Soil Resource

INTRODUCTION

"The soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth, which differs from the parent material below in morphology, physical properties and constitution, chemical properties and composition, and biological characteristics," (J.S. Joffe 1936). This is just one of many scientific definitions of soil, and to date there is no known universal agreement on the actual definition of soil, and there seems to be no need for one. Farmers, scientists, engineers, theologians, and presidents of nations have long contemplated soil. Thomas Jefferson is known as the first soil surveyor in the United States, taking great care to inventory the soil on his farm. Franklin Delano Roosevelt once noted, "The nation that destroys its soil destroys itself." Soils are typically formed through a combination of five factors: climate, landscape, biological influence, parent material, and time. A sixth influential factor is human activity, and this factor can often play the greatest role in soil development and productivity.

The desired condition for the soil resource on the Monongahela National Forest (MNF) is to maintain or improve soil quality and soil productivity. Soil protective cover, soil organic matter, and coarse woody material are at levels that maintain the natural infiltration capacity, moisture regime, and productivity of the soil. Soils also have adequate physical, biological, and chemical properties to support desired vegetation growth. Exposed mineral soil and soil compaction from human activity may be present but are dispersed and do not impair the productivity and fertility of the soil.

Need for Change

Two Need for Change topics that helped generate Forest Plan revision for the Monongahela were the ongoing subject of sedimentation and the new topic of acid deposition related to air quality and soil productivity. When asked to identify issues or concerns for revision during the scoping process, many people focused on water quality and soil productivity. Citizens wanted to see a continued emphasis on improving water quality and addressing erosion and sediment on the Forest so as to promote healthy aquatic habitats. Some individuals, organizations and agencies also wanted to see the Forest address acid deposition, and the effect it may be having on Forest resources. In the 1986 Forest Plan, acid deposition was an issue considered but not brought forward due to the general feeling that the Forest could not do anything about the potential effects from acid deposition. This position has changed and will be discussed in greater detail later in this analysis.

Issues and Indicators

Issue Statement

Forest Plan management strategies may affect the soil resource.

Background

Erosion and acid deposition occur to varying degrees across the entire Forest, and their effects to soil can be exacerbated by soil disturbance. The Management Prescriptions (MPs) in the Forest Plan provide for a variety of activities to occur on varying soil types, ranging from little or no management (i.e., soil disturbance) in Wilderness areas to activities that call for a total commitment of the soil resource where soil is removed and replaced with a permanent facility. Although certain soil-disturbing activities, like mineral development or livestock grazing, can occur in localized areas throughout the Forest, large-scale soil disturbance associated with timber harvest and road construction most often occur in MPs with suitable timberland. Because the amount and distribution of these MPs and their predicted activities vary by alternative, the alternatives can be used to show relative differences in the potential that timber harvest and road construction may have for impacts on soil quality and productivity related to:

1) Soil erosion and sedimentation, and
2) Soil nutrient depletion and soil acidification related to acid deposition

Indicators

The following indicators will be used to reflect the potential relative change under each alternative based on anticipated levels of management activities that could have substantial effects on the soil resource.

- Acres of Potential Timber Harvest in Suited MPs by Alternative

The Soil Erosion Hazard Rating layer was overlaid with MPs that have land considered suitable for timber production, and it was determined that all alternatives have a consistently high percentage of their suitable land in areas that have a “severe” rating for soil erosion potential. However, each alternative would have a different amount of potential timber harvest activities that could occur on those soils that are more susceptible to erosion from harvest and road-related soil disturbance.

- Acres and Percent Of High-Risk Acid-Sensitive Soils By MP by Alternative

The Soil Nutrient Sensitivity and MP layers were overlaid to show where the Forest potentially has soils that are more susceptible to further soil acidification from harvest and road-related soil disturbance.

These indicators where chosen in part due to scale. At a Forest-wide analysis level, soil disturbances associated with timber harvesting and road building account for by far the largest percentage or acreage of soil disturbance. Minor disturbances related to recreation improvements, grazing, mineral development, and watershed restoration occur but are typically negligible when compared to timber harvesting and road building.

Scope of the Analysis

For sedimentation and erosion, the affected area for direct and indirect effects to the soil resource is the lands administered by the Monongahela National Forest (MNF). Further focus will be placed on MPs with suitable timberlands that are most likely to have activities that produce soil disturbance. The affected area for cumulative effects will include private land within the Forest proclamation boundary. This expanded area will facilitate a discussion of how other activities on Forest land may affect soil erosion and sedimentation both on and off the Forest, and how activities off the Forest may have a cumulative influence on forest soils.

For soil nutrient loss related to acid deposition effects, the affected area for direct and indirect effects to the soil resource is the land administered by the Forest. Further focus will be placed on the MPs with suitable timberland that are most likely to have activities that produce soil disturbance. The affected area for cumulative effects will extend beyond land administered by the Forest to include entire watersheds because of the links between air quality, soil quality, water quality and aquatic habitat. Pollution source areas well beyond the Forest boundaries will also be discussed in order to show the far-reaching nature of this issue.

This analysis will identify potential temporary, short-term and long-term effects. Temporary effects are assumed to last weeks or months, short-term effects 1-15 years, and long-term effects last greater than 15 years.

CURRENT CONDITIONS

Soil Erosion and Sediment

The soils of the MNF are developed under a mesic climatic temperature regime (mean annual air temperature is 48 degrees Fahrenheit) and an udic soil moisture regime (mean annual precipitation is 58 inches). The parent material that underlies the soils is comprised of sedimentary geology that makes up the Appalachia Ridge and Valley and the Allegheny Plateau Provinces. The soils on the Forest have been subject to the effects of extensive tree cutting and slash burning, most of which occurred between 1890 and 1935. These human-induced activities resulted in damaging floods, severe erosion, topsoil loss, and pollution of streams used for water supply. Subsequent fires further increased erosion. The fires at the turn of the century burned so hot that soil carbon was lost to the atmosphere, and lost soil productivity in some areas on the Forest was irreversible. Although there has been recovery over the past century, soils on many forested landscapes on the Forest still have thin surface horizons, and in some areas soil is essentially non-existent.

The soils of the Forest have developed from sedimentary rocks, and are divided into two zones, which differ in soil patterns. The Allegheny Plateau Province has relatively flat-lying bedrock. Soils on the plateau are characterized by high moisture content, thick humus, acidic conditions, and low nutrient levels. High timber productivity in the province is more a function of soil moisture than fertility. Limestone areas are more fertile and have often been cleared for pasture. In the Ridge and Valley Province, bedrock is folded, faulted, and fractured. Rock outcrops and

escarpments are common. Soils are often shallow, shaley, draughty, and not highly productive. Most of the forest soils exhibit moderate to severe erosion potential, and high hazard areas exist in areas of shale and limestone. High hazard with regard to limestone refers to karst formations and caves. Sinks and land subsidence can occur and pose a risk, and ground disturbance within these areas can introduce sediment into the under workings of the karst formations. High hazard areas with regard to shale refer to shale formations that have exposed dips and sometimes result in large mass wasting events. Also, often soil types forming from these shales are shallow, droughty, and difficult to keep vegetated. Therefore, operating in these areas could result in substantial loss of sensitive habitat (i.e., shale barrens) or result in a loss of soil productivity that could prevent the return of vegetation.

Soil inventory was a major emphasis in the 1986 Forest Plan. Soil inventories were completed on 85 percent of the Forest during the past 18 years. The Natural Resource Conservation Service is currently updating an existing but outdated soil inventory in Tucker, Barbour, Preston, and northern Randolph Counties. The anticipated date of completion for these soil surveys is 2010. The Forest will then have a complete updated soil inventory layer that can be utilized in an integrated manner to assess effects from management activities. Existing information can now be accessed through the Internet and NRCS databases.

This analysis focuses on harvest and road-related management activities and their specific relationship with erosion/sedimentation potential. The reason for this is the intensity and magnitude that the effects from these activities have on the soil resource. Road construction/ reconstruction has perhaps the most dramatic and long-lasting effect of Forest Service land management activities and timber harvest is probably the most widespread of our activities.

Erosion is considered in this document as soil movement and not soil loss. Soil material may or may not move from a site or to a stream channel. Many factors influence soil movement, and when soil moves, it is deposited somewhere. Depositional areas may benefit from the addition of this eroded soil. Gully erosion is an extreme case of soil movement and would be considered a long-term negative effect to soil productivity. Gully erosion is evidence that large amounts of soil have moved away and will only be replaced over the long term (over 100 years). Other forms of erosion are not as detrimental and would only continue until vegetative cover is established.

Gully erosion is difficult to predict and depends on several factors. There is evidence on this Forest that some soil types are more susceptible to gully erosion and mass movement than other soil types. Soils that form from the geologic parent material of the Mauch Chunk formation have exhibited this behavior both naturally and with human-caused soil disturbance. An excellent example of the induced erosion and mass movement of these soils occurs along the Highland Scenic Highway. Other soil types over geologies such as the Chemung and Hampshire formations are also susceptible to mass movement. Areas in the northern portion of the Forest have large portions of the landscape that are overlain with colluvial soils. In some areas, hidden ancient landslides dot the landscape, posing potential risk for mass movement when disturbed. Steep slopes and the dip of the geologic formation also increase the risk of mass movement. These areas are typically identified in watershed assessments and are further scrutinized when planning for a project. Most often avoidance is the best mitigation.

Recent work with NASIS (Natural Resource Conservation Service, National Soil Information System database) shows that the majority of the Forest soils have a moderate to severe erosion potential when disturbed. A soil erosion susceptibility layer was created for the Analysis of the Management Situation for Forest Plan revision (Soil AMS, Appendix A, Map 1, Forest Plan project record).

Historically, soil erosion was the principal concern affecting forest soil productivity. The issue was loss of organic matter that harbors nutrients and helps maintain soil aeration. However, it has been since found that soil organic matter is not lost from harvest sites, even those clearcut or where all the tree boles, tops, and limbs are removed (Johnson et al. 1991). Instead, it is redistributed in the upper mineral soil layers during harvesting. In addition, it is now known that root decay re-supplies the organic matter more quickly than erosion or respiration depletes it. Soil erosion continues to be a concern for potential sediment production and effects on aquatics. More information can be found in the *Watershed, Riparian and Aquatic Resources* section.

Today, there is a more general concern about soil nutrients, especially the loss of calcium due to a combination of impacts from atmospheric deposition and timber harvest (Federer et al., 1989). Calcium is important for such plant functions as growth regulation and disease resistance. The concerns here include possible changes in forest health, forest productivity, and forest species composition.

Because forest health issues differ by temporal and spatial scales, any definition of forest health is likely to be conceptual in nature. The use of the term “health” is controversial since health is easy to comprehend in terms of the human body, however it may not be appropriate for ecosystems such as a forest. However, some researchers and managers have determined characteristics of what are considered healthy forests. Kolb et al. (1994) propose the following characteristics as a definition of forest health: 1) physical and biotic resources to support forest cover; 2) resistance to dramatic change; 3) functional equilibrium between supply and demand of essential resources; and 4) diversity of seral stages and stand structures. Forest productivity in a broad sense can be defined as the goods and services provided by the land base. Forest species composition is associated with the number of different species present and includes the range of habitat characteristics that each species needs to survive. The loss of calcium in the ecosystem could potentially lead to a decline in these forest factors, but this is very difficult to assess given the variability of external and internal influences that affect forest health, forest productivity and forest species composition.

