Post Harvest Evaluation of Best Management Practices for the Prevention of Soil Erosion in Virginia

by

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(ABSTRACT)

Poor harvesting practices can accelerate soil erosion and decrease water quality and site productivity. Forestry Best Management Practices (BMPs) were developed to protect water quality, primarily by minimizing erosion during and after timber harvests. Although properly employed BMPs mitigate against the immediate potential for soil loss, little information exists regarding their long-term effectiveness.

Since 1993, the Virginia Department of Forestry (VDOF) has conducted random water quality audits on forest harvesting operations. The VDOF will recommend remedial BMPs immediately if there is an active water quality law violation, and these recommendations are usually obviously clear to all parties. However, the potential for water degradation is more controversial and debates can arise over these recommendations.

The VDOF, as in most states, does not have the resources to make visits to post harvest sites over time. Therefore, it is imperative that the BMPs employed at the closeout of the timber harvest be sufficient to ensure erosion control until the site has recovered, yet, BMP evaluations should represent real or potential problems.

This study was undertaken to provide a quantitative analysis of erosion rates over time on VDOF random audited harvest sites and to identify key factors of erosion rates for log decks, skid trails, access roads, harvest areas, and stream crossings within each of Virginia's physiographic regions. A secondary objective was to provide a greater level of decision support for VDOF field staff, through the identified key factors which would indicate potential problem areas of erosion and water quality degradation particularly from logging activities and temporary roads.

To better understand the primary causes of erosion over time the Dissmeyer and Foster Universal Soil Loss Equation (USLE) was used to establish quantitative erosion rates which officials can use to focus BMP recommendations. Such a decision support system for field staff, based on quantifiable erosion estimates, provides a proactive targeted prevention assessment prior to the development of actual water pollution problems.

Analyses of logged tracts throughout Virginia revealed that estimated erosion rates were not statistically significant between physiographic provinces as well as VDOF audit classifications. Timber access roads were the greatest source of erosion in the Piedmont and Mountains, while harvested areas were the largest identified erosion area in the Coastal Plain, based upon the disturbance categories ratio to the total tract area.

Estimated erosion rate trends over time indicated that the majority of disturbance categories were essentially recovered between eight to ten years after harvest. Further, disturbance categories in the Coastal Plain recovered faster than the other province. Erosion rates could not be explained by the year since harvest, since numerous variables interact to cause erosion.

Overall predicted erosion rates and VDOF audit classifications of problems did not have consistent agreement. This indicates the need for additional calibration of VDOF ratings and perhaps the establishment of more quantifiable BMP inspection criteria.

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1. Introduction

Forestry Best Management Practices (BMPs) are techniques or methods used by foresters and loggers to control erosion from silvicultural activities. Forestry BMPs work in two ways; 1) prevention measures such as planning, policy, and management that avoid problems and 2) in order to control problems, reduction measures which usually involve active physical practices that are applied to the land as an integral part of silivculture activity (USEPA, 1993). For example, when constructing an access road, BMPs include 1) proper planning for road layout and design, and 2) road construction BMPs such as water turnouts, broad-based dips, and rock cover.

BMP requirements will vary from site to site. BMPs range in size, function, and applicability for each phase of silviculture, from site preparation to access road closeout. The lack of adequate BMPs or their misapplication can result in erosion and possible sedimentation, which causes water quality degradation. Sedimentation of surface waters, as a result of timber harvesting, has been a water quality concern for over 100 years in the southeastern United States.

In Virginia, BMP implementation is quasi-regulatory, because BMPs are not mandatory unless obvious water quality degradation has taken place. In 1993, the Virginia Department of Forestry (VDOF) was given the responsibility to inspect harvesting operations for water quality degradation. The VDOF officials are authorized to specify BMP requirements where water quality violations due to silvicultural activities take place. However, most audits of timber harvest sites also focus on the potential for sedimentation, by conducting subjective estimates of what might happen without BMPs. When VDOF officials determine a potential for water quality pollution, without an objective quantitative analysis, their decisions can be controversial with the landowner or logging contractor, since water pollution has not actually occurred.

In Virginia, timber harvesting operations are inspected through two different processes. The first inspection process is performed at the local level by VDOF personnel. This equates to roughly 4,000 site visits annually throughout the state. VDOF personnel complete the harvest inspection form, which evaluates tract information such as the type of harvest, future land use, regeneration, and other pertinent information. In order to facilitate water quality protection the form has a “BMP/Water Quality Law Information” section, which provides information regarding potential for water quality problems or ongoing water quality problems at the harvesting site[1]. If any water quality impacts are occurring, or if there is a perceived potential for water quality problems as a result of operations, then a Notice of Required Action (NORA) is issued to the logger/landowner. The logger/landowner is encouraged to implement the BMP recommendations from Virginia’s BMP manual in conjunction with best professional judgment for controlling erosion. If the problem is not remedied continued water quality impairment results, then the VDOF forester can issue a Stop Work Order to the logger/landowner. Stop Work Orders typically occur for severe infringements on water quality, such as skidding through a creek.

A second type of harvesting inspection process occurs whereby the VDOF performs a random biannual audit of 30 harvested sites throughout the state, examining for water quality law violations and BMP implementation effort and effectiveness. These random audits are conducted by the state’s six forest engineers (one for each region) and are considered to be a more comprehensive inspection of water quality. To reduce potential audit bias, the state has their six forest engineers change regions for their biannual inspection. Once a site has been audited it will receive one of the following classifications: 1) nonactive, 2) potential, and 3) active sedimentation. The person responsible for the active or potential sedimentation problems has the opportunity to remedy the situation before further action is taken. Again, these inspections are based on the experience of the inspector and rely primarily on subjective criteria.

If a more quantifiable technique were used to provide an objective examination of soil loss from harvested sites, the VDOF will obtain a more accurate estimate of erosion rates both at the time of harvest as well as afterwards, and be able to evaluate which factors influence site recovery over time. Current BMP inspections are performed through subjective visual inspections, but we believe it is important to provide an objective, repeatable estimate of soil loss in order to aid the 1) VDOF personnel, 2) landowners, and; 3) logging contractors. This type of quantifiable information identifies the situations that lead to both ongoing and post harvest water quality infringements that

1 Appendix A, Virginia’s Harvest Inspection Form.

warrant more intensive scrutiny in the future, and what situations are unlikely to cause infringements and should receive more or less emphasis in the future, depending upon physiographic province.

1.1 Project Objectives

This project has three objectives 1) to quantify soil loss from VDOF biannual audited sites throughout Virginia that range from zero to eight years since harvest in order to compare the quantifiable estimates of erosion with the initial VDOF audit evaluations, 2) to investigate the recovery of harvested sites, as estimated via erosion rates, with time by Virginia's physiographic provinces, and; 3) to examine how southeastern state BMP monitoring and compliance inspections, as well as effectiveness studies, differ in order to suggest improvements.

