutrient Dynamics
(Nitrogen, calcium, and other elements included in monitoring as part of the water chemistry protocol, above.)

- How is water chemistry changing over time in response to acid deposition, climate change, and forest compositional changes? [especially base cations, SO^4, nitrogen, carbon (TOC/DOC), organic acids; linked with soil chemistry]

Water - Water Quality /Water Chemistry: Microorganisms
(Coliform counts for selected rivers, with suspected sources of contamination).

- What are the status and trends of bacterial contamination of selected streams?
- What are the links to nutrient enrichment and climate change? (e.g., lower Abrams Creek, the spur, etc.—areas not adequately covered by state authorities)

Air Quality – Acidification

- What are the status and trends of water quality as they relate to acid deposition and nutrient cycling? (see Air Quality, above)

Aquatic Macroinvertebrates and Algae

- What are the status and trends in macroinvertebrate communities (biotic indices and tolerance values, IBI) and how are they linked to other biological/climate/chemical factors? [Representative watersheds tied into other monitoring (soils, water quality, etc.)]
- What are the status and trends of diatom malformations in high elevation springs related to water quality and changes in climate, hydrology, and deposition? (needs more research to define the monitoring question; may tie in macroinvertebrates, amphibians, etc.)

Toxics
(Status of mercury and pesticide concentrations in the environment, including bioaccumulation in target organisms; see also Air and Climate-Acid Deposition section, above.)

- What is the status and persistence of current and historic PCBs, pesticides, and their metabolites in the park? (include dust-borne deposition, imidacloprid treatments)

Biological Integrity – Communities

- Are high elevation shrublands (i.e., heath balds) serving as mercury methylation sites? (this may be a research question)

Biological Integrity – Wetlands

- Are wetlands serving as mercury methylation sites? (this may be a research question)

Air Quality – Deposition

- What are the status and trends in ecological indicators of mercury deposition as measured by selected indicator species (e.g., birds, fungi, insects, etc.)?

Appendix B. Research Questions Generated by the Monitoring Review (2009)

A. Water Chemistry, Water/Hydrology, Freshwater Communities:

1. What are the changes in ground water hydrology/water quality due to anthropogenic sources at high elevations? Will vegetation changes due to acid deposition, climate change, forest pests, and/or ozone levels alone affect water discharge rates at high elevation springs?
2. How is water quality impacted by point-sources (i.e., waste-water treatment plants, sedimentation, concession waste, septic systems, mines, etc.) and non-point sources (i.e., road runoff, fertilizer, de-icers, crush and fill, trampling, moving rocks, erosion, acid deposition, etc.) of pollution?
3. How are deformities of diatoms in high elevation springs linked to water quality, especially as it affects human health? Can monitoring of the prevalence of these deformities be a cost-effective way of monitoring the water quality of these springs, especially by trained volunteers? Do the causative agents of these deformities have impacts on the macroinvertebrate [e.g., chironomids (Janssens de Bisthoven et al. 1998)] and salamander communities in these habitats?
4. Why are high elevation springs showing such differences in conductivity, nitrogen, aluminum, etc. even when on similar geology and even when adjacent?
5. What is the role of ground water in surface water features and how is this changing with climate change, etc.?
6. What are the responses of the aquatic communities in restored brook trout streams?

B. Acid Deposition, Toxics, Ozone Pollution, Haze and Visibility:

1. How is the distribution/deposition of organic mercury different from that of total mercury and is inorganic mercury being methylated to a significant extent in the park (and if so, where and under what conditions)? Do heath balds and/or wetland/riparian communities in the park serve as methylation sites of importance to the park?
2. What are good indicator species for monitoring the ecological effects of mercury deposition in the park? Feather and blood samples collected from several resident bird species have had high concentrations of mercury; several aquatic invertebrate species have had high but not alarming levels of mercury in them; and several salamander species, especially those that frequent the sides of streams, have shown fairly high levels of mercury. Are there indications of deleterious effects of these mercury levels, or if not, what would be the threshold above which one would expect deleterious effects?
3. Aerosol, particulate concentrations, and cloud cover may reduce the amount of solar radiation reaching forest trees. What is the effect of aerosol, particulate concentrations, and cloud cover on forest productivity, measured at different scales with remote sensing, on-the-ground particulate sensors, etc.? Evaluate the concentration and sources of particulate matter affecting haze and its impact on visibility, solar radiation, and plant growth. Use findings to

help establish critical/target loads and model effects to determine where key source areas and types may be most critical to regulate.