Soils at higher elevations on the Forest tend to be hydrologically shallow and on steep terrain. With few exceptions, these lands have severe soil erosion hazard ratings related to road construction and lower forest productivity relative to lower elevation sites. Also higher elevations, especially above 3,000 feet, receive greater amounts of atmospheric pollutants (MNF Wet Sulfate Deposition Map), especially sulfate (SO_4^{-2}) and nitrate (NO_3^-). These pollutants affect the chemistry of the soil in a way that may lead to loss of important nutrients, such as calcium, and mobilization of others, such as aluminum, that may affect forest productivity. Accelerated human-induced soil erosion is associated with certain management activities, and it can indirectly affect water quality and aquatic habitats when the sediment reaches a stream

channel. However, this issue now shares the spotlight with soil productivity concerns related to acid deposition. This newly addressed issue is described below.

Acid Deposition

Soil acidification can be seen as a balance between acid inputs and mineral weathering (Binkley et al. 1989). Therefore, when soil-acidifying processes (such as acid deposition and forest growth) exceed mineral weathering inputs of base cations, acidification occurs. Base cations are nonacid positively charged ions of calcium, magnesium, potassium, and sodium.

Changes in soil chemistry are difficult to quantify due to the long periods of time over which they occur, the complexity of the factors controlling them, and the inherent spatial heterogeneity of soils. A study of soil acidification in the Calhoun Experimental Forest in South Carolina using soil data from 1962 to 1990 showed that the upper 60 centimeters of soil acidified at an accelerated rate due to acidic deposition while the naturally acidifying processes of biomass accumulation, root and microbial respiration, and organic matter incorporation also occurred (Markewitz et al. 1998).

Soil acidification increases cation leaching, decreases soil pH and base saturation, increases the nitrogen content of trees, and negatively affects many biological processes (Adams and Kochenderfer 1999). Adams (1999) found that calcium losses were particularly large when a forest soil becomes acidified. A nine-year acidification study at Bear Brook watershed in Maine showed accelerated loss of base cations from the soil, which subsequently leached into the streams (Fernandez et al. 2003). Base cations also are removed from the soil by plant uptake, leaching, and harvesting (Gbondo-Tugbawa and Driscoll 2002).

The major base cations in atmospheric deposition, soils, and geologic materials are calcium, magnesium, potassium, and sodium. Of these, calcium and magnesium typically provide the greatest contribution to buffering because they usually are more abundant than potassium and sodium, and they possess a greater positive charge. Mineral weathering of soil and geologic materials controls base cation availability over the long term, but the major short-term sources of base cations to soil are litter fall and atmospheric deposition (Johnson and Todd 1990; Jenkins 2002). Slope position affects base cation supplies because litter accumulates more on lower slope positions than on higher ones (Johnson and Todd 1990; Jenkins 2002; and Schnably 2003).

The National Acid Precipitation Assessment Program (NAPAP) indicated that base cation depletion may affect the health of forest ecosystems, though forests have not yet shown adverse effects from acid deposition (NAPAP 1998). However, mortality and decline of red spruce *(Picea rubens)* at high elevations in the Northeast have been significant and provide recent evidence of forest damage by acidic deposition (NAPAP 1998). Sugar maple *(Acer saccharum)* also is a species of concern (Horsely et al. 2000; Likens et al. 1996; Bailey et al. 2004), because it is particularly sensitive to decreases in calcium and magnesium soil pools.

Water Quality and Aquatic Resources on the MNF

The MNF is the fourth largest national forest in the Eastern Region and contains the headwaters of five major rivers: the Monongahela, Potomac, Greenbrier, Elk, and Gauley. Portions of twelve rivers on the MNF are considered eligible for potential inclusion in the National Wild and Scenic Rivers System. Rivers and streams across the Forest provide more than 900 kilometers of coldwater trout streams and an additional 200 kilometers of warm water fishing. Although the State of West Virginia manages many stream segments as put-and-take trout fisheries with seasonal trout stocking, some estimates indicate that 90 percent of West Virginia's native brook trout streams occur on the MNF.

Water chemistry of streams and rivers is the by-product of dynamic nutrient pathways and chemical processes occurring within the contributing watershed environment – atmospheric, terrestrial, and biological. The significance of water chemistry is perhaps no more apparent than in aquatic ecosystems composed of diverse geology, particularly when these systems are exposed to acid deposition. Watersheds across the MNF are composed of a wide range of surficial geologies that have variable capacities for neutralizing acid inputs.

Healthy, reproducing trout populations and their associated communities have various habitat requirements. Water quality in rivers and streams is an important consideration when establishing management priorities on the Forest to provide for the maintenance of healthy aquatic ecosystems. Water chemistry is one component of water quality and represents a fundamental building block for aquatic communities. For example, harmful effects to certain aquatic organisms begin to occur as pH values in streams fall below 6.0; detrimental effects occur to most aquatic organisms as pH falls below 5.0. Also, values less than 50 for acid neutralizing capacity (ANC) indicate a stream system is acid sensitive, values less than 25 suggest a system likely experiences episodic acidification during storms, and negative ANC values indicate a system is already acidic (http://www.dep.state.wv.us).

In 2001, the MNF initiated an effort to establish Forest-wide monitoring of water chemistry properties in streams across the Forest. Sample sites were strategically located to increase the level of understanding of the relationships between water chemistry and various local environmental factors including the geologic composition of contributing watershed areas, rates of acid deposition, and supported aquatic communities. Results of water chemistry monitoring from fall low flow and spring high flow sampling across the Forest demonstrated a high degree of variability between sample locations and sample periods, as expected. For example, measures of pH ranged from 3.88 to 8.2 (mean = 6.8) during fall 2001 samples (low flow conditions) and from 3.73 to 8.55 (mean = 6.4) during spring 2002 samples (high flow conditions). Measures of ANC ranged from -166 to 2868 (mean = 407) during fall 2001 samples, and from -195 to 1599 (mean = 135) during spring 2002 samples.

Variation in measures of pH and ANC between sample locations was largely explained by the variable capacity of a watershed's geology to neutralize acid inputs. Variation in measures of pH and ANC between sample periods at a given site was largely explained by the different stream discharge conditions. Except where acid mine drainage is an issue, water samples collected at low flow conditions during the late summer to early fall period are typically expected to exhibit

higher pH and ANC values due to the greater influence of groundwater on stream flows as compared to spring high flow conditions when direct inputs from melting snow and precipitation (i.e., acid rain) have greater influence.

State water quality monitoring programs are also documenting cases of stream acidification in West Virginia. In an attempt to mitigate impacts of stream acidification on native trout streams and the recreational fishing opportunities they provide, the State has developed and refined a program to treat acid impaired streams with limestone sand. Limestone sand is currently being applied to acid-impaired streams on the Forest and across the State to help neutralize acidity. Forest monitoring results show water chemistry downstream from treatment areas exhibit notable increases in ANC, pH, and Ca when compared to untreated water upstream. Although this action helps to mitigate against many symptoms of stream acidification within the effective stream treatment zone, it does not affect the underlying cause of the condition to address risks to aquatic and terrestrial ecological processes and functions that extend beyond the treatment zones (McClurg 2004).

The Occurrence of Acid Conditions and Acid Sensitivity on the MNF

Soil, water, and stream acidification are real phenomena that have been shown to occur in West Virginia. Evidence of nutrient depletion in certain soils on the MNF has been found (Jenkins 2002; Schnably 2003; unpublished soil chemistry data for 2004 Soil Resource Monitoring Report). Long-term, increasing losses of base cations to stream water due to ambient acid deposition have been documented in stream water on a control watershed in the Fernow Experimental Forest, which is located in the MNF (Edwards and Helvey 1991). Other watersheds on and near the Fernow Experimental Forest that have been artificially acidified with sulfur and nitrogen to determine effects on soils and stream water have shown mobilization of base cations in soil and consequent leaching to stream water and substantial reductions in the acid-neutralizing capacity of soil water (Edwards et al. 2002a, 2002b).

Otter Creek Wilderness is a popular recreation area on the MNF, and because it also is designated a Class I air quality area it has been intensively monitored to characterize the extent of acidic water, soils, and geology (Webb et al. 1997; personal communications with Jenkins 2004; Adams et al. 1991.) An estimated 71 percent of the Otter Creek Wilderness is underlain by geologic material of the Pennsylvanian age. The dominant geology is the Pottsville Group, which generally has very acidic strata. Many of the sandstones associated with Pottsville geology are resistant to weathering, and weathered materials produce very acidic soils, with pH values ranging from 3.5 to 4.6. Only small base cation reserves exist to be weathered to the soil, so there is little to no acid-neutralizing capacity available (Jenkins 2002).

Some of the soil types found in the Otter Creek watershed also have elevated aluminum, which poses a threat to forest productivity and exacerbates soil nutrient deficiencies (Jenkins 2002). Jenkins (2002) found that some of the soils studied from Otter Creek have such a low buffering capacity for acid deposition that these forests are at nearly a 100 percent risk for decline in productivity. High aluminum concentrations are present in soils supporting declining spruce stands in northeastern United States and are commonly thought to inhibit calcium uptake and transport (Shortle and Smith 1988). Red spruce *(Picea rubens)* is a dominant tree species

growing in the high elevation soils of Otter Creek Wilderness, and it is an important ecosystem component for several rare or listed species on the MNF.

While Otter Creek has been intensively monitored, more widespread continuous monitoring of soils around the MNF has taken place since before the 1970s through cooperative efforts between the USDA - Natural Resource Conservation Service (formally the USDA Soil Conservation Service) and the MNF to develop and publish county soil survey reports. While the data are not complete and the soil pits from which the data were obtained were not always located in areas of interest to the MNF, the soil data were collected across multiple geologies over time and are very useful in helping to assess soil productivity.

Since 1995, additional intensive soil data collection continues to be done to develop baseline soil chemistry data across the MNF, especially in areas assessed by the Soil Nutrient Sensitivity Map (described below) to be highly sensitive to acidification. More than 500 soil samples have been collected across varying soil types, landscape positions, and varying aspects and analyzed for physical and chemical characteristics. Preliminary results show that soils in highly sensitive areas are affected adversely by acid deposition. Base saturation values often are below 15 percent, and calcium to aluminum ratios are often less than 1.0 for soils found on ridgetops and benches in the surface horizons. Some south-facing cove soils have soil aluminum levels in the surface horizon and subsurface horizons that might indicate possible toxicity for vegetation.

Soil Nutrient Sensitivity on the MNF

Acid deposition and its effects on soil productivity arose as an emerging issue during the scoping phase of Forest Plan revision in 2003. After a review of the literature, discussions with research scientists, and discussions with internal interdisciplinary team members, the issue was brought forward as a primary Need for Change topic during Forest Plan revision. Soil productivity issues and mitigations on disturbed land were addressed in the 1986 Forest Plan (USDA-Forest Service, p. 79 and Appendix S), but there was no consideration of soil productivity losses caused by base cation depletion on undisturbed soils.