The specific assumptions to be tested are:

H_{a1}: Erosion rates are significantly dissimilar between the three physiographic provinces.

Ha_2: Time since harvest significantly influences estimated soil loss from harvested sites.

Ha_3: Quantifiable estimates of soil erosion problems are comparable to those predicted by VDOF audits.

Ha_4: Slope and vegetation are the two most important factors, which influence erosion.

2. Literature Review

2.1 Source of Today's Forestry Regulations

Forest practices such as harvesting and transportation have been regulated since the Rivers and Harbors Act of the 1890s, which regulated the river transport of logs in order to prevent obstruction of navigation (AF&PA, 1993). Forest silvicultural activities were further regulated with the passage of Section 208 of the 1972 Clean Water Act (CWA), which specified the management of nonpoint sources of pollution (NPS) from silviculture activities. Nonpoint source pollution is defined as diffuse discharges entering receiving water in a diffuse manner at intermittent intervals based on rain and snowmelt (Novotny, 1994). The U.S. Environmental Protection Agency (EPA) (1993) defines pollutants associated with silvicultural activities as nonpoint source pollutants. This form of pollution occurs during a rainfall or snowmelt event, which can erode or dissolve naturally occurring and human-made pollutants and transport pollutants into lakes, rivers, wetlands, coastal waters, and groundwater. Potential NPS pollutants from silvicultural operations include sediments, nutrients, organic matter, and toxic compounds, with sediment the primary transport mechanism during a rain or snowmelt event.

In 1987, congress amended the Clean Water Act and enacted Section 319, which established a national program for the control of NPS pollution (USEPA, 1993). Section 319 requires states, tribes, and territories to address NPS pollution by assessing the causes and sources as well as implement management programs to control them. Section 319 also authorizes EPA to issue grants to states, tribes, and territories to assist them in implementing various aspects of their programs. In addition to 319, Congress passed the Coastal Zone Act Reauthorization Amendments (CZARA) in 1990 to help define management measures for NPS pollution in coastal waters. As a result, EPA created and is currently updating the "Guidance Specifying Management Measures For Sources of Nonpoint Source Pollution In Coastal Waters." A management measure as defined by EPA (1997), is an economically achievable measure to control the addition of pollutants to coastal waters, which reflects the greatest degree of pollutant reduction achievable by best management practices (BMPs). The EPA (1993) suggests that BMPs have two major components 1) prevention measures as a part of planning, policy, and management, and 2) reduction measures applied to the land as an integral part of silviculture activity. BMPs are an approach to control NPS pollution. More specifically, they are practices, methods, or measures used as a system to prevent or reduce potential sources of water pollution (Brooks et al. 1997).

Virginia has 15.1 million acres of forestland, comprising roughly 61% of the total land area (Birch et al.1998). Approximately 13 million acres of forestland are owned by non-industrial private landowners (NIPFs), with the remaining acres owned by public and industrial forest companies. NIPF landowners constitute approximately 75 percent of all timber harvesting operations in Virginia (Birch et al.1998).

It is this diverse forest landowner type in Virginia that complicates the issue of water quality protection. For example, public agencies follow strict water quality guidelines to set the example on how to properly manage for water quality pollution potential. However, the degree to which private and industrial landowners protect water quality can vary. This is due to the voluntary nature of Virginia's silvicultural exemption, which states that BMPs are not mandatory unless a water quality problem is evident from timber harvesting.

As recently as the 1970's little consideration was given to the effects of disturbing significant quantities of soil when building forest access roads and conducting silvicultural operations (Tetra Tech, 1999). However, in more recent years, scientists and the public alike have become more aware of increasing water quality issues surrounding timber harvesting.

2.2 Factors Influencing the Erosion Process

Soil erosion from silviculture operations is the primary forest water quality concern therefore it is important to understand the erosion process. Although soil may be eroded by wind, water, or ice, water erosion is the primary concern in the eastern United States. Erosion has 3 components: 1) detachment of soil particles by raindrop splash or water movement, 2) soil transport in water, 3) deposition of eroded soil. If this deposition (also known as sedimentation) occurs on land then water pollution has been avoided. If the sediments are deposited in a water body, then water pollution has occurred (Brooks et al. 1997).

Erosion is a natural process, but it can be exacerbated when soil is exposed through silvilcultural activities. Dissmeyer and Foster (1984) define erosion as “the amount of soil delivered to the toe of the slope where either deposition begins or where runoff becomes concentrated.” The erosion process is conducted primarily through wind and water. Weathering process such as freeze-thaw and wet-dry events (Azola, 2001) would especially weaken bare soil structures over time and increase the potential for erosion. This potential is amplified with the increase of slope percent, slope length as well as soil’s texture, erodability, structure, and the amount of organic matter present in the soil.

The erosion process caused by water begins with a rainfall or snowmelt event. In the Eastern United States, rainfall erosion tends to be greater than wind erosion. For example, rainfall is the Coastal Plain Province of Virginia’s primary erosive force (Azola, 2001). The primary factors that influence erosion from rainfall events are rainfall intensity, duration, parent material, and climate. The dependent variables on the ground include the type and amount of cover, topography, and soil type (Novotny, 1994).

Typically, rainfall’s kinetic energy first dislodges soil particles. After detachment soil particles may become suspended in water. The suspended sediment, will collect, gain momentum, and transport other detached particles, thus increasing the sediment load and its abrasive capabilities to collect more detached soil particles. Additionally, raindrops contribute to surface sealing. Surface sealing is the process in which soil macro and micropores, through which water infiltrates, become sealed or clogged with fine soil particles (Dillaha, 2000). Therefore, surface sealing prevents water infiltration and increases runoff potential. In time, water’s erosive capacities can cause rill and gully erosion to occur which further concentrates water and increases water velocity.

Rill erosion is described as small, shallow, well-defined visible channels where concentrated overland flow occurs (Azola, 2001). Unlike rills, gullies are much larger in size. With respect to timber harvesting activities, rill and gully erosion typically occur on disturbed sites with little vegetative cover. Gully erosion begins to occur at a concentrated area called a nickpoint (Brooks et al.1997), where there is an abrupt change in slope and elevation. As this occurs, flowing water headcuts the hillside and eventually downcuts it, moving the gully in the down slope direction (Brooks et al. 1997). A third form of erosion, sheet erosion, is often overlooked because of no visible signs of its occurrence. Sheet erosion, often called interrill erosion, takes place between rill and gully channels on a uniform slope, which evenly distributes overland water flow. Sheet erosion typically creates and destroys rills as fast as it creates them and the erosion is so uniform that it appears that no erosion is occurring (Dillaha, 2000).