4. What are the critical loads for the park (or for different major habitats in the park) for deposition of sulfate, nitrate, ammonium, major cation concentrations and wet deposition, dry chemistry and deposition, and cloudwater/throughfall deposition?
5. How are bats, birds, and other species affected by particulates in the air above GRSM? Is there any evidence that higher particulate levels have an adverse impact on these species (foraging, reproduction, longevity, etc.)?
6. What is the status and persistence of current and historic PCBs, pesticides, and their metabolites in the park, including dust-borne deposition from agricultural areas outside the park and imidacloprid use within the park? What is the status of mercury and pesticide concentrations in the environment, including bioaccumulation in target organisms? (see work by Lindquist 2003)

C. Climate:
1. Develop a model of precipitation for the park to assist with ecological investigations and monitoring.
2. How is climate change affecting hydrology, soils, disturbance events, mercury methylation, zoonotic and wildlife diseases, exotic plant and animal distribution, etc.?
3. What are the trends of physical effects of wind: blowdowns (and erosion-altered forest structure), increased evapotranspiration, and cloudwater inputs (percentage of precipitation/deposition as rain or fog)?

D. Soils, Geology:
1. How and where did soil structure change in relation to legacy land-use practices and how is it recovering? Can a map be produced of the different classes of soil disturbance in GRSM? Can natural disturbance of soils in old-growth forest be characterized? Are areas of former alterations more prone to exotic invasion and if so, why?
2. How does soils disturbance affect biogeochemical cycling? Are there differences in residence time of elemental nutrients or metals moving through the disturbed versus undisturbed soils? Are there differences in moisture retention? How might that affect terrestrial and aquatic species/resources?
3. How will forecast increases in temperature (via new NOAA report), and differing precipitation regimes affect our soils resources? Will oxidation increase? Will soils in particular environments become more stressed than others (e.g., steep slopes, on southwest aspects at low elevations)? Will carbon sequestered in finer soil textures be mobilized?
4. Are there changes in slide event frequency and magnitude on a decadal scale associated with climate and forest structure/composition changes?
5. How are calcium and phosphorus cycled in different parts of the park and how is that altered by climate change, deposition, and loss of major forest species?

6. We have a number of gravel or gravel-added dirt roads in the park, the most significant being around Cades Cove, and also in Cataloochee. The park road crew in Cades Cove has used limestone gravel, in keeping with the bedrock geology of the site, but most of the North Carolina roads use granitic gravel. We have anecdotal reports from lichenologists that the limestone dust from the Cades Cove roads has killed most species of tree trunk lichen 50 m back from the roads. This does not appear to be happening along granitic gravel roads. What are the relative impacts of different sorts of gravel and its dust on the areas adjacent to roads, terrestrial and/or aquatic?
7. How is soil structure changing in relation to invasive exotics (worms, pigs, etc.), fire (or lack thereof), current land-use, and forest change impacts? (there is a series of research questions here to identify previous conditions and identify mechanisms of change)
8. How is soil quality impacted by point-sources (fertilizer application, spills, concession waste, etc.) and non-point sources (i.e., road runoff, fertilizer, de-icers, trampling, erosion, acid deposition, etc.) of pollution?

E. Vegetation Communities, Communities of Concern, Landscape Change:

1. What is the status of riparian community species abundance, species composition, and distribution related to human disturbance (e.g., invasive species, recreation, Elkmont restoration, Chilogatee reclamation, compaction, trampling) and natural disturbance regimes (e.g., floods, drought, rock slides), and what is a baseline for undisturbed riparian communities upon which to compare future trends, especially for the globally imperiled Montane Alluvial forest community?
2. Of globally or regionally imperiled taxa and/or communities, which are leading indicators of environmental changes? Is there any economy that can be reached by monitoring a sub-set of them or more common species that would track their status and trends?
3. What is the relationship between wildfire intensity/frequency and habitat change (i.e., vegetation composition, invasive plants and animals, soil alteration, vertebrate parasite loads, native animal community composition, etc.)?