To address this issue in Forest Plan revision, areas on the MNF susceptible to potential effects of acid deposition first were identified and mapped using a multi-step process. The initial map data layer in the analysis was the geology layer; geology was ranked as high, medium, or low for sensitivity based on the geochemistry from county geology documents and personal knowledge of MNF geologists. Geology known to have substantial sources of alkalinity was assigned low sensitivity because it could provide a reasonable level of buffering capacity to soil. Geology known to have only trace amounts of alkaline-producing minerals was rated as high sensitivity. All other geologic formations were rated as moderate based on general knowledge about the availability of moderate amounts of alkalinity in the strata (Edwards et al. 2004).

The second map data layer included in the analysis was the stream layer of the MNF. Streams were analyzed for water quality impacts from acid rain and mine drainage using the current 303d listing from the state (http://www.dep.state.wv.us). Sources of acidity were identified in the stream layer. The correlation between geology and stream water quality is strong. Where high geologic sensitivity exists on the MNF, acid rain impaired streams are typically present. Some

streams flow through areas of low sensitivity but remain impaired due to the large effect from upstream geochemistry, soil chemistry, and precipitation chemistry.

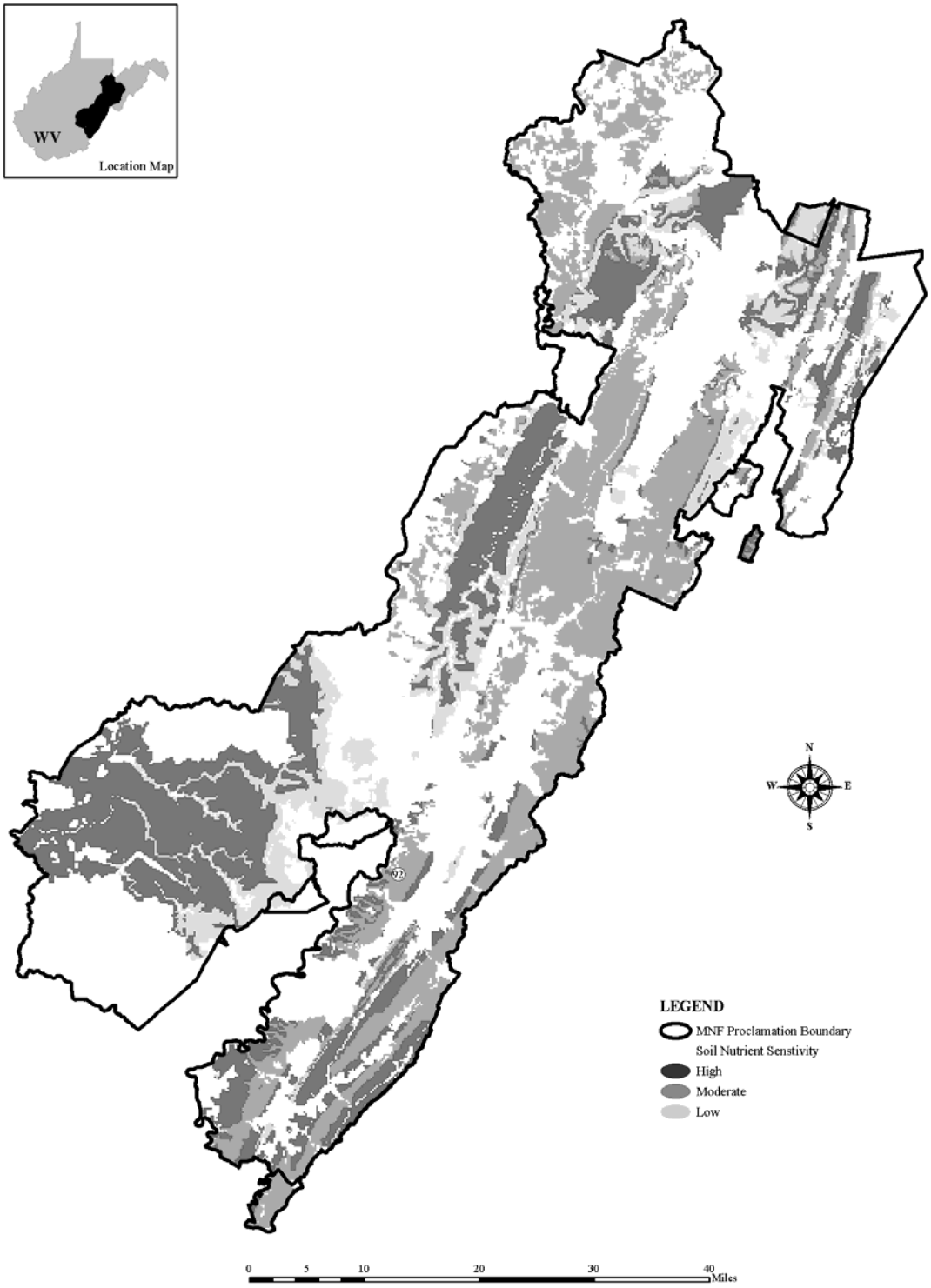
The third map data layer was SO_4^{-2} deposition across the MNF. Deposition data were generated by Dr. James Lynch at Pennsylvania State University. Areas of the MNF that received high amounts of wet SO_4^{-2} deposition rates were identified with this map layer (see Sulfate Deposition Map in the Map Packet). The combination of these three analysis layers provides an overall picture of acid deposition sensitivity across the MNF (see Figure SL-1).

In general, an area with highly sensitive geology, high rates of sulfate deposition, and acid rain impaired streams would indicate potential soil productivity concerns in the surrounding watershed. An area with moderate sensitivity, high rate of sulfate deposition, and a non-acid impaired stream may indicate an area that may not be susceptible. However this area would require an assessment of any monitoring data and a site visit by a specialist. The acid deposition sensitivity layer (Soil Nutrient Sensitivity Map) is being used at the Forest Plan revision level, the Forest-wide level for analysis, and the watershed assessment level.

Critical Loads

Ultimately, the ability to calculate an array of target sulfur and nitrogen deposition loads based on specific forest management alternatives is a goal that the Forest would like to achieve. While critical load is the amount of pollution that results in a specific harmful level of effect to the environment, a target load is chosen to reflect policy or management decisions for resource protection. In areas where critical loads have been exceeded such as acidified streams, a target load would be set as a milestone toward recovery. Currently, the Forest does not have all the necessary data to determine critical target loads for the many combinations of deposition, geology, soil, and water chemical characteristics present on Forest. Data collected within the Forest's various resource staff areas, routine monitoring programs, and data that will be collected as a result of the monitoring program set forth in Forest Plan revision will be used to evaluate and refine current conditions using the Soil Nutrient Sensitivity Map and eventually to develop target loads. The necessary stream, soil, and soil water data have been collected from a few sites on the Forest to calibrate the MAGIC (Model of Acidification of Groundwater in Catchments) model, which will be used to calculate an array of loads. Selection of critical or target loads for the many types of sites on Forest will provide a tool that land managers can use to better protect resources. Land managers can then assess how various land management alternatives might affect desired future conditions based on an array of critical loads. At the regional or national scale, policy makers can use critical loads to help determine what levels of pollutant reductions would be needed to achieve desired future conditions on larger landscape or regional scales.

Figure SL-1. Potential Soil Nutrient Sensitivity to the Effects of Acid Deposition on the Monongahela National Forest



ENVIRONMENTAL CONSEQUENCES

Resource Protection Methods

Below are the mitigation or management requirements common to all alternatives that will be used to protect soil resources. Resource protection methods come in the form of laws, regulations, policies, Forest Service Manual and Handbook direction, Regional guidance, Forest Plan direction, and Forest Plan implementation procedures.

Laws, Regulations, and Policies

Numerous laws, regulations, and policies govern the management of soil resources on National Forest System (NFS) land. National laws and regulations have also been interpreted for implementation in Forest Service Manuals, Handbooks, and Regional Guides. All management activities and facilities must comply with these laws, regulations, and policies, which are not only intended to provide general guidance for implementation, but also protection of soil resources. Some of the more influential laws, regulations, and policies governing management on federal land are referenced below.

- Forest and Rangeland Renewable Resource Planning Act (RPA) of 1974, as amended by the National Forest Management Act (NFMA) of 1976) – The NFMA directs the Secretary of Agriculture to protect and, where appropriate, improve the quality of soil, water, and air resources. The RPA requires an assessment of the present and potential productivity of the land. Regulations specify guidelines for land management plans developed to achieve the goals of the program that "…insure that timber will be harvested from NFS land only where …soil, slope or other watershed conditions will not be irreversibly damaged." The NFMA amended RPA by adding sections that stressed the maintenance of productivity, the protection and improvement of soil and water resources, and avoidance of permanent impairment of the productive capability of the land.

- Water and soil resources are also protected in order to comply with State water quality management plans and applicable provisions of the Clean Water Act of 1977 (P.L. 95-217). The Act contains direction to minimize non-point source pollution to the maximum extent that is technically and economically feasible.

In addition to this guidance, there are other laws, policies, and direction that pertain to soils management on private land and direct the National Soil Survey Program administered by the USDA Natural Resource Conservation Service. Because the Forest Service partners with other agencies, we also utilize additional laws, policies, and direction to accomplish partnership goals and objectives.

Regional Guidance

The Region 9 Soil Management Handbook (FSH 2509.18) has a threshold of 15 percent reduction in "measurable or observable soil properties or conditions, or any measurable or observable reduction in soil wetland or hydrologic function", referred to here as soil productivity

or soil quality. This measurement is applied to activity areas. System roads, trails, and administrative facilities such as campgrounds, are not included in measurements for loss of soil productivity.

Forest Plan Direction

In the 1986 Forest Plan, direction for the management and protection of soil resources occurs at three levels, Forest-wide, MP, and Appendix S. For Forest Plan revision, Forest-wide direction has been expanded to include additional goals, and a new description of desired conditions. Objectives, standards, and guidelines have also been rewritten in some instances to provide more concise and clearer direction, and better integration between soils and other resources. Some 1986 Forest Plan direction has been removed, including items that were process-oriented, or that repeated existing law or policy, or that conflicted with other resource management. Appendix S in the 1986 Forest Plan was reviewed in order to identify key management direction to carry forward into the 2006 Forest Plan. Once the direction was incorporated, there was no longer a need for Appendix S in the 2006 Forest Plan.

The principal task of the Forest Soils Program is to protect, maintain, and enhance the soil productivity of forests and rangelands. Activities in the soil program include updating inventories, assessing effects of management activities to the soil resource, planning proper mitigating measures, and monitoring the land's capability to produce goods and services sustainably.

In general, standards and guidelines are established to prevent erosion of the soil and overall loss of soil productivity from the Forest. Specifically, the standards and guidelines are designed to:

- Prevent or reduce erosion generated by management activities.
- Minimize the amount of time soils are exposed to potential weather events.
- Minimize loss of topsoil and overall management of topsoil.
- Minimize effects that land management activities have on the soil resource.
- Restore or rehabilitate disturbed soils to a level of stability and fertility so that vegetation can regrow.