2.3 Cover Effects on Erosion

Ground cover such as grass, slash, forest litter, rocks, and other cover can reduce the potential for erosion to occur. Novtony (1994) states that vegetative cover is extremely important because it provides additional resistance to shear stresses caused by falling and running water and wind. The primary function of vegetation canopy, in relation to soil erosion, is that the canopy shields bare soil from the rainfall's kinetic energy (Summer et al. 2000). Dissmeyer and Foster (1984) stated that as percent vegetation cover increases the amount of bare soil decreases and infiltration rates can exceed the rainfalls intensity, which drastically reduces the erosion rates. Further, forest litter protects the underlying soil from the erosive force of raindrop impact (Swift, 1984). El-Hassanin et al. (1993) concludes that forest over story in conjunction with herbaceous ground cover is the most effective cover combination against soil loss and runoff. In particular, vegetative cover protects from soil erosion through: 1) interception, 2) ground cover, 3) retention, and; 4) infiltration.

Interception is the portion of precipitation that is intercepted by vegetation or other surface cover and is evaporated into the atmosphere. Interception is a function of the type and density of vegetation or surface cover, rainfall volume, intensity of precipitation, and wind speed. Shorter stature vegetative cover also provides protection from raindrop's kinetic energy, which dislodges soil particles and places them in suspension for possible transport downslope. However, taller vegetation (>30ft) may have little impact on the erosive force of rainfall, raindrops on leaves collect and form larger drops. This canopy drip may have as much force as raindrops especially when falling from greater heights.

Water retention is primarily a function of surface roughness, land slope, soil infiltration rates, and soil saturation, as well as vegetation's ability to slow down and retain water onsite and prevent overland flow. The effectiveness of vegetation to retain water is a function of rainfall intensity, volume, type, and density of vegetative cover, especially the littler layer. Through retaining and changing the flow hydraulics, retention assists in the infiltration of water, which reduces the volume of overland flow.

2.4 Erosion and Sedimentation Concerns

Erosion and sedimentation rates from undisturbed or recovered forests are significantly less than that from recently disturbed forests (Wynn et al. 1999). However, it is important to differentiate between erosion and sediment delivery as it relates to water quality. According to Yoho (1980), eroded material that is deposited downslope before reaching a water body has no impact on water quality. Eroded soil becomes a water pollutant when it enters a surface water body such as a stream, river, pond, or lake. Sedimentation has a negative cascading effect on stream quality, because sediment concentration increases downstream from its point of origin as a result of natural stream scour and erosion or human made introductions.

Sedimentation can lead to a reduction in a water quality standard, which refers to the physical, chemical, and biological characteristics of water in relation to a specific use (Brooks et al. 1997). Sedimentation from timber harvesting has a potential to 1) devastate fish habitat by filling channels, 2) increase flooding potential downstream, 3) create unusable drinking water, and 4) reduce visual clarity, which can increase stream temperature and reduce the dissolved oxygen in the stream. Again, negatively influencing many aquatic organisms.

Poorly planned and implemented silvicultural operations such as site preparation, harvesting, and road construction and maintenance can potentially increase stream water temperatures, resulting from removal of streamside vegetation. Streamside management zones (SMZ) have been shown to minimize the increase in stream temperatures (Brown and Binkley 1994; Brown and Krygier, 1970). The removal of the SMZ is the catalyst for other potentially detrimental effects on water quality. According to Klapproth (1999) streamside vegetation protects water quality by filtering water runoff, decreasing water velocity and increasing infiltration and sediment deposition. Further, Klapproth states that SMZ vegetation protect the surface of the soil from wind, stabilizes stream banks, and moderates temperature, light, and humidity within the SMZ area. For example, Aitken (1936) and Trautman (1939) have concluded that sediment has the largest effect on stream biota. Additional sedimentation impacts include reduced light penetration, smothering of aquatic benthics and habitat reduction (Chutter, 1969; Gammon, 1970). Sediments can also carry adsorbed pollutants (pesticides, metals, and nutrients) that may enter into solution after deposition (Lenat et al.1981). Moyle et al. (1996) in a report to congress discussed the management options of riparian areas suggested that SMZ removal should not occur unless their removal would benefit riparian-dependent resources, control insects and disease, protect public safety, or facilitates timber harvesting on adjacent land (i.e. stream crossings). However, to properly cross a stream Moyle et al. (1996) suggests great care when designing the road and to use permanent or seasonal closures to avoid or minimize the impacts on the riparian area. Although poorly designed and implemented silvicultural practices increase erosion and sedimentation, erosion rates from silviculture are deemed to be one to two orders of magnitude less that that from cropland due to the significant quantities of vegetation residues remaining on the surface, (Brown, 1985).

2.5 Sources of Erosion from Silviculture

2.5.1 Roads and Skid Trails

The major source of sediment from forest operations is from construction and maintenance activities associated with roads (Anderson and Potts, 1987; Askey and Williams, 1984; Brown and Krygier, 1971; Burns, 1972). Anderson et al. (1976), Megahan (1980), Patric (1986), and Rothwell (1983) considered roads to be the major source of erosion from forestlands, contributing up to 90 percent of the total sediment production from timber harvesting operations.

Within the U.S. Forest Service there are an estimated 373,000 miles of forest roads (Coghlan and Sowa, 1998), which currently have an $8 billion dollar maintenance backlog. Forest road miles and road density on industry and private lands, when totaled, would be considered much greater than the Forest Service and private road maintenance is highly variable.

Roads contribute sedimentation caused by erosion on cut and fill slopes, the road surface, and by stream diversion. Cut and fill slope roads occur when the topography of the landscape does not permit direct access up the slope. In Virginia, this is typical of the mountainous regions as well as some Piedmont locations. When constructing this road type, the upslope portion “cut slope” is removed and cast downslope to serve as fill to construct the road. The fill slope is side-cast material as well as the foundation of the down slope area of the road. On topography that has little change in grade and does not need a cut or fill slope, the majority of erosion occurs from the road surface.

In the Coastal Plain of Virginia, roads typically are constructed as ditch and elevated roadbed known as elevated roads. Road ditches in the Coastal Plain typically contain standing water. These roads are subject to Section 404(a) of the Clean Water Act and require a permit from the Army Corps of Engineers for nonsilviculture activities or maintenance. Appelboom et al. (1998) cited in Tetra Tech (1999), conducted a study measuring sediment loads from the ditches on elevated roads. They found a correlation between sediment loading rates and rainfall intensity, duration, infiltration, and antecedent soil moisture conditions. Appelboom et al. (1998) recorded during one rainfall event that released 33 mm of water with an intensity of 4 mm/hour, resulted in 0.13 Mg/hectare of erosion. This is an insignificant amount of sediment when compared to soil loss from roads constructed in mountainous topography.

There is additional potential for erosion from access roads at stream or other water crossings. Rothwell (1983) found that stream crossings are the most frequent source of sediment since these areas are typically where soil enters the stream. In his study, Rothwell recorded an average of 2.3 Mg/hectare eroding during a rainfall event at a road/stream crossing. Swank et al., (1982) found that 75 percent of soil loss from newly constructed forest road stream crossings occurred within the first three months after construction. The remaining 2.5-year period of the study recorded a significant decline in erosion due to the effect of grass cover on roadbed and fill slope. Swift (1985) stated that in conjunction with rain and snowmelt, a newly constructed stream crossing also erodes because of in-stream scour.