F. Invasive Plants, Invasive Animals, Infestations and Diseases:

1. What is the best integrated pest management for hemlock woolly adelgid (including new insecticides, seasonal timing of treatments, treatment intervals, individual tree and/or stand factors in chemical uptake, biological control applications?
2. What are the impacts of loss of host species (e.g., hemlock, fir, beech) and establishment of exotic species on watersheds, hydrology, soils, associated species and ecosystems?
3. What are the distribution, prevalence, and interactions between *Ranavirus* and the chytrid fungus (Bd) within the park, especially in stream-dwelling and terrestrial salamanders? What are the strains of *Ranavirus* in park amphibians and why have they varied so significantly within site from year to year? Under what conditions do these pathogens cause mortality in park salamanders and are there compounding factors (drought, acid deposition/run-off, etc.)?

4. What role do mammals play in zoonotic disease transmission, such as Rocky Mountain spotted fever, hanta virus, or Lyme disease? How do trends in mammal populations affect disease incidence/transmission? What are the status and trends of mammal populations serving as disease reservoirs? (note: work by J. New, and CDC)
5. What are the best integrated pest management techniques for garlic mustard, Japanese grass, mimosa and *Ailanthus* (including selective herbicides, time of treatment, biological and mechanical control options)?
6. What are possible biological controls for balsam woolly adelgid on Fraser fir?
7. What are survey techniques for rapid detection and early response for new exotics, particularly: wood-borers (such as emerald ash borer, Asian long-horned beetle, *Sirex* wood wasp); plant diseases (such as sudden oak death) which are difficult to detect from remotely sensed data; and exotic diseases of native species of wildlife, including birds, amphibians, and pollinators?
8. Are there genetic mechanisms of resistance to exotic forest insects and diseases, including HWA, BWA, beech scale, and dogwood anthracnose; and if so, what are they?
9. What are the interactions between fire and exotic species invasions, with regard to their introduction and spread, as well as for their management?
10. What is the distribution of pseudorabies in exotic wild hogs, what are the impacts, and what is the appropriate management action?
11. What is the exact threat to soils and native soil life offered by exotic earthworms, especially *Amynthas*? They feed in the litter layer, not so much in mineral horizons, and reduce native invertebrates, and perhaps salamanders. They may also impact rare plants, assist exotic plant establishment, and have an effect on soil transport. Can their current status be mapped? Are disturbed soils more easily invaded then undisturbed soils? Can the future spread of these species be modeled for the park as a whole? What will the ecological impact be if they become widespread? (note: preliminary work conducted by Snyder and Pechmann)
12. What is the distribution of fire ants in the park, what are their impacts, and what is the suggested management?
13. What are successful programs for preventing the introduction of invasive exotics, as far as educational programs within the park, outreach to surrounding areas, and regulations and enforcement?
14. How does the management of reservoirs affect the introduction of exotics?
15. Pear thrips (*Taeniothrips inconsequens*) were discovered in the park in recent years and have been associated with die-backs of sugar maples (*Acer saccharum*) in the Northeast, especially under conditions of drought and low cation availability, factors many park maples experience. Decline is most likely to occur in higher elevation [>1219 m (4000 ft.)] northern hardwood forests. These forests occur over poorly buffered and acidic sandstone bedrock and are subject to relatively high levels of acid deposition. Sugar maple trees

occurring in protected coves on lower slope are less likely to experience decline. What is the current status and distribution of thrips and related injury in the park's sugar maples, and what is the potential for this becoming a serious threat to the park's maples?