Forest Plan Implementation

The 2006 Forest Plan's Forest-wide Management Direction (Chapter II) and Monitoring and Evaluation Plan (Chapter IV) will guide the protection, mitigation, and rehabilitation of the soil resource. This guidance will be used in project design to protect soils, while allowing an acceptable level of soil disturbance where appropriate. However, appropriate management of the soil resource also depends on current and site-specific information about existing physical conditions, desired conditions, and localized biophysical and socio-economic factors. These factors are not easily addressed at the programmatic level. Thus, management activities with the potential for disturbing or restoring the soil resource will also be addressed through a combination of watershed assessment, site-specific inventory, NEPA analysis, and monitoring.

Watershed Assessment – Assessments at the watershed scale can be used to identify past management history, geological considerations, soil-related concerns, general mitigation, and opportunities for resource restoration.

Inventory – Soil concerns related to erosion, sedimentation, or nutrient depletion can be identified at the watershed or project level through soil erosion sensitivity and soil nutrient sensitivity screening using Forest level mapping. Once concerns are identified, field visits are made for an Order 1 Soil Resource Inventory and/or soil and water chemical analyses.

NEPA Analysis – Proposed management activities and mitigation measures are analyzed for potential effects to the soil resource by alternative. Effects are disclosed to interested individuals, organizations, and agencies for review and comment. Site-specific design features and mitigation are carried forward into the decision document and applicable contract clauses, permits, or operating plans for the proposed project or activities. Based on field data collected, site-specific mitigation can be designed. This may include the simple application of Forest-wide direction, or it may include additional measures to protect or restore the soil resource such as siltation fences, sediment traps, alteration of proposed activities or methods, avoidance of high-risk areas, buffer extensions, leaving additional nutrient sources on site, liming, or fertilizing.

Monitoring and Evaluation – Monitoring can occur at the Forest-wide or project level to confirm that specific mitigation is occurring and that it has the desired effects. If evaluation of monitoring data shows that desired effects are not occurring, activities or mitigation can be adjusted to provide additional protection or restoration of the soil resource in the future. The Forest expects that research will advance in the area of monitoring acid deposition effects related to land management activities within the next decade. The Forest will need to be flexible in its implementation and monitoring methodologies in order to stay current with this evolving issue.

Effects Common to All Alternatives

Soil is an integral component of all national forest settings, and contributes to the quality of ecosystems. Soils have been altered in numerous locations across the Forest by both human and natural forces. Obvious and significant effects on the soil resource arise from a variety of resource management activities and public uses such as logging, mining, and utility corridors that alter the landscape. The relative amount of these activities and uses may, in some cases, vary by alternative. However, they are likely to be present to some extent in all alternatives.

General Effects - Soil Erosion and Sediment

An indirect effect of removing a soil's vegetative cover and its organic layer to create bare mineral soil is erosion, meaning soil movement. An undisturbed soil with soil layers intact and growing biomass is not highly susceptible to erosion. When the ground is disturbed in some way to expose bare mineral soil (A-horizon and lower), then soils on slopes become susceptible to raindrop impact, displacement, and overland flow with water. These forces can cause soil to move down slope, sometimes into stream channels, where it then becomes sediment and is incorporated into the bed load of the stream channel. Erosion will be considered a temporary or

short-term effect and will be estimated mainly to consider the potential risk of sediment delivery to stream channels.

Forest management activities that may affect soils include timber harvest; road construction, reconstruction, and decommissioning; prescribed fire; facility relocation and modification; fish habitat improvement; stream bank stabilization; slope stabilization; and mining reclamation. Their effects are described in greater detail below.

Timber Harvest - Effects can vary depending upon the quantity and type of timber removed, logging methods, and the setting. Generally, timber removal—and any associated roads, skid trails and slash treatments—results in adverse effects to the soil resource arising from vegetation change or removal and ground disturbance. Thinnings and selection harvests usually have lower impacts and are also evident for a shorter duration than shelterwood harvests and clearcuts. Helicopter logging does not create skid trails or yarding corridors that contribute to the soil impacts of ground-based and cable logging systems. In helicopter logging or yarding, soil disturbance is much less. Field observations and ocular estimates of MNF timber sales in 2001 (North Gauley Mountain, Marlinton Ranger District), 2004 (Dry Run Timber Sale, Cheat Ranger District), and 2005 (unpublished soil monitoring data from the Smokecamp Timber Sale, Greenbrier Ranger District) show that very little ground disturbance occurs within an activity area during timber harvesting when using helicopters. A good estimate would be less than one percent of the activity area is disturbed. Therefore, effects from this harvest method are minimal.

The majority of soil disturbance in timber harvesting activities is associated with conventional operation methods (i.e., ground-based skidding.) In conventional harvesting methods using rubber tire skidders, skid trails and/or skid roads are created in order to extract the timber. Landings are also created in order to temporarily deck the timber until it can be loaded onto trucks and hauled off-site. The percent of land disturbed is often dependent on slope of the activity area. In general, the steeper the slope the higher the road density will be in order to safely operate on that slope. A 1977 study conducted near Parsons, WV showed that the lowest measured road density of 5.6 percent occurred in a selectively cut harvest area with slopes less than 30 percent (Kochenderfer 1977). A study on the nearby Fernow Experimental Forest indicated that roads on slopes greater than 30 percent in the Haddix watershed occupied 10.6 percent of the logged area (Kochenderfer et al. 1997).

Kochenderfer et al. (1997) reported that the amount of exposed soil because of skid trails and trucking roads decreases rapidly after logging. This is because grasses and shrubs become re-established in the disturbed areas. The study measured skid and truck roads in 1987 and again five years later in 1992. The percent of disturbed area in the skid roads decreased from 6.2 percent of the logged area in 1987 to 5.1 percent in 1992. The percent of disturbed area in truck roads decreased from 4.5 percent to 3.1 percent. It is thought that practically all of the skid roads, especially in heavily cut areas, would eventually convert back to forest. However, Kochenderfer et al. (1997) recommended that water-control structures (broad-based dips, waterbars, and other mitigations in the Hydrology Report) are necessary on closed-out roads whether they are skid roads, skid trails, or abandoned system roads, because bare soil can remain on these roads even after six growing seasons.

Landings are used in both conventional and helicopter harvest systems. Helicopter landings are generally around two and a half acres in size using conventional harvest systems. It is estimated that 100 percent of landing sites have reduced soil productivity because most of the topsoil and some of the mineral soil is cleared away to create a relative flat area for stock piling logs. This loss of soil is referred to as soil displacement. Revegetation can occur on these sites very quickly if treated by seeding, mulching and fertilizing. However, soil compaction can be a problem with lasting long-term effects. Landings are often revegetated and used as wildlife openings.

Roads and Trails - Construction, reconstruction, and decommissioning can all affect the soil resource. Road construction and reconstruction are usually associated with timber harvest, facility development, utility corridors, telecommunications sites, mineral and energy development, and recreation activities. The extent of effects depends on topography, service type (will the road receive aggregate?), soils, geology, hydrology and the nature of surrounding vegetation. The effects from trails is usually somewhat less due to their smaller width, which reduces the level of soil disturbance and makes effects easier to mitigate in most cases. Road and trail decommissioning includes a variety of management actions ranging from simple closures to complete obliteration. Obliteration can often ameliorate the soil quality effects of a road or trail over the long term as the soil stabilizes, hydrologic function returns, compaction decreases and vegetation matures in former road or trail locations; however, temporary or short-term effects of soil disturbance are often greater than if the road is simply closed with properly applied mitigation measures (i.e., waterbars, dips, out-sloping).

Mineral and Energy Exploration, Development, and Reclamation – Exploration and development activities can result in both short-term and long-term effects from associated structures, vegetation clearing, soil-disturbing activities, release of pond effluent, and rehabilitation work. The effects on the soil resource vary depending largely on the scale and location of development and mineral ownership. Underground mining would have limited effects to the soil resource, while small-scale and large-scale surface mining operations typically have major effects on the soil quality of the surrounding area. As noted in the *Mineral Resources* section of this chapter, soil disturbance associated with the most common mineral activity, natural gas development is estimated at no more than 15 to 16 acres per square mile. Mining reclamation activities can also result in temporary or short-term effects to the resource, but these effects are generally no worse than the conditions being reclaimed, and reclamation results in long-term improvement to the overall site productivity, including soil productivity. In that the level of mineral exploration and development is largely driven by market forces and regulated by existing mining law, there would be little difference between the alternatives in effects on the soil resource. The inherent uncertainty also does not allow for a meaningful predictive analysis between alternatives.

Facilities and Structures – These include a broad array of physical developments and structures, such as administrative facilities, utility developments, communications sites, dams and diversions authorized under special use authorizations, and mining facilities. Usually, there are both short-term and long-term effects from structures, site clearing, and soil disturbance. These effects vary depending on the scale and nature of the development, as well as the setting. Road construction for installation and/or maintenance purposes can contribute to the impacts from the facility. In general, once an area is committed to a facility or structure, the soil

disturbed and soil productivity lost is viewed as a permanent commitment of the soil resource. The Region 9 Soil Management Handbook (FSH 2509.18) provides direction in how to account for soil disturbance of these areas.

Recreation - Activities can result in effects to the soil resource depending on recreation activity levels and soil types. Off-road and off-trail travel and dispersed camping can cause erosion, compaction, and/or ground disturbance resulting in bare mineral soil exposure, or loss of vegetation. Although all forms of travel have the potential to cause these types of impacts, effects associated with most forms of motorized travel are usually the most pronounced due to the combination of vehicle weights, widths, and their creation of continuous track lines. Off-road and off-trail vehicular traffic is currently prohibited on the Forest. Horse travel, which is not prohibited, is the second-most impactive activity on trails. Mountain biking also has the ability to cause soil disturbance that may lead to erosion and sedimentation. Volume of use also contributes to the effects. Some trails are more popular for horse use, while others are more appealing for mountain bike use. Trail access and uses are not expected to vary significantly by alternative. There are no foreseeable future plans to develop any large-scale recreation facilities or make any changes in the types of recreation allowed on the Forest. Therefore, there are no measurable differences in soil-disturbing recreation-related activities that can be analyzed by alternative.

Range Management - Livestock grazing and range improvements may result in extensive soil effects, especially on sensitive soil types and in areas where grazing is concentrated. Effects to the soil resource from grazing depend largely on the intensity and timing of forage utilization. Normally, allotment management plans require permitees to move their livestock so that they do not concentrate in sensitive areas, like meadows and riparian areas. Although there could be effects from seasonal trampling and heavy utilization of the soil, the potential for change to the soil resource is relatively slight, especially as livestock grazing only occurs on less than one percent of the entire Forest and the animal units per acre are strictly regulated. Mitigation may include developing feeding pads, water cisterns for drinking with an associated hardened pad, and fencing of riparian areas and sensitive wet soils with associated meadow habitat. All of these mitigations act to lessen soil compaction, soil disturbance, erosion and sediment production, and changes in the soil hydrology. Fertilization and liming of pastures by permitees can also help replenish nutrients lost by grazing. There is currently no expectation to change the size or amounts of the range allotments under the 1986 or 2006 Forest Plan direction under any alternative. Therefore, there are no measurable differences in soil disturbance activities that can be compared by alternative.

Watershed Improvements - A broad array of physical alterations to the riparian habitat may include stream bank and channel stabilization structures (rock gabions, rock riprap, etc.), road reconstruction (culvert replacements, road re-alignment, etc.), slope stabilization structures, and revegetation. Virtually all of the alterations require soil disturbance in order to conduct these improvements. The duration of effects from these types of structures ranges from short term to long term and also depends on the scale of the structures themselves. Generally, most improvements are relatively small and localized, and have a minor effect on the loss of soil and short-term pulses of sediment added to the riparian corridor. These structures have the beneficial effect of reducing erosion and sedimentation over the long term. Additional mitigation such as

seeding and mulching can ameliorate the short-term effects from sediment until soils are stabilized.

There will likely be opportunities to reduce soil productivity losses and soil erosion on the landscape through activities that decrease the effects of existing development and historic activities. One such activity that has that potential is road decommissioning. Although decommissioning can range from road closures to complete road obliteration and restoration, all activities would generally allow for some revegetation to occur along road prisms and cut and fill slopes. This revegetation and re-contouring would reduce the potential for soil erosion, increase hydraulic conductivity, and decrease soil compaction of existing road openings. Usually road decommissioning is a long-term benefit to soils that increases in effectiveness over time as vegetation is re-established and soil forming processes take hold. However, these opportunities will not be compared across alternative because of the uncertainty of where and when these opportunities may occur at the Forest-wide scale. They are typically and appropriately identified at the watershed or project levels.

Fish and Wildlife Habitat Improvements - A broad array of physical alterations may include vegetation manipulations (maintained wildlife openings, browse species plantings, etc.), prescribed burning, and habitat improvement structures. Structural improvements do not adversely affect the soil resource. Soil disturbance is minimal. Wildlife openings are often associated with areas previously used as log landings for timber harvest. Converting these landing areas into a wildlife opening acts to stabilize the soil and encourage vegetative growth on site. The A and O horizons of the soil are scraped off in some places and some compaction remains in the area, but overall the site is generally mitigated with minor losses of soil productivity. Waterholes result in a permanent loss of soil productivity. These areas are less than a half acre in size and add up to less than .01 percent total acreage of the entire Forest. Savannahs result in the greatest negative effect to the soil resource. The soil is greatly disturbed in the creation of a savannah. Short-term effects are the loss of the A and O horizon being incorporated into the soil profile. The site is converted into grassland. These areas can be up to 10 acres in size or more. Negative impacts may be mitigated through design and location considerations and vegetative cover plantings where possible. Other than savannahs, improvements are small and localized, and have a minor effect on the soil quality of the surrounding area. However, improvements will not be compared across alternatives because of the uncertainty of where and when these opportunities may occur at the Forest-wide scale.

Wildfire Suppression – Fire suppression activities produce effects to the soil resource both directly and indirectly. Some firefighting activities, such as mechanical fire line and safety zone construction, can result in direct, long-term effects from vegetation clearing and soil disturbance. In the case of fire line construction, these effects are usually magnified by the linear nature of the pattern of disturbance and the crossing of stream channels. This linear nature of the soil disturbance can result in routing sediment directly into a stream. This effect can be mitigated by hand constructing waterbars and small dips to disperse flow onto sideslopes. These areas can also be rehabilitated after suppression with mulching and seeding to stabilize disturbed soils. Although the risk of wildfire associated with aging timber stands could vary somewhat by alternative, the timing, location, and intensity of actual wildfires and suppression activities are unpredictable and will therefore not be included in this analysis.

Prescribed Fire –Prescribed fire is generally used in areas characterized by non-lethal or mixed fire regimes to reduce ladder fuels and restore or maintain desired vegetative conditions. In these circumstances, fire intensity, severity, and scale are generally lower and smaller, and result in less impacts of shorter duration than wildland fire events. Studies in the Southern Appalachians show that, in general, even high-intensity prescribed fire on steep slopes did not significantly increase soil movement or nutrient losses (Van Lear and Danielovich 1988.) This activity may vary by alternative; but due to the nature of prescribed fire on this Forest (see *Vegetation Management* section), it does not produce large-scale soil disturbance. If prescribed burn plans are followed and low-intensity burns typically occur as planned, then the effects would be minimal and temporary to the soil resource.

Special Uses – Special use authorizations vary greatly, from operating concessions to erecting and maintaining large facilities like transmission lines. Some of these activities have the potential for soil disturbance, others do not. The general activities associated with special uses that would affect soils—such as facility and road construction, timber removal, or recreation events—are addressed above. Individual authorizations are for localized areas, and the number, type, and location are unpredictable. Proposals would be analyzed on a case-by-case basis at the project level and would not likely vary by alternative for this analysis.

General Effects - Acid Deposition

Current investigations about long-term soil productivity are focusing on soil calcium and forest health. This is because some site-specific evidence, based on small watershed studies, indicates that calcium is being depleted from the soil in the Appalachian provinces. Forest productivity and forest species composition are often mentioned as possible concerns related to calcium losses; however, long-term monitoring of forest growth and composition, including calcium-poor sites, does not support these concerns. Estimated losses of soil calcium may be attributed to acid deposition, declining contributions of calcium from atmospheric deposition, and timber harvesting. Losses are buffered by mineral weathering in the soil and some continuing calcium deposition. Biogeochemical modeling reveals that atmospheric deposition, especially $S0_4^{-2}$, had the greatest effect on estimated soil calcium loss, while timber harvesting led to only a slight decrease in exchangeable soil calcium (Solomon et al. 2003). This study was done for the period 1950-2000 for a northern hardwood timber stand. A study in spruce-fir forest also revealed that acid deposition is a more important factor in soil acid-base relationships than timber harvesting (Hornbeck 1992).

Direct effects of timber harvesting are the removal of calcium with forest products. The magnitude of this impact depends mainly on the quantity of biomass removed and the species selected. In general, clearcut harvest that removes the entire aboveground portion of a tree (bole, leaves, and branches) removes the most calcium, while a bole-only clearcut, a thinning, or selective harvest removes incrementally less (Adams et al. 2000.)

Indirect effects may include possible changes in available or exchangeable soil calcium, changes to base saturation levels, and possible impacts on forest health, productivity, or species composition. Biogeochemical modeling suggests that losses in soil exchangeable calcium may

occur over a long period of time (Solomon et al. 2003); though plainly, atmospheric deposition is by far the most significant factor. However, actual on-site measurements do not support any change in exchangeable calcium, even with the practice of whole-tree, clearcut harvest. Research at the Hubbard Brook Experimental Forest following a whole-tree clearcut harvest in northern hardwood forest indicates no change in the exchangeable calcium in the first fifteen years (Johnson et al. 1997). Similar results were found in mixed oak forest when comparing both conventional and whole-tree harvest fifteen years after harvest (Johnson and Todd 1998). In fact, it is suggested that deep rooting reserves or non-exchangeable reserves at this mixed oak site probably replenished the exchangeable calcium reserves. More research is being conducted in this arena, and the Forest will continue to monitor findings and recommendations from the scientific community in order to apply appropriate management practices to protect the soil resource.

Direct and Indirect Effects by Alternative

Each of the alternatives has the potential to maintain, alter, or enhance the soil resource to varying degrees. Projects implemented on the Forest under any alternative would require a site-specific assessment of their potential impacts on the soil resource. Forest Plan standards and guidelines are used to help design and implement management activities so that an individual project does not exceed the established thresholds of change to the soil resource.

In general, standards and guidelines are established through consideration of the physical and chemical properties of soil and the needs for management of other resources. All of these factors vary by location across the Forest. Knowledge about the location of sensitive soils can help constrain management activities to protect the soil resource. In some cases, management decisions are made that constrain activities to levels below those allowed by established standards and guidelines to protect other resource values like aquatic or wildlife habitat, scenery, or hydrologic resources. These decisions benefit the soil resource in that it is always desirable to retain more of the natural soil or undisturbed soil on the landscape.

Individual projects are tailored to address the standards and guidelines for soil resource protection in the Forest Plan. Once established, this direction becomes a fixed expectation or criteria for project-level performance and is constraining enough to limit changes to the soil resource to an acceptable level. At the same time, standards and guidelines must also be consistent with the attainment of the established multi-resource goals and objectives stated in the Forest Plan.

Soil Erosion and Sediment

The alternatives present differences in the amounts and types of activities that would potentially occur across the landscape. Some activities would have relatively minor potential to cause noticeable change in the soil resource, while others have the potential to cause very noticeable changes. The actual impacts to the soil resource will vary according to the soil type, the topography, the extent to which the activity disturbs the soil, and the overall watershed condition. The assignment of mitigations may control the magnitude and intensity of impacts permitted across the landscape in some areas. In other areas, other factors such as the presence

of highly erosive soils, steep slopes, soil nutrient sensitive soil types, or high levels of water quality concern may play an even greater role in controlling the magnitude and intensity to the degree of soil disturbance on the landscape.

While the specific effect of an individual activity is dependent on many site-specific variables, the overall amount of various activities can be used as a gross indicator of the overall changes that would occur across the soil resource and how those would vary by alternatives. Alternatives with greater amounts of soil disturbance and road construction would, as a general rule; have a greater potential to affect soil productivity. However, system roads and other permanent type activities such as facilities are not included in soil productivity loss according to Regional Soil Quality Standards and Guidelines for estimating soil productivity analyses. These activities are viewed as a permanent commitment of the soil resource. These activities do have associated direct, indirect and cumulative effects but those effects are addressed at the site-specific project level and not at the Forest-wide level. The Roads Analysis Report for the MNF (completed January 2003) provides an assessment of how the road system on the Forest impacts the soil resource.

The following activities are compared by alternative. These activities occur across the Forest to varying degrees and have the most potential to affect soil productivity through soil disturbance and associated erosion and soil movement or loss.

Timber Harvest and Associated Activities - This grouping consists of even-aged harvest, commercial thinning, and uneven-aged harvest when referring to timber harvest. Associated activities include openings for yarding logs and other small-scale disturbances (less than one acre) related to timber removal, skid trails, skid roads, and temporary roads. While there is a wide range of potential effects due to the variability in the intensity of tree removal, generally the change is subtle and does not dominate the landscape. Temporary soil effects generally would occur from ground disturbance and potential logging residue from harvest operations. Short- and long-term effects such as changes in soil nutrient cycling (decomposition rates), changes in soil moisture and changes in soil temperature would occur from a reduction in forested cover density and a more open forested appearance.

Road reconstruction, skid trail development, and temporary road construction all result to varying degrees in soil disturbance. The Forest implements a wide variety of existing road improvement activities under the category of reconstruction. The impacts of these activities vary considerably, and may be negative or positive. Negative effects are associated with newly disturbed soil available for sediment transport, potential destabilization of slopes, and reductions in hydrological flow patterns on the landscape, potentially affecting down slope soil moisture content. Positive benefits include opportunities to address existing non-point source sediment problems, hardening of road surfaces to help reduce sediment production, and opportunities to increase flow away from road beds, minimizing the risk for road bed failure and associated economics costs in repairing roads. Partial road relocation, for example, would have long-term effects similar to road construction. Road widening can also have long-term impacts, though typically not as noticeable as relocation. Other activities—such as bridge repair, culvert replacement, or road graveling—may have minor and temporary effects during implementation, but are designed to improve soil conditions over the long term.

Road Construction – The building of new roads has the potential to create very noticeable long-term alterations in the soil resource. A number of site-specific variables such as elevation changes, soil sensitivity (erositivity rating, wetness, geotechnical characteristics), and cross slopes can influence the degree of impact. Typically road construction produces long narrow openings that allow for a transport of sediment to stream channels and an avenue for soil loss. The density of the road system affects the overall soil productivity of a given watershed. Road densities also affect hydrology as well. Road density and associated effects on the watershed are further discussed in the *Water, Aquatic, and Riparian Resources* section. Although vegetation regrowth may occur on road cut and fill slopes over time, the road prism and associated infrastructure remain unstable and need constant maintenance to minimize soil and associated sedimentation effects to the watershed indefinitely. It is assumed that an unspecified amount of construction would occur in association with timber harvest and that the amount would vary relative to harvest levels by alternative.

Alternative Comparison - Timber harvest numbers in Table SL-1 are estimates from the SPECTRUM model of maximum activity that could occur given certain management constraints (see Appendix B for modeling assumptions and application). These numbers are used for the relative comparison of alternatives, but are not intended to represent actual acres of projected activities.

Table SL-1. Maximum Potential Timber Harvest Acres by Alternative
(Annual averages of acres for the first two decades)

Activity	Alt. 1	Alt. 2	Alt. 2M	Alt. 3	Alt. 4
Maximum Potential Acres – Conventional Yarding	3,445	2,853	2,826	2,638	3,498
Maximum Potential Acres – Helicopter Yarding	2,296	1,902	1,884	1,759	2,332
Maximum Total Acres Treated	5,741	4,755	4,710	4,397	5,830

Alternative 3 would have the least amount of timber harvest over the next two decades, followed in ascending order by Alternatives 2M, 2, 1, and 4. The risk for soil productivity losses would also be the least for Alternative 3, followed in ascending order by Alternatives 2M, 2, 1, and 4, based on both total harvest acres and conventional methods used to harvest those acres. This risk is associated with harvest activities and their potential effects on soil productivity loss (see General Effects section). The basic assumption is that the more acres of timber harvest activities there are in an alternative, the more potential there is for associated soil disturbance and consequential loss of soil productivity. Overall, there is about a 33 percent difference between the highest amount of acres treated in Alternative 4 and the lowest amount treated in Alternative 3.

Harvest methods were reported separately because the effects of harvesting stands via helicopter cannot be considered on an equal basis with conventional harvesting and road construction. The SPECTRUM model has been adjusted to account for soil sensitivity concerns—such as highly erosive soils, steep slopes, excessively wet soils, and soils prone to mast wasting—by incorporating the assumption that at least 40 percent of timber harvesting would occur with

helicopter yarding, which produces very little soil disturbance. This assumption is based on past and current management trends to address other resource concerns at the site-specific level. On-site forest monitoring shows there to be less than 1 percent soil disturbance in harvested timber stands. The soil resource effects of conventional harvesting and road construction have the potential to be more extensive and long term due to increased soil disturbance, and this was modeled to occur in the remaining 60 percent of treated acres.

As mentioned in the Issues and Indicators section, acres of soil disturbance associated with timber harvest is further analyzed in relation to severe erosion potential. An overall assessment of the Forest shows that approximately 80 percent of the Forest has soil types that are rated severe for potential erosion from disturbed soils (NRCS-NASIS database). This uniformity can be explained by the overall consistency of soil types from the sedimentary geology on the Forest and the K factor (measure of erodibility) of the soils formed in this type of geology. On the ground experience, however, has shown that there is considerable variability of erosion potential for soils with a severe rating. There are some soil types on the Forest, such as those that form over Mauch Chunk geology, that are more erodible than others. This personal knowledge is used when planning site specifically at the project level. In addition, some harvest treatments and associated road construction would likely occur in areas with low erosion potential, which would greatly reduce effects.

Because such a high percentage of the Forest is rated with severe soil potential, the acres treated under each alternative would also occur on a high percentage of these soils. Indeed, the percentage of the suitable land MPs (2.0, 3.0, 4.0, 4.1, and 6.1) that occur on soils with severe erosion potential is fairly constant across all of the alternatives, but the amount of acres potentially treated varies. With the highest levels of predicted timber harvest and associated activities (Table SL-1), Alternative 4 would likely have the greatest potential for long-term, short-term, and temporary risk of erosion on soils with severe potential, followed in descending order by Alternatives 1, 2, 2M, and 3.

The risk of erosion needs to be put in proper context. All soils have the potential to erode and move, and soils rated as “severe” have a relatively high potential, all other considerations being equal. Whether and how much the soil actually erodes and moves is influenced by a number of factors. Some of these factors—like climate, topography, and soil type—are beyond the control of the Forest. However, the Forest can influence soil erosion and sedimentation, largely through management activities that disturb and expose soils and that provide conduits (roads, skid trails/roads, fill slopes) for the soil to move downhill toward streams. Forest managers can control these factors to a large extent through practices such as helicopter logging, designated skid trails/roads, stream channel buffers, silt dams, geotextiles, seeding and mulching, and even avoidance in extreme cases. Areas with severe erosion potential can be and have been managed successfully—i.e., without long-term impacts—but that management often involves additional mitigation to protect the soil resource and site-specific layout design to avoid high-risk areas. That mitigation can vary widely depending on local conditions but typically includes some combination of management requirements (as seen in Table SL-2), site-specific mitigation measures determined through project-level analysis, and timber sale contract clauses. These practices are periodically monitored for implementation and effectiveness and can be adjusted as

needed for better management in the future. The Forest has an adequate range of mitigation in place to protect ALL soils on the Forest, and that mitigation has been used effectively in the past.

Because mitigation potential is determined spatially on a site-specific basis, it cannot be predicted accurately in a programmatic analysis. However, it is worth emphasizing that, under all alternatives, management standards and guidelines would be used to address potential effects to soils. The Forest-wide mitigation measures in the 2006 Forest Plan would include those listed in Table SL-2.

Table SL-2. Forest-wide Direction for Soil Resource Protection - Soil Disturbance

Standard	SW03	Disturbed soils dedicated to growing vegetation shall be rehabilitated by fertilizing, liming, seeding, mulching, or constructing structural measures as soon as possible, but generally within 2 weeks after project completion, or prior to periods of inactivity, or as specified in contracts. Rip compacted sites when needed for vegetative re-establishment and recovery of soil productivity and hydrologic function. The intent is to minimize the time that soil is exposed on disturbed sites or retained in an impaired condition.
Standard	SW04	Erosion prevention and control measures shall be used in program and project plans for activities that may reduce soil productivity or cause erosion.
Standard	SW05	Maintain at least 85 percent of a vegetation management activity area in a non-detrimentally disturbed condition. Existing system roads and trails, and other administrative facilities within the activity area, are not considered detrimentally disturbed conditions when assessing compliance with this standard.
Standard	SW06	Severe rutting resulting from management activities shall be confined to less than 5 percent of an activity area.
Standard	SW07	The use of wheeled and/or tracked motorized equipment may be limited on soil types that include the following soil/site area conditions: a) Steep Slopes (40 to 50 percent) – Operation on these slopes shall be analyzed on a case-by-case basis to determine the best method of operation while maintaining soil stability and productivity. b) Very Steep Slopes (more than 50 percent) – Use is prohibited without recommendations from interdisciplinary team review and line officer approval. c) Susceptible to Landslides – Use on slopes greater than 15 percent with soils susceptible to downslope movement when loaded, excavated, or wet is allowed only with mitigation measures during periods of freeze-thaw and for one to multiple days following significant rainfall events. If the risk of landslides during these periods cannot be mitigated, then use is prohibited. d) Soils Commonly Wet At Or Near The Surface During A Considerable Part Of The Year, Or Soils Highly Susceptible To Compaction. Equipment use shall normally be prohibited or mitigated when soils are saturated or when freeze-thaw cycles occur.
Standard	SW09	Winter logging is allowed but may only be used where it will meet Forest-wide soil and water quality standards.
Guideline	SW10	Inventory the soil resource to the appropriate intensity level as needed for project planning and/or design considerations.
Guideline	SW11	Soil stabilization procedures should take place as soon as practical after earth-disturbing activities are completed or prior to extended periods of inactivity. Special revegetation measures may be required.
Guideline	SW12	Use Forest-wide soils map(s) and county soil survey report interpretations to help determine soil characteristics and protection needs.

Guideline	SW14	Mulch should be applied on severely eroded areas, or areas with high potential for erosion, such as new road cut and fill slopes.
Guideline	SW15	Topsoil should be retained to improve the soil medium for plant growth on areas to be disturbed by construction. Topsoil should be salvaged from an area during construction and stockpiled for use during subsequent reclamation, or obtained from an alternate site. On some areas, the addition of soil material may be needed to obtain vigorous plant growth. Soil to be used for this purpose should have chemical tests made to determine its desirability for use.
Guideline	SW16	Where the removal of vegetative material, topsoil, or other materials may result in erosion, the size of the area may be limited from which these materials are removed at any one time.
Guideline	SW17	During watershed or project-level analysis, incorporate soil protection or improvement into project planning through an awareness of: a) Soil, geology, and landform conditions; b) The inherent capability of the soils involved; and c) The degree and duration of soil disturbance.
Guideline	SW18	Topsoil or substitute materials used in reclamation should consist of friable soil reasonably free of grass, roots, weeds, sticks, stones, or other foreign material.
Guideline	SW19	Management activities that may result in accelerated erosion and loss of organic matter should have one or more of the following practices applied to mitigate potential effects: a) Limiting mineral soil exposure, b) Appropriately dispersing excess water, c) Ensuring sufficient effective groundcover, d) Stabilizing disturbed soils through revegetation, mulching, or other appropriate means, e) Preventing or minimizing excessive compaction, displacement, puddling, erosion, or burning of soils, and f) Preventing or minimizing the initiation or acceleration of mass soil movement (e.g., slumps, debris flows, or landslides).

The range of direction and mitigation described above should be more than adequate to address soil resource concerns at the project level. Also, a well-defined monitoring plan of implementation has been designed to track and verify predicted effects, and allow specialists to adjust input and mitigation needs for future projects. If monitoring shows that the direction is inadequate, adjustments can be made through Forest Plan amendments and/or changes in management practices.

Acid Deposition

Acid deposition does not vary by alternative. It is a phenomenon that exists across the Forest and begins as an air resource concern. But over time this phenomenon has affected the water resource and aquatic habitat, and recent research has shown that it can also affect soil productivity and quality in certain types of nutrient-poor geologies. The measurable item that does vary by alternative is land allocation and MP in areas assessed to be highly sensitive to the effects of acid deposition. Forty-one percent of the total acreage on the Forest is considered to be of high risk to acid sensitivity. Tables SL-4 through SL-7 show the distribution of those high-risk acres by Management Prescription (MP) for each alternative.