Diversion potential at road/stream crossings occur when a stream exceeds the capacity of a crossing structure, such as a culvert, and is diverted from its’ channel and onto the road or into the cutbank. Furniss et al. (1997) stated that “the physical consequences of exceeding the capacity of stream crossings in wildland environments usually depends on the degree of accidents, crossing fill volume, fill characteristics, soil characteristics, and the flowpath of overflowing stream discharge.”

Road stream diversion potential has been shown to occur more frequently on insloped roads, which diverts water down the road and not across it (Best et al. 1995). Further, water diversion potential will increase on continuous climbing road grades at stream crossings.

Megahan et al. (1986) reviewed several studies on forestland erosion and concluded that surface erosion rates on roads often equaled or exceeded erosion reported for severely eroding agricultural lands.

Based on a six year study in Idaho, Megahan and Kidd (1972) reported about 30 percent of the erosion from roads was caused by surface erosion; the remainder resulted from mass erosion where fill slopes failed. The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater. Swift (1984) found that soil loss is greatest during and immediately after road construction. This is due to the unstabilized road prism and disturbance by passage of heavy trucks and equipment. The same holds true for skid trail construction. Brown and Krygier (1971, cited in EPA 1993) found that sediment production doubled from natural erosion rates after road construction during a project on three separate watersheds in Oregon's Coastal Range.

Skid trails, like forest access roads, can be sources of sedimentation of surface waters. Skid trails are used by conventional logging systems, whereby a skidder extracts the timber to the log deck. Rubber-tired skidders are common practice in timber extraction in the southeast. These tires can cause rutting and puddling of soils (Rummer et al. 1998). Aust et al. (1993) found that the use of regular tired skidders (single tired) affects subsurface hydrology by increasing the soil's bulk density and decreasing hydraulic conductivity, in the wet pine flats of South Carolina.

Skid trails, in the mountains often require construction resulting in cut and fill slopes and are subject to the same erosion processes as access roads. In the Coastal Plain province, skid trails are typically not constructed and timber reaches the log deck via right-of-ways cleared out by heavy equipment.

Skid trials on wet soils, typical of some areas of Virginia's Coastal Plain, have the potential to reduce efficiency and increase maintenance costs as a result rutting on wet sites. Therefore, the use of dual tired skidders to haul logs on forest roads have shown to reduce ground pressure, thus reducing soil disturbance and minimizing sedimentation to local waterways (Kroger et al. 1984). Extra wide high floatation tires have been shown to reduce rutting on forest skid roads from 30 kilopascals (kPa) of pressure on the soil to 21 kPa proving to significantly reduce erosion (Rollerson 1990; Aust et al. 1993).

2.5.2 Log Decks

Log deck staging areas for loading and transporting timber are typically smaller areas relative to the size of timber tract being harvested. However, these areas are often highly disturbed due to high volumes of traffic so they have the potential to contribute significant amounts of erosion. There have been few research studies, which have focused on log decks, however, state officials have seen a need to control erosion from these sites.

Log decks sizes depend upon the type of harvest system. Therefore, in the Coastal Plain of Virginia, with larger mechanized harvesting systems, log decks are usually larger than those found for less mechanized mountain harvesting systems. Although the log deck size may be larger in the Coastal Plain, erosion may be of less concern than on smaller decks located in the steeper terrain of the Mountains.

2.5.3 Newly Constructed Roads Versus Old Roads

Water quality impacts from new and old roads are dependent on the design and maintenance level of the road (Swift, 1986). Poorly designed roads are prone to have significant erosion regardless of recovery period or maintenance. According to Adams and Ringer (1994), the potential for erosion from forest roads has decreased over the years because of better road design and layout practices. Swift (1984) cites numerous examples of how road construction methods have improved over the past 50 years. Harr and Fredriksen (1988) as cited in Tetra Tech (1999), inventoried 97 km of roads within several watersheds. The roads were classified as 1) active (haul roads/recreation), 2) inactive (still used for fire suppression), and; 3) roads planned for decommissioning. Most of the roads, which were constructed in the 1950s and 1960s were of poor design and layout. The failure rate for these roads produced 110-times as much sediment as compared to an undisturbed forest and needed to be properly maintained.

2.5.4 Off Road Vehicles (ORVs)

ORVs usage is a popular means to explore the countryside. ORVs include, four-wheelers (ATVs), trucks, and jeeps. These vehicles can cause considerable road degradation by creating deep ruts, compromising stream bank integrity, destroying vegetation on forest road sides, and compromising forestry BMPs after harvest (Reynolds, 1998). Because of the increased recreational use of forest roads, the George Washington and Jefferson National Forests in Virginia created a list of BMPs for ORVs. This list includes: avoid running over young trees, shrubs, and grasses, stay off soft and wet trails, or trails that are badly rutted; obey road closures; travel at reasonable speeds; and ford streams only at designated crossings. Not only are ORVs a concern on federal lands, they also can pose a threat to the water quality on private and industrial timber lands if access is not properly restricted during and after a harvest.

2.5.5 Harvesting

According to EPA (1993), the most detrimental effects from harvesting are related to the access and movement of vehicles and machinery, and the skidding and loading of trees or logs. These effects include soil disturbance, soil compaction, and direct disturbance of stream channels. The planning of logging operations, soil and cover type, and slope are the most important factors influencing harvesting impacts on water quality (Yoho, 1980). Megahan (1986) found that in some cases erosion rates from harvest operations may approach erosion rates from roads and that prescribed burning can accelerate erosion beyond that from logging alone.

In Virginia, Carr (1990) examined harvesting impacts on steep slopes. The purpose of the study was to assess ground disturbance from rubber-tired skidders on slopes greater than 30 percent. Soil compaction and soil erosion were examined. Carr discovered that the percentage of tracts falling into the severely disturbed category was generally for access to timber created by bladed contour skid trails. Bladed contour skid trails constituted approximately 13 percent out of 30 percent of the total tract area that was classed as site disturbance. Further, Carr (1990) found that overland methods of skidding on steep slopes resulted in 7 percent site disturbance. The low percentages indicate a small amount of sediment transport on the tract over long distances following harvesting (Carr, 1990).

2.5.6 Site Preparation

Site preparation is a crucial component of forest regeneration in many forest management regimes (Smith, 1986). Impacts of site preparation that promote erosion are the reduction of transpiration, vegetative cover removal, soil disturbance, soil compaction, and channel disturbance (Yoho, 1980). Dissmeyer (1975) as cited in Golden et al. (1984), found that data from river basin reports in the Southeast indicated that site preparation contributed 30 to 80 percent of sediment produced by forest management in the areas studied.

There are several site preparation treatments and each one may promote soil loss. Yoho (1980) compared sediment yields from a two-year period from site preparation using chop-burn; shear-windrow-burn; and shear-windrow-burn-bed. The combination of shear-windrow-burn produced the least amount of sediment (2.21 Mg/ha) in the second year, while the combination of shearing, windrowing, burning, and bedding produced the highest second-year erosion rate (5.53 Mg/ha), mostly due to channels formed between the beds (Yoho, 1980). The erosion rates decreased by 10.57 Mg/ha from the first to second year for the shear, windrow, and burn and 8.7 Mg/ha for the combination shear, windrow, burn, and bed method. To increase water quality protection, Yoho (1980) stated that highly erodible sites, steep slopes, and lands adjacent to channels should be hand planted.

2.6 Virginia's Response to Potential Water Quality Degradation

Through enacted state and federal water quality laws as well as the advent of BMPs, the forestry profession has adopted and continues to advance the science of soil and water interaction control.

According to the Virginia laws pertaining to forestry, the VDOF (2000) regulation § 10.1-1181.1 defines pollution as follows:

""Pollution" means such alteration of the physical, chemical or biological properties of any state waters resulting from sediment deposition as will or is likely to create a nuisance or render such waters (i) harmful or detrimental or injurious to the public health, safety or welfare, or to the health of animals, fish or aquatic life; (ii) unsuitable with reasonable treatment for use as present or possible future sources of public water supply; or (iii) unsuitable for recreational, commercial, industrial, agricultural, or other reasonable uses."

Virginia landowners are subject to civil penalties if they are found in violation with this definition. Landowners are first provided the opportunity to remedy the situation spelled out in the Notice of Required Action (NORA). If no remedy has occurred over a determined amount of time, then a stop work order is given and according to section § 10.1-1181.3 of VDOF (2000), the following is in order.

"Any owner or operator who violates, or fails or refuses to obey any special order may be assessed a civil penalty by the State Forester. Such penalty shall not exceed $5,000 for each violation. Each day of a continuing violation may be deemed a separate violation for purposes of assessing penalties. In determining the amount of the penalty, consideration shall be given to the owner's or operator's history of noncompliance; the seriousness of the violation, including any irreparable harm to the environment and any hazard to the health or safety of the public; whether the owner or operator was negligent; and the demonstrated good faith of the owner or operator in reporting and remedying the pollution."

There are a few instances in Virginia where landowners were fined several thousand dollars for not complying with the NORA and Stop Work Order. This tends to correlate with national water quality surveys, such as EPA's 1996 *National Water Quality Inventory: Report to Congress,* which estimates that 7 percent of impaired river and stream miles; 7 percent of impaired lake, pond, and reservoir acres; and 3 percent of impaired estuarine square miles are impaired due to silvicultural nonpoint sources of pollution (USEPA, 1998).

When EPA's numbers are compared with Klapproth's (1999) figures for Virginia's over 50,000 miles of streams, 248 publicly owned lakes, and almost 2,500 miles of coastal estuary, there would be an estimated 3,500 miles of stream, 17 lakes, and 750 estuarine square miles impaired by silviculture.

Some of these waters play an important role in industry, transportation, and agriculture, and provide Virginia's citizens with recreational opportunities. Unfortunately, human activities, including silviculture, within and around surface waters have often led water quality degradation. As a result, 48% of Virginia's streams, 6% of

Virginia’s lakes and 71% of Virginia’s estuaries are now considered threatened or impaired by some form of pollution (Klapproth, 1999).

The types of silvicultural activities that have the potential to contribute the following forms of NPS pollution: sediment, nutrient, organic matter, and toxic compounds, are road and skid trail construction and usage, harvesting activities, log decks, and site preparation. Other potential affects are loss of habitat for aquatic species through physical disturbances, such as stream crossings.

In an attempt to control the extent with which pollutant sources may harm Virginia’s and the Nation’s surface waters, EPA created the Total Maximum Daily Loads (TMDL) program as part of Clean Water Act Section 303. A TMDL as defined by EPA (1999), is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. A TMDL is the water quality standard set by States, Territories and Tribes. They identify those waterbodies, which are not meeting the water quality standard for fishing, swimming, drinking water supply, or other uses. Historically, the TMDL program has focused primarily on effluent limits from point sources. However, EPA’s proposal to change the CWA designation of silviculture to a point source has raised many concerns (Stuart, 2000). The states of Oregon, California, Alaska and more recently Georgia have been confronted with the identification of certain stream segments and watersheds that have not met state water quality standards. Therefore, these states must identify all of the potential contributors of pollution into the specified watershed. Once the pollution sources are identified, an allocation of a daily load limit for each contributor will be issued.

EPA’s 1998 Section 303 (d) report indicated that approximately 7,098 miles of streams were impaired nationwide as a result of silviculture activities, out of the total 3.5 million miles of streams and rivers. This equates to 0.002 percent of all streams and rivers in the U.S. . This differs from EPA’s 1996 Report to Congress, which stated that 7 percent of all streams and river miles are impaired due to silvicultural nonpoint sources of pollution or Brooks (1997) 3 percent of all stream and river miles are impaired as a result of silviculture. According to Stuart (2000), Section 305 (b) reported a total of 20,018 miles of streams impaired by silviculture NPS pollution. Eleven states reported that silviculture contributed to water quality problems (EPA, 1998). Stuart (2000) describes that only 14 out of the 49 states have been involved in TMDL development. Table 1, provides a summarization of state responses on the TMDL program.

Table 1. Summary responses on TMDL related survey questions (from Stuart, 2000).

Total Maximum Daily Load Program	
Exercise	Number of States Involved
Number of States Reporting	49
Impaired Water Bodies	39
Impaired Water Bodies from Silviculture	14
Natural Conditions Listed as Impairment	20
Basis of Information Listing:	
A. Field Data	30
B. Documented Impairment	18
C. General Opinion	18
Accuracy of Impaired Listing:	
A. High	13
B. Moderate	12
C. Low	8
Forest Agency involved in TMDL	14

The apparent difficulty for implementing TMDLs is the variation of regional and state specifications on how BMPs are implemented. The difficulty increases when trying to compare BMP implementation standards between states. For instance, the minimum recommended width for riparian buffers in Georgia is 20 feet verses 25 feet for intermittent streams in Virginia. Maximum recommended widths of riparian buffers are 165 feet in Kentucky and 80 feet in West Virginia, Georgia, and South Carolina. Recommended buffer widths in Alabama are dependent on soil erodability, and in Virginia may depend on the presence of trout (Aust, 1994). Further, not all states equally participate in water quality protection, as seen by a lack of state representation (Table 2). Although each state has a general water quality law for timber harvesting, the influence that states have for protecting water quality depends upon each states perception of water quality problems from timber harvesting activities.

Table 2. States within Regions with State-Level Regulatory Provisions for Protection of Water Quality from Timber harvesting Activities (Tetra Tech, 1999).

Region	States with State-Level Regulatory Provisions for Protection of Water Quality for Timber harvesting
North	ME, MD, MA, MI, NH, NJ, NY, PA, RI, VT, WV
South	AL, GA, LA, NC, VA (out of 13)
Interior West	ID, MT, NV, NM
Western Coastal	AK, CA, OR WA

2.7 State BMP Implementation

EPA (1997) defines monitoring as a check or evaluation of something on a constant or regular basis. Further, EPA (1997) states that implementation monitoring is used to determine whether goals, objectives, standards, and management practices are being implemented as detailed in the design plan.

Compliance monitoring/implementation/compliance have different meanings depending upon each individual state. For example, compliance monitoring is also known as implementation monitoring in Minnesota and Oregon, silviculture audits in British Columbia, monitoring surveys in Maryland, site-level audits in Michigan, and forest practices inspections in both California and Oregon (Ellefson et al. 2001). In the southeastern U.S. implementation and compliance mean different things for different states. As defined by Ellefson et al. (2001) “compliance monitoring is the systematic gathering of information to determine whether forest practice guidelines or rules are actually being applied in the intended manner by landowners and timber harvesters.”

Compliance monitoring and effectiveness monitoring are two different kinds of studies. While compliance monitoring looks at specific BMP implementation, effectiveness monitoring examines whether a forest practice actually achieved the desired goal (i.e. do waterbars and grass cover reduce sediment loadings into a stream).

Thirty-four states implement some form of BMP compliance monitoring to determine whether voluntary or mandatory forest practice are being applied by landowners and timber harvesters (Ellefson et al. 2001). For Pacific Coast states, BMP implementation is mandatory, while many eastern states implement BMPs on a voluntary basis. However, both mandatory and voluntary states monitor BMP implementation through visual subjective inspections, which are often subject to personal interpretation and temporal influences (most sites are not visited during a rainfall event).

The purpose of monitoring BMP programs is to measure the success of state efforts to educate and provide technical assistance for both loggers and landowners on practices to prevent water pollution. However, as Ellefson et al. (2001) points out, the degree and manner for which states monitor their BMP programs are as diverse as the program titles (Vermont: acceptable management practices, Connecticut: guidelines and suggestions, California: forest practice rules, EPA: management measures). States monitor BMP implementation through various means. In Virginia, there is the harvest inspection and the random biannual audit. North Carolina visits a site in response to a complaint, while Florida creates a random stratified sample of 200 sites to visit annually for BMP compliance.

Monitoring for compliance is a function of the agencies ability to visit sites on the ground. This is enacted by state law and typically occurs for those states with a regulatory forest practices program (Ellefson et al. 2001). Virginia is quasi-regulatory which provides the VDOF permission to examine voluntary BMP implementation compliance.

To assist southeastern states with a BMP monitoring framework, George Dissmeyer (retired U.S. Forest Service) initiated the BMP Monitoring Task Force. In 1997 the task force created the, "Silviculture Best Management Practices Implementation Monitoring," document. Its purpose was to assist state agencies in creating their own monitoring protocol for BMP implementation. The basic outline of the document provides the concepts needed to initiate a BMP monitoring program. Although this lengthy document was promoted by the U.S. Forest Service, it was not necessarily adhered to as a result of various states willingness to implement. Further, those states that followed the suggested monitoring guideline lack continuity among each other. Therefore, it is difficult to compare state programs throughout the southeast. The southern region of the U.S. Forest Service (USFS) consists of 13 states each is at a different phase of BMP implementation inspection and effectiveness studies. For example, Alabama conducts BMP implementation surveys through aerial reconnaissance and reports 98 percent compliance for implementation, although no on the ground inspections are conducted. While Virginia conducts on the ground inspections and records that 20 percent of all sites are 100 percent compliant with BMP implementation. The difference in monitoring between these two states are 1) Alabama does not have a "right to trespass law," which requires aerial BMP surveys, while, 2) Virginia has a right to trespass law, which allows VDOF foresters to survey BMP implementation onsite. Further, each southern region state records and reports BMP implementation different (Table 3).

Table 3. Southeastern state BMP monitoring status

State	Right To Trespass	BMP Monitoring Compliance Rate	BMP Effectiveness Studies	State's With Starting BMP Monitoring Programs	Method of Monitoring
Alabama	No	98%		✓	
Arkansas	No	79%		✓	
Florida	No	96%	✓		Bioassessment
Georgia	No	98%			
Kentucky	No	?			
Louisiana	?	?		✓	
Mississippi	No	N/A		✓	
North Carolina	No	>90%			
Oklahoma	No	?	✓		Water quality Monitoring
South Carolina	No	91.5%	✓		Bioassessment
Tennessee	?	?		✓	
Texas	No	88.6%			
Virginia	Yes	90%	✓*		This study

* Indicate ongoing study

For the southeast, the estimated average state BMP implementation compliance rate is approximately 91 percent (Table 3). Forestlands in states with well-established regulatory programs, average 95% BMP implementation compliance (Brooks et al. 2001). The national BMP compliance rate from Brown and Binkley (1994) calculated out to 85 percent. However, compliance by some classes of landowners falls below these levels. State BMP compliance is generally lower for nonindustrial private landowners rather than for public or industry land and lower for small rather than for large land holdings. Reasons for the lower compliance relate to the onsite costs of BMP implementation borne by the landowner. Since the benefits of many of the BMPs favor aquatic organisms and downstream water users, landowners might view noncompliance as a preferable alternative, especially in states with voluntary compliance programs.

In 2000, Gordon Stuart conducted a National Association of State Foresters (NASF) survey of 47 States and 2 Trust Territories on the implementation and trends of BMPs in the United States. Stuart (2000) calculated the rate of compliance for all harvesting based on those operations near water bodies and those forestry operations away from water bodies. By default, harvesting that was away from water was considered in full BMP compliance with this survey, this means that any silvicultural operation that was not adjacent to a water body received 100% BMP compliance.

According to the 29 state respondents who conducted surveys on 35,136 sites from 1996 to 2000 overall BMP compliance was 86 percent. Table 4, provides an adaptation of the data presentation in Stuart (2000).

Table 4. Compliance Rates for BMP Implementation (adapted from Stuart 2000).

Component	1996 Percent (number reporting)	2000 Percent (number reporting)	Averaged Percent for Selected Components
Overall (BMPs)	86 (19)	86 (23)	
Preharvest Plans	n/a	96 (4)	
SMZs	86.5 (13)	80 (14)	81% average for “near water” silviculture
Roads and Trails	87.1 (13)	83 (16)	
Stream Crossings	87 (12)	79 (13)	
Site Preparation	94 (6)	95 (6)	
Wetlands	n/a	88 (4)	
Closure	84 (7)	77 (7)	
Chemical Use		92 (6)	

Upon examining the percentages of BMP compliance, the average BMP trend is 81 percent for those areas that are considered to be near a waterbody. This tends to skew the overall NASF BMP compliance rate. The table combines percent implementation with the areas that are considered hyrdologically connected with those areas that are not hydrologically connected. By comparing the two, it essentially averages 81 percent and 100 percent compliance rates, which raises the BMP compliance rate to 86 percent.

2.8 Virginia’s BMP Compliance Monitoring

In Virginia, the VDOF (1998) reported that surveys show that most landowners sell timber and make other forest management decisions without professional advice. These same studies have demonstrated that landowners who sell timber with assistance of a professional forester receive 50 percent more for their timber. Since professional foresters are knowledgeable about water quality protection, having landowners contact a professional is to the benefits of both landowner and the environment (VDOF, 1998).

Furthermore, VDOF county foresters will provide management plans for timberland owners at no cost. Each plan provides an inventory of tree species, stand composition, age, merchantability, growth rate, wildlife habitat conditions, and recommends methods for protection water quality and sensitive natural areas. In the preharvest planning, the Department recommends BMPs to loggers and landowners that focus on preservation of SMZs, proper haul road layouts, and wetland protection. During the harvest the VDOF, forest industry, and consulting foresters cooperate in monitoring harvest operations to encourage proper stream crossings, installation of water diversion devices, seeding of haul roads, and maintenance of streamside forests.

During logging operations, the logger, forester, and/or landowner are also contacted concerning BMP installation. The VDOF inspects harvesting sites for compliance with the Silviculture Water Quality Law. Since 1988 the VDOF has monitored the sediment yield from various forestry operations as well as the implementation of the recommended voluntary BMPs (VDOF, 1999).

Virginia's random BMP site inspections/audits began in 1993 and are performed biannually. According to the VDOF (1999), each audit examines the effectiveness of BMP implementation and assesses potential or ongoing water quality problems in accordance with Virginia water quality regulations. A noted difference between audits conducted before 1994 is that partial or sub-standard BMP implementation were not counted on the final score. This was because the voluntary BMPs only needed to be installed to ensure that it met the minimum water quality protection requirements.

In Fall 2000 Virginia's forestry BMP installation percentage was 97 percent. Additionally, the VDOF (2000) reported 100 percent BMP compliance at 20 percent of all sites inspected while 10 percent of total inspected sites had active water quality problems. These values were based on the 30 randomly picked sites inspected in the fall audit, where three of these sites were considered to have water quality problems.

2.9 Types of BMP Effectiveness Monitoring

Monitoring is an important and necessary aspect for documenting BMP effectiveness, which can focus on the physical, chemical, or biological aspects of water quality. However, effectiveness monitoring is the final step after selecting and applying specific BMPs. The Natural Resource Conservation Service (NRCS) does not include monitoring of BMPs as part of their criteria for BMP implementation. One of the main reasons for the apparent lack of nationwide BMP monitoring is cost. Monitoring erosion requires time, money, and people. Time is also considered an important factor since it could take several years of data collection to provide a result of BMP effectiveness. Other considerations include the problems of installing monitoring stations and collecting background data on preharvest water quality conditions.

There are several types quantifiable stream parameters that serve as indices of BMP effectiveness, including, stream temperature, stream sediment loads, aquatic life, dissolved oxygen, nutrients, chemicals. It is not unusual for all six of these focuses to be combined in one study.

In Otto, North Carolina the USFS Coweeta Hydrologic Laboratory, established in 1934, conducted several long-term watershed size studies on the relationship between water quality and timber harvesting operations. All of the parameters mentioned above were examined. The key findings described in their “Summary of Research Results” indicate the following:

1. Road construction has the greatest potential for water quality damage.
2. Forest cutting can alter water temperature and chemistry but does not cause erosion.
3. Methods of removing logs from the woods vary greatly in their potential for causing erosion.

It was these early studies that prompted the creation and implementation for several BMPs used today.

Effectiveness studies were conducted in both Florida and South Carolina implementing EPA’s Rapid Bio-Assessment Protocol, which looks at benthic macroinvertebrate species richness (aquatic life). Each state compared both up stream and downstream conditions before and after the time of harvest. Through comparing visual BMP compliance rates with macroinvertebrate richness, both states found that voluntary

BMPs are an effective measure to protect water quality. Vowell (2001) found that aquatic habitat, water quality, and stream biota were not adversely affected by intensive silviculture operations when BMPs were properly installed.

The advantages of these index type-monitoring studies are their ease of establishment. The apparent disadvantage of such a monitoring procedure is the expertise needed to identify macroinvertebrates, as well as the time and money required. Further, short-term responses may not capture impact, or different indices may be more or less sensitive to different seasonal disturbances.

The cost of Florida's effectiveness study was $290,000, which was acquired through a grant for a 1.5-year project. In contrast, South Carolina conducted its bioassessment study through the use of a Ph.D. student at an in-state school.

The benefits of BMP monitoring for effectiveness are numerous. It can be used to indicate whether or not pollution has actually occurred, is ongoing, or an indicator of what might happen over time.

According to Stuart (2000) there are currently 17 states (including Florida and South Carolina) performing one or more forms of effectiveness monitoring. Table 5, adapted from Stuart (2000) provides the methods currently being used.

Table 5. State BMP Effectiveness Monitoring (from Stuart, 2000).

Effectiveness Monitoring	
	Number of States Performing Activity
Number of States Involved in Monitoring	17
Visual observation of sediment delivery	14
Visual observation of impairment	14
Water sampling	2
Biological sampling	3
Research	3

Throughout Virginia, a study was conducted from 1989 to 1997 examining water quality impacts from timber harvest on private lands. The study incorporated the use of eight monitoring stations located in the various ecosystem provinces of Virginia, (mountains, piedmont, coastal plain). This was the first time the VDOF had become involved with in-stream water quality issues in Virginia (VDOF, 2000). The project measured changes over time in both up-stream and down-stream sediment loads and the various associated pollutants transported by sediment in dilution and solid phases. Further, macroinvertebrate species composition, were used as environmental indicators of water body health. This project concluded that the use of BMPs could mitigate the impacts of logging on water quality. Further, it deduced that a lack of proper planning of roads and BMPs during the preharvest phase of operations lead to reduced water quality and loss of aquatic habitat.

Wynn et al. (1999) evaluated a long-term study in three small watersheds situated within Virginia's Coastal Plain. Each watershed was monitored to evaluate the impact of forest clearcutting and site preparation on surface water quality and to evaluate the effectiveness of the employed BMPs. The project was blocked into three treatment types to match the three watersheds. One watershed was treated with a clearcut without BMP implementation, the second watershed treatment was a clearcut with BMPs employed, and the third treatment was left undisturbed as the control (Wynn et al. 1999). The results of this study indicated that clearcutting and site preparation without the use of BMPs significantly impacted the water quality of that watershed. In addition, the sediment loadings in g/ha/storm from the BMP treated watershed were relatively constant, indicating that the BMPs were significantly effective. In fact, the control, which was not harvested and the no-BMP treatment watersheds showed sediment loadings fluctuating throughout the monitoring timeframe, further indicating the effectiveness of BMPs (Wynn et al. 1999).

The Maryland Department of Natural Resources published the results of their project evaluating Maryland's BMPs effectiveness. This was a paired watershed study, which consisted of a control and treatment as well as two periods of study-calibration and treatment. The study was situated within Sugarloaf Mountain in south central Maryland, which has similar terrain to the Blue Ridge province of Virginia. Treatments were truck haul roads, skid trails, landings, SMZs, wetlands, and stream crossings. According to Pannill et al. (2000), an ISCO 4230 Bubbler Flowmeter was installed to continuously measure stream stage and to sample when a rise of stream level exceeded a half-foot. Parameters measured from the water samples were Total Suspended Solids (TSS) concentrations, habitat and species richness of benthic macro invertebrates, and stream temperature. The efficiency of BMPs was documented through a photographic log of onsite inspections both during and/or immediately following a storm event (Pannill et al. 2000). Results showed TSS levels for the treatment “timber harvesting operations” watershed yielded 0.5 tons/acre/year (1.2 Mg/hectare/year). By comparison to other land uses such as agriculture or urban development, timber harvesting is one to two orders of magnitude below the TSS production from those land management practices. Further, stream temperature and richness of benthic macro invertebrates did not significantly degrade as result of the suite of BMPs implemented. It is important to understand that different land uses results in varying erosion rates. Erosion rates from the forest operations resulted in 1.2 Mg/ha/yr, when contrasted with the total contribution of sediment in streams from other land uses, forestry’s contribution is considered to be much lower (Table 6).

Table 6. Sediment sources and their total contribution to sediment in streams in the United States (taken from Robinson, 1979).

Sediment Source	Total Sediment Mg x 1 million	Percent of Sediment
Agriculture Lands	680	40
Streambank Erosion	450	26
Pasture and Rangeland	210	12
Forest Lands	130	7
Other federal lands	115	6
Urban	73	4
Roads	51	3
Mining	18	1
Other	14	1
Total	**1,741**	**100**

There are less direct mechanisms for protection of water quality. Non-BMP methods to improve water quality include technical assistance, fiscal incentives, educational programs, and tax incentives.

In Virginia, there is a tax incentive for landowners who are burdened with the responsibility of maintaining water quality on their property. Called the Riparian Buffer Tax Credit, it allows landowners to obtain tax credit on the value of standing timber within the SMZ. SMZ values are different because each tract is assessed on the average value of the harvest sale. An area forester reviews the statement of value for the timber remaining in the buffer, after a maximum of 50% basal area removed, to determine if it appears reasonable.

A case study, by Ellefson et al. (1995), asked forest program administrators from all states to rate effectiveness of various nonstructural methods to implement silvicultural BMPs. The programs were rated for achieving a variety of management goals, including protecting water quality. The overall ratings of programs for water quality, from most effective to least effective, were: technical assistance, fiscal incentives, educational programs, voluntary programs, regulatory programs, and tax incentives (for example, the new “Riparian Tax Buffer” program in Virginia). Ellefson’s results presented water quality protection ratings table that appears bias for silviculture and forest roads only and are individual ratings of responding foresters for the various non-BMP methods (Table 7).

Table 7. Effectiveness of State Forestry Programs to Protect Water Quality (from Ellefson et al. (1995)).

Nonstructural method for protecting water quality	**Effectiveness Program**		
	Effective	Ineffective	Neutral
Educational Programs	17	12	19
Technical Assistance	26	6	17
Voluntary Guidelines	10	20	19
Tax Incentives	12	32	13
Fiscal Incentives	14	11	21
Regulatory Programs	18	23	8

Numerous surveys have shown that there is still needed improvement in BMP compliance and effectiveness both on private and public lands. Potential reasons may be (1) landowners and loggers do not fully understand the BMPs, (2) some BMPs are considered too costly for implementation, (3) landowners or operators believe that likelihood of being reprimanded is low, (4) landowners may consider certain BMPs as forgone revenue, (such as SMZs), and; (5) site specific BMPs are often not considered.

2.10 Cost of Monitoring

The costs of monitoring for BMP implementation compliance and effectiveness are typically a state borne cost. The cost for one previously mentioned BMP effectiveness study in Florida was $290,000 over 1.5-year study period. According to Ellefson et al. (2001), monitoring BMP implementation compliance costs the 34 states that monitor $940,000 in 1997 (excluding states with compliance checks required by regulatory initiative). Further, this cost is 2.5 times more than the dollars spent towards monitoring BMPs in 1996 (NASF, (1996) cited in Ellefson et al. 2001). Ellefson et al. (2001) stated that those states with voluntary programs had a BMP compliance monitoring costs that ranged from $20,000 to $150,000 annually per state. This would indicate a highly variable level of BMP monitoring compliance. States with regulatory programs invested $500,000 to $750,000 per state in compliance checks annually. At the minimum, this is 25 times the low cost for voluntary programs. For example, a comparison of Virginia's voluntary BMP administrative costs to California's regulatory BMP administrative costs (both states forested area are relatively equal) showed almost a 5-time increase in annual expenditures in 1991 (Ellefson and Chang (1994) cited in NCASI, 1994).

The majority of money for BMP effectiveness monitoring by a state has been derived from EPA's 319 program. Congress enacted the 319 program of the 1987 Clean Water Act to control nonpoint source pollution. Under 319, states, tribes, and territories address nonpoint source pollution sources and causes and enact management programs to control them (EPA, 1993). States must apply for a 319 grant in order to procure the necessary funding to conduct a study. However, there is a discrepancy among the states capabilities to acquire 319 grants. For instance, in Virginia 319 grants are typically awarded to the state water quality agency, Virginia Department of Environmental Quality, and are therefore difficult to acquire because of other state agency needs. Also, there is a lack of state agency understanding as to how to apply for 319 grants, which reduces that agencies ability to perform necessary BMP studies and monitoring. Some states, such as West Virginia, do not depend on 319 funds to run their program. They rely completely on special taxes and certification fees while other states depend on state general funds.

Shaffer et al. (1998) found that in Virginia, the cost for BMP implementation depends upon the topography of the land. BMP implementation in mountainous terrain proved to be more expensive than the Coastal Plain province. The median per acre BMP costs on sites less than 75 acres were \$48 in the Mountains, \$29 in the Piedmont, and \$9 in the Coastal Plain. Sites greater than 75 acres showed a reduction of the median cost per acre to \$21 in the Mountains, \$25 in the Piedmont, and a decrease of one dollar in the Coastal Plain