G. Amphibians and Reptiles, Birds, Mammals:

1. What is the link between fire and reptile distribution and abundance? Some of the least common species in the park are known from dry pine and oak-pine communities in the western part of the park. Is there any evidence that fire has benefited or harmed these species in the park?
2. What are the distribution, abundance, phenology, and species composition of transient migratory birds in spring and fall? Are there areas of the park, habitats, and/or food plants that are especially important to migrating birds in the park? Does this vary from year to year, with wind patterns, soft mast crop, or other factors?
3. What are the distribution, abundance, phenology, and species composition of overwintering bird species in GRSM? Are there areas of the park, habitats, and/or food plants that are especially important to wintering birds in the park?
4. Where do the seven southern Appalachian endemic races of birds spend the winter? How much of their wintering range is protected within the park? Are there specific partnerships that can be developed with land management entities that control their wintering range (including Caribbean nations)?
5. How does bat activity relate to lunar phase in the park and in different locations of the park? What is bat behavior once they are in the caves as far as the amount of activity before roosting and use of non-roosting areas of the caves?
6. What are the natural population cycles and interactions of the park's small mammals in different habitats? What is the normal range of population sizes, and how is this changed by climate/disease/invasive-induced vegetation community changes?

H. Human Impacts:

1. What is the status and trend of legal consumptive collecting in the park, and what (and where, in terms of concentrated use) are the impacts of this on the consumed species in the park, especially fungi?
2. How is anthropogenic sound affecting human recreational experiences (backcountry, hiking, driving, camping, picnicking, and interpretation)? (Establish baseline sound qualities and levels, better sound monitoring technologies, and better human response/opinion patterns). How is anthropogenic sound above baseline affecting wildlife resources, such as bird territory placement and size, and large animal movements?
3. How is light pollution impacting the visitor experience and biological resources? Specific examples of impact may include lepidopteran populations and movements, salamander movements and reproduction, etc.

4. Does poaching and other collection affect amphibian, reptile, rare plant, and moss populations, and if so, to what extent does it alter abundance, reproduction, and distribution? What is the effectiveness of replanting poached plants?

Appendix C. Connect-the-dots.

All anticipated monitoring measures are compiled into the table below. Some metrics have been collected for an extended period of time; therefore both current condition and reference condition are given. However, many metrics are new and do not have current or reference data yet. These are given "to be determined" (TBD) designations. After program implementation, this table will be used to show selected metrics and their trends in comparison to established reference values.

Vital Sign	Indicator	Metric	Current Condition	Reference Condition
Soil Chemistry	A horizon	Ca	soil series dependent	TBD
		Mg	soil series dependent	TBD
		Al	soil series dependent	TBD
		K	soil series dependent	TBD
		sulfate	soil series dependent	TBD
		N	soil series dependent	TBD
		carbon: TOC, DOC	soil series dependent	TBD
		organic acids	soil series dependent	TBD
		P	soil series dependent	TBD
		pH	soil series dependent	TBD
Acid Deposition	acid deposition	total N deposition (critical load)	16-39 kg/ha/yr[1]	3-7 kg/ha/yr (soil Al:Ca and BS)[2]
		total N and S deposition (TMDL)	58 kg/ha/yr N and S[1]	TBD – 303(d) for pH[3]
		natural N in precipitation	5-19 kg/ha/yr[1]	0.5 kg/ha/yr[4]
		natural S in precipitation	5-9 kg/ha/yr[1]	0.5 kg/ha/yr[4]
		natural pH in	4.7 pH[5]	5.6 pH[6]

Vital Sign	Indicator	Metric	Current Condition	Reference Condition
		precipitation		
		N deposition (single source)	NA	≥0.01 kg/ha/yr[2]
		S deposition (single source)	NA	>0.01 kg/ha/yr[2]
Water Chemistry	baseflow and episodic water quality	temperature (^{o}C)	TBD	TBD
		stream pH	6.372	6.0-9.0[7]
		copper	0.001 ppm	0.007 ppm[7]
		zinc	0.007 ppm	0.05 ppm[7]
		ANC (min)	-14.36 µeq/l	50 µeq/l[7]
		ANC (avg)	94.488 µeq/l	50 µeq/l[7]
		sulfate	50.985 mg/l	250 mg/l[7]
		nitrate	16.159 mg/l	10 mg/l[7]
		TOC, DOC	TBD	TBD
		organic acids	TBD	TBD
	high and low elevation watershed input/output budget	temperature	TBD	TBD
		stream Ph	5.59-5.83	TBD
		copper	0.001 ppm	0.009 ppm[7]
		zinc	0.007 ppm	0.120 ppm[7]
		sulfate	29.4-40.8 mg/l	TBD
		nitrate	41.5-46.6 mg/l	TBD
		TOC, DOC	TBD	TBD
		organic acids	TBD	TBD
Freshwater Communities	macroinvertebrate diversity/ abundance	biotic index (BI)	excellent (BI=5) to good/fair (BI=3)	excellent (BI=5)