Table SL-3. High-Risk Acid Sensitive Soils by MP for Alternative 1

Management Prescription	Acres of High Acid Sensitivity	Total Acres	% High Acid Sensitivity within MP	% High Acid Sensitivity of Total NF acres
MP 2.0	12,600	13,700	92%	1%
MP 3.0	52,000	137,000	38%	6%
MP 4.0	400	440	91%	0%
MP 5.0	48,300	78,700	61%	5%
MP 6.1	96,800	284,400	34%	11%
MP 6.2	52,500	124,500	42%	6%
MP 6.3	43,100	136,100	32%	5%
MP 7.0	900	1,100	82%	0%
MP 8.0	68,300	130,500	52%	7%
Not assigned	900	9,700	9%	0%

Alternative 1 - The MPs with the highest percentages of high acid sensitivity land are 2.0 (92%), 4.0 (91%), and 7.0 (82%). Together, these areas only comprise about 1 percent of the total NFS land on the Forest. The MPs with the next highest percentages are 5.0 (61%), 8.0 (52%), and 6.2 (42%), all of which would have little or no soil disturbance related to timber harvest or road construction. The lowest percentages fall within MPs that have land that are suitable for timber production: 3.0 (38%), 6.1 (34%), and 6.3 (32%). There are an estimated 148,800 total acres of high acid-sensitive soils in MPs 3.0 and 6.1.

Table SL-4. High Risk Acid Sensitive Soils by MP for Alternative 2

Management Prescription	Acres of High Acid Sensitivity	Total Acres	Percent High Acid Sensitivity within MP	% High Acid Sensitivity of Total NF acres
MP 3.0	68,400	196,900	35%	7%
MP 4.1	85,800	155,700	55%	9%
MP 5.0	48,300	78,700	61%	5%
MP 5.1	21,700	27,700	78%	2%
MP 6.1	89,000	286,600	31%	10%
MP 6.2	36,900	97,500	38%	4%
MP 8.0	24,600	73,600	33%	3%

Alternative 2 - The MPs with the highest percentages of high acid sensitivity land are 5.1 (78%), 5.0 (61%), and 4.1 (55%). MPs 5.1 (Recommended Wilderness) and 5.0 (Designated Wilderness) would have no soil disturbance related to Forest-initiated timber harvest or road construction activities. Although MP 4.1 (Spruce Restoration) has a minor amount of land that is suitable for timber production, most of the high-elevation land in this MP with spruce and spruce-hardwood ecosystems would not be considered suitable timberlands and would receive very little disturbance from harvest or road construction related activities. These high-elevation areas likely have some of the highest concentrations of acid deposition on the Forest. Two of the lowest percentages fall within MPs that have land that is suitable for timber production: MP 3.0

(35%) and MP 6.1 (31%). There are an estimated 157,400 total acres of high acid-sensitive soils in MPs 3.0 and 6.1.

Table SL-5. High Risk Acid Sensitive Soils by MP for Alternative 2 Modified

Management Prescription	Acres of High Acid Sensitivity	Total Acres	% High Acid Sensitivity within MP	% High Acid Sensitivity of Total NF acres
MP 3.0	69,200	195,100	35	8
MP 4.1	85,200	154,500	55	9
MP 5.0	48,300	78,700	61	5
MP 5.1	21,700	27,700	79	2
MP 6.1	87,500	277,600	32	10
MP 6.2	40,200	106,800	38	4
MP 8.0	26,000	76,500	34	3

Alternative 2 Modified - The MPs with the highest percentages of high acid sensitivity land are MPs 5.0 (61%), 5.1 (78%), 4.1 (55%). MPs 5.1 (Recommended Wilderness) and 5.0 (Designated Wilderness) would have no soil disturbance related to Forest-initiated timber harvest or road construction activities. Although MP 4.1 (Spruce Restoration) has a minor amount of land that is suitable for timber production, most of the high-elevation land in this MP with spruce and spruce-hardwood ecosystems would not be considered suitable and would receive very little disturbance from harvest or road construction related activities. These high-elevation areas likely have some of the highest concentrations of acid deposition on the Forest. Two of the lowest percentages fall within MPs that have land that is suitable for timber production: MP 6.1 and 3.0. There are an estimated 156,700 acres of high acid-sensitive soils in MPs 3.0 and 6.1.

Table SL-6. High Risk Acid Sensitive Soils by MP for Alternative 3

Management Prescription	Acres of High Acid Sensitivity	Total Acres	Percent High Acid Sensitivity within MP	% High Acid Sensitivity of Total NF acres
MP 3.0	57,300	183,400	31%	6%
MP 4.1	46,400	90,100	51%	5%
MP 5.0	48,300	78,700	61%	5%
MP 5.1	40,300	99,400	41%	4%
MP 6.1	50,600	177,900	28%	6%
MP 6.2	108,500	225,900	48%	12%
MP 8.0	23,200	60,600	38%	3%

Alternative 3 - The MPs with the highest percentages of high acid sensitivity land are 5.0 (61%), 4.1 (51%), and 6.2 (48%). MPs 5.0 (Designated Wilderness) and 6.2 (Backcountry Recreation) would have little or no soil disturbance related to Forest-initiated timber harvest or road construction activities. Although MP 4.1 (Spruce Restoration) has a minor amount of land that is suitable for timber production, most of the high-elevation land in this MP with spruce and

spruce-hardwood ecosystems would not be considered suitable and would receive very little disturbance from harvest or road construction related activities. These high-elevation areas likely have some of the highest concentrations of acid deposition on the Forest. Two of the lowest percentages fall within MPs that have land that are suitable for timber production: 3.0 (31%) and 6.1 (28%). There are an estimated 107,900 total acres of high acid-sensitive soils in MPs 3.0 and 6.1.

Table SL-7. High Risk Acid Sensitive Soils by MP for Alternative 4

Management Prescription	Acres of High Acid Sensitivity	Total Acres	Percent High Acid Sensitivity within MP	% High Acid Sensitivity of Total NF acres
MP 3.0	72,900	202,900	36%	8%
MP 4.1	106,600	199,800	53%	12%
MP 5.0	48,300	78,700	61%	5%
MP 5.1	0	0	0	0%
MP 6.1	98,400	310,300	32%	11%
MP 6.2	23,800	51,000	47%	3%
MP 8.0	24,600	73,600	33%	3%

Alternative 4 - The MPs with the highest percentages of high acid sensitivity land are 5.0 (61%), 4.1 (53%), and 6.2 (47%). MPs 5.0 (Designated Wilderness) and 6.2 (Backcountry Recreation) would have little or no soil disturbance related to Forest-initiated timber harvest or road construction activities. Although MP 4.1 (Spruce and Spruce-Hardwood Restoration) has a minor amount of land that is suitable for timber production, most of the high-elevation land in this MP with spruce and spruce-hardwood ecosystems would not be considered suitable and would receive very little disturbance from harvest or road construction related activities. These high-elevation areas likely have some of the highest concentration of acid deposition on the Forest. Two of the lowest percentages fall within MPs that have land that are suitable for timber production: 3.0 (36%) and 6.1 (32%). There are an estimated 171,300 total acres of high acid-sensitive soils in MPs with suited timberlands.

Summary – For all alternatives, the areas on the Forest with the highest sensitivity to acid deposition and potential nutrient loss tend to fall in those MPs where little or no regulated timber harvest or road construction would occur. MPs 5.0, 5.1, 6.2, and large portions of MPs 4.1 and 8.0 would provide widespread protection related to the effects of acid deposition by greatly reducing the potential for soil disturbance and removal of soil nutrients.

Alternative 4 would have the most acid-sensitive acres in MPs 3.0 and 6.1, followed by Alternatives 2, 2M, 1, and 3. However, the areas on the Forest with the lowest sensitivity to acid deposition and potential nutrient loss tend to fall in those MPs (3.0, 6.1) where regulated timber harvest or road construction could occur. The relatively low percentages of high sensitivity areas mean that there should be a relatively high percentage of land to manage without potentially affecting soils that are highly sensitive to acid deposition and nutrient loss. On NFS land within MPs 3.0 and 6.1 that is determined to be highly sensitive to acid deposition, additional mitigation would be applied to reduce the potential for soil nutrient loss. This mitigation could include any

combination of the management requirements shown in Tables SL-2 and SL-7, as well as site avoidance, which is known to be 100 percent effective.

Table SL-8 shows the Forest-wide management direction of the 2006 Forest Plan that specifically addresses acid deposition and soil nutrient loss concerns.

Table SL-8. Forest-wide Direction for the Soil Resource - Acid Deposition

Standard	SW08	Management actions that have the potential to contribute to soil nutrient depletion shall be evaluated for the potential effects of depletion in relation to on-site acid deposition conditions.
Guideline	SW10	Inventory the soil resource to the appropriate intensity level as needed for project planning and/or design considerations.
Guideline	SW12	Use Forest-wide soils map(s) and county soil survey report interpretations to help determine soil characteristics and protection needs.
Guideline	SW13	Consider liming soils with a surface pH of less than 5.5 on seeding projects, except where there is an objective to maintain acidic ecosystems.
Standard	TR05	Whole-tree yarding shall be prohibited where site-specific soil inventories determine the need for on-site nutrient retention. Whole-tree yarding may be allowed elsewhere based on site-specific management objectives.

On a site-specific basis, there currently is a range of mitigation options available that the Northeastern Research Station has developed for land managers and other researchers have proposed (Horsely et al 2000; Hornbeck 1992; Federer et al. 1989). One expensive but potentially effective option may be watershed-scale liming. Also, adjustments to harvest methods and silviculture prescriptions can reduce potential effects. Longer rotation ages and longer periods between harvest entries can be considered in areas of concern.

As noted above, 2006 Forest Plan direction for soil erosion/disturbance (see Table SL-2) also has beneficial mitigating effects on potential effects from acid deposition/soil nutrient loss. The less soil is disturbed; the more potential there is for nutrients to remain on site. This is why helicopter logging is viewed as a viable means to harvest in the high sensitivity areas.

CFR 219.14 states that land is not suited for timber production if "technology is not available to ensure timber production from the land without irreversible resource damage to soil productivity, or watershed conditions." It has been suggested that the Forest should remove land from the suitable timber base that is mapped as highly sensitive to acid deposition because harvest-related activities would cause soil nutrient losses that would irreversibly damage soil productivity. The Forest took a hard look at this regulation and determined that removing mapped high acid sensitivity areas from the suitable timber base is not appropriate at this scale or time for the reasons listed below.

The acid sensitivity mapping was done at the Forest-wide scale, based on broad geologic patterns rather than soil types. Past inventories have shown that soil types can vary greatly within any given area, including areas identified as highly sensitive to acid deposition. In order to

determine the level of concern related to soil nutrient depletion, soil types and chemistries need to be evaluated site-specifically. The sensitivity map will be validated as site-specific information is gathered.

- The range of management direction and mitigation measures described above should be more than adequate to address soil resource concerns at the project level. The technology exists to mitigate soil nutrient losses and to avoid irreversible damage to soil productivity. The same technologies and mitigation measures have been applied successfully elsewhere on the Forest to address soil erosion and water quality concerns.

- If inventories show that site-specific soil buffering capacity is depleted to the point that the land is unsuited for timber production, it can be removed from the suited base. Land can be designated unsuitable by re-assigning its suitability classification in the timber stand database. This approach would be the same as the one used now to re-assign stands based on slope steepness, inaccessibility, or lack of regeneration potential. These areas would likely be small inclusions within larger areas of suitable land.

- Monitoring for acid deposition (see Chapter IV, 2006 Forest Plan) will track predicted effects and allow specialists to adjust planning and mitigation needs for future projects. If over the life of the plan monitoring shows that direction is inadequate, adjustments can be made through Forest Plan amendments or changes in management practices.

Cumulative Effects

The cumulative effect of applying standards and guidelines and any other additional measures applied would be to keep effects from management activities on the soil resource small in extent and short term or temporary in duration.

Soil Erosion and Sediment

Soil productivity losses for cumulative effects are not calculated for activities being conducted on adjacent private land. Obtaining these numbers would be difficult due to the variability in landowner activities and the absence of any State-wide databases documenting soil disturbance. The Forest is aware that private land activities include timber harvesting, skid road development, grazing, agriculture activities, and residential disturbances that can reduce soil productivity. All of these activities contribute to the overall cumulative effect of decrease in soil productivity within a watershed, but the degree of effect is not known.

In areas of interspersed ownership within NFS land, there is potential for combined effects to the soil resource from Forest activities and those on other ownership land. Development and timber harvest on private land adjacent to the Forest are often accomplished with different objectives than on public land. Harvest types vary on commercial private timberland, and harvest levels generally tend to increase as federal timber supplies decrease, given stable or improving market conditions. In that these harvests may increase with reduced levels of timber sales on NFS land, the potential effects associated with this development are likely to be highest under Alternative 3, and lowest under Alternative 4.

Another recent development trend is the conversion of adjacent agricultural land to rural residences. Private land development trends generally run parallel to national economic trends, and increased with the strong economy in the late 1990s. The development of private land has affected the overall soil quality within watersheds with mixed ownership by decreasing the soil quality and overall soil productivity of the watershed. This development includes utility lines, access roads, timber harvests, residences, and business structures. Some homeowners remove all or some of their trees to provide views. Public desires to live in a rural, mountain environment have resulted in urbanization of some adjacent ownership. Development of agricultural land to rural residences can result in pastoral landscapes changing to rural or, in higher density developments, near-urban landscapes with an associated increase in adverse effects to the soil resource. In some areas, summer home developments are defining the Forest boundaries. These effects are likely to vary under any alternative with the national economy.

Acid Deposition

Cumulative effects are the impact of past, present, and foreseeable future actions, which in this case includes consideration of early land use (forestry and agriculture); long-term changes in atmospheric deposition (SO_4^{-2}, NO_3^- and particulate matter); and future land uses. Early land use information dates to the late 1800s and early 1900s. Future harvesting can be considered for about a 50-year time frame. It is hoped that changes in air quality will continue to improve, and they are expected to improve under current regulations. However, recent modeling predictions show that even with current regulations, some streams would continue to acidify. These predictions also show that chronically acidified streams may not recover after 100 years, even if acidic inputs reach zero (Sullivan and Cosby 2004). Drought and repeated defoliations may also be critical but unpredictable factors, given their role as pre-disposing factors in soil calcium related forest health issues. In other words, this is a classic cumulative effects concern that also points out the complexity and difficulty of measuring environmental changes. For example, while elevated levels of carbon dioxide and nitrite may increase forest productivity, ozone may decrease it. Recent modeling indicates that intact forests may show relatively little evidence of altered growth since pre-industrial times, despite substantial changes in their physical and chemical environment (Ollinger et al. 2002).

Mitigations can be used to delay or temporarily abate the effects of acid deposition but liming of both streams and terrestrial ecosystems is not a permanent solution. Although limestone treatment can alter chemical and biological conditions in a stream so that aquatic habitats are present, the loss of base cations from watershed soils will continue as long as elevated acidic deposition continues and SO_4^{-2} persist in the soil. In a 30-year retrospective look at soil characteristics at specific sites on the Allegheny Plateau, Bailey et al. (2005) discovered that soils at the sites that formed from the underlying Pottsville geology had significant losses of calcium and magnesium that could not be accounted for in biomass accumulation. The only explanation to account for the additional loss of the macronutrients was the leaching and transport of those nutrients off-site. This new evidence may further influence scientists and land managers to believe that acid deposition can have a cumulative effect on the overall long-term productivity of soils. Current data sets from 2003 and 2004 on the Forest further support such conclusions. Eventually the magnitude of potential recovery will be limited by both the

magnitude of reductions in sulfur deposition and the magnitude of cumulative long-term damage due to base-depletion in watershed soils (Webb 2004).

Acid deposition is a recognized concern for the Forest. The relationships between air, water and soil chemistry are not always clear; however, science has shown links and associated effects. The results from Forest stream monitoring sites are supported by the acid sensitive geology classification developed by combining data from the US Geological Survey with information on rates of acid deposition from the 2002 Southern Appalachian Mountain Initiative Report (Grim and Lynch 2004). That is, water chemistry monitoring on the Forest indicates a link between poor water chemistry buffering in aquatic systems and contributing watershed areas dominated by geologies classified as higher acid sensitivity, and in some cases dominated by a combination of moderate and higher acid sensitive geologies (Edwards et al. 2004). Soil productivity monitoring is providing additional information that will lead to the ability to model long-term cumulative effects in watersheds. This information will ultimately help land managers answer questions about the potential long-term effects of management activities in highly sensitive areas, and the Forest's ability to achieve future desired conditions.

Management Implications

Implementing Forest programs and activities on sensitive soils is a matter of risk management. The risk to soils cannot be fully assessed at the Forest-wide scale, as we do not yet have the site-specific data needed to appropriately make such an assessment over such a large area. Forest scale mappings of soil erosion potential and acid-sensitive geologies are helpful indicators of relative risk, but this broad-scale and unconfirmed information is inappropriate to use for management prescription assignments, suitability determinations, or project-level decisions. The maps simply cannot account for the variations of soil properties and inherent risk that occur at the site level.

Forest-wide management direction has been designed to provide a range of tools and options to help land managers address risk to soils. However, the magnitude and type of risk still need to be assessed at the project level, based on site-specific soil conditions and proposed activities, before the appropriate tools and options can be determined and applied. Soil Standard SW08 and Guideline SW10 direct land managers to collect the appropriate level of soil information at the project level to help assess risk.

Risk assessments for soils can lead to various management implications, including adjustment of management activities or the addition of site-specific mitigation. For example, timber harvest practices can be modified to take into account areas with low Ca:Al molar ratios. Harvest methods affect the nutrient cycling of the forest floor differently (Elliott and Knoepp, 2005). Methods such as whole-tree harvesting that remove excess organic material have more detrimental effects on nutrient availability than stem-only harvests that leave organic material (branches, leaves, tree crowns) at the harvest site (Elliott and Knoepp 2005). Short harvest rotations also have shown decreases in soil base cations due to the lower accumulation of organic matter and higher soil disturbance (Grigal 2000). Likewise, soil-disturbing activities, including skidding and log yarding, decrease soil productivity by removing soil organic matter and

compacting the soil (Berger et al. 2004). Thus, the Ca:Al molar ratio can be used to guide the placement of soil-disturbing activities and determine harvest method and rotation length.

The majority of tree roots occur within 90 centimeters of the surface of the soil, with feeder roots in the upper 60 centimeters (McDaniel 1997; Oettinger 2005). The upper B horizons of the some soils sampled on the Forest were above 60 centimeters in the zone of the feeder roots. The upper B horizon chemistry also has been correlated most strongly with foliar chemistry in sugar maple (Bailey et al. 2004). Therefore, the upper B horizon data can be used for making management recommendations as well.

Because the majority of the base cations in a watershed come from litter fall, soil disturbance and litter removal can be limited in areas of high risk for cation depletion. Harvest methods can leave woody debris and slash material on site to augment nutrient and organic matter input (Mann et al. 1988). Whole-tree harvesting can be replaced by stem-only or sawlog harvesting. An effective way to preserve organic matter on the soil surface is by helicopter or skyline logging. On average, helicopter and skyline logging disturb only 2.5 percent of a site compared to 10 percent or greater for more conventional harvest methods (Grigal 2000).

Harvest rotations in areas of high risk can be extended in order for the base cations in the soil to be replenished (Blanco et al. 2005). Longer rotations have higher percentages of base cation return (Blanco et al. 2005). Soil disturbance can be prohibited or limited on landscape positions that have higher Ca:Al molar ratios. For landscape positions with low Ca:Al ratios--such as the shoulders, benches, and back slope positions--the mitigation costs for forest productivity may be high. Because forest productivity is at the highest risk on these positions, they can be the best places to place skid roads and log landings, because further disturbing these areas would have less effect on productivity than detrimental disturbance on more productive sites. The positions with lower risk tend to have better potential for vegetative growth, and therefore, the soil should not be disturbed (Mann et al. 1988, Grigal 2000).

Due to the variability of the soil conditions across the Forest, site-specific management recommendations cannot be made without a site-specific risk assessment. Although the soil chemistry data set for the Forest is increasing, the density of sampling is not yet sufficient to use the information for project-level decisions. More soil samples will likely need to be taken within project boundaries, with an adequate sample density. Soil sampling can be used in cumulative effects analyses, as the samples indicate past effects and current conditions, and the sampling data can also be used in project design and mitigation to help reduce future impacts. The revised Forest monitoring plan (2006 Forest Plan, Chapter IV) incorporates the probability for such sampling.

In general, areas with a high density of samples that show a moderate or high risk to soils can apply a higher level of mitigation to maintain soil productivity, such as helicopter or sky-line logging. Also, areas with a high density of samples at high risk can be used for placement of skid roads and log landings. On particularly high-risk sites, the Forest has the ultimate option of avoiding management-related disturbance, shifting project activities to safer locales, and removing the site from the suitable timber base.

A possible mitigation for these high risk areas is liming. There have been several research projects focusing on the liming of forest soils. However, the results from these studies have been mixed and many could not be replicated (Rengel 2003). If liming is used for mitigation, there are considerations that should be taken into account. Pelletized lime and limestone sands are the only products that can currently be used in ground spreading equipment (Mizel 2005). The liming materials that have worked the best in the studies have been dolomitic limestone (Rengel 2003), and coarse limestone sands have been found to be more cost efficient than pelletized lime (Mizel 2005). Detrimental effects of liming forest soils have been noted as well. In some studies, liming has been seen to cause leaching of organic carbon and nitrogen from the soil due to increased microbial activity (Rengel 2003). Although liming is a possible mitigation for high risk soils, due to the associated risks and unknowns, more research is likely warranted to help us effectively answer the how, when and where questions related to appropriate application.

The results of ongoing research efforts, both on and off-Forest, will likely play a role in future land management. These findings should provide additional information on the entire issue of soil risk management, ranging from monitoring protocol to mitigation methods. In the meantime, the Forest has direction in its 2006 Forest Plan that is broad and flexible enough to mitigate effects from current management activities and adjust to new science as it becomes available.