Vital Sign	Indicator	Metric	Current Condition	Reference Condition
	amphibian diseases	presence/absence	*Ranavirus* and chytrid fungus detected in some locations[8]	TBD
	algal malformations	% malformed	Some high elevation springs have high % of deformities[9]	near-zero deformities
	algal diversity	chlorophyll *a*	TBD	TBD
	fish diversity, species richness, condition, distribution, and relative abundance	index of biotic integrity (IBI)	55	TBD
	fish condition, diversity relative abundance	depletion estimates	based upon current data	within 20% of 10 yr. geometric mean of abundance
Climate Change	temperature	air - Δ in mean temperature	analysis underway	individual station history
		Δ in area of air temperature zones, according to park model	TBD	will be determined by observing decadal Δ's in models since 1930s
		soil - Δ in mean temperature	TBD	TBD
		water (streams) - Δ in mean temperature	TBD	TBD
	precipitation/moisture	Δ in seasonal mean	TBD	TBD
		Δ in area of precipitation zones, according to park model, by watershed	model to be developed	TBD
		Δ in soil moisture	TBD	TBD

Vital Sign	Indicator	Metric	Current Condition	Reference Condition
		Δ in stream discharge	TBD	TBD
		Δ in mean seasonal relative humidity	TBD	TBD
	phenology	date of plant vernalization and peak reproduction	appears to be earlier than 20 years ago	some species-specific data available (Mathis 2008)[10]
		dates of amphibian, bird, insect calling	some neo-tropical birds reported as earlier arrivals	some species-specific data available (Mathis 2008)
	landscape disturbance	amount of wind damaged forest (ha)	TBD	TBD
		number and size of landslides	frequent in wet years	TBD (from historic air photos)
		forest stand defoliation/mortality (ha)	significant increase	intact forest (as determined by historic aerial photos, current observations)
		forested land within 25 km of park (% and ha)	significant decrease	1000% increase in homes from 1949 to 2000 (NPScape)[11]
	solar energy (received at surface)	watts/m^2	TBD	TBD
Vegetation Communities	species composition	relative abundance	TBD	TBD
	species richness	count	TBD	TBD
	growth rates (woody plants)	% Δ basal area	TBD	TBD
	tree mortality rates	%	TBD	TBD
	tree regeneration	seedling count	TBD	TBD

Vital Sign	Indicator	Metric	Current Condition	Reference Condition
	canopy recruitment	% Δ canopy trees	TBD	TBD
	canopy cover	%	TBD	TBD
	nativity	% non-native	TBD	TBD
	downed woody debris	% Δ	TBD	TBD
	vegetation communities	% Δ aerial extent	TBD	TBD

Footnotes/References:

1. 2000-2008 annual average deposition for Elkmont and Noland Divide, respectfully
2. Pardo L. and N. Duarte. 2007. Assessment of effects of acidic deposition on forested ecosystems in Great Smoky Mountains National Park using critical loads for sulfur and nitrogen. U.S. Forest Service, 131 pp.
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5. 2008 National Atmospheric Deposition Program (NADP) data from Elkmont, TN (TN11)
6. National Acid Precipitation and Assessment Program (NAPAP) – State of the Science & Technology Report Volume I. 1990. pg. 6-53 to 6-70.
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8. USGS. 2009. Gainesville report.
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NPS 133/126595, September 2014

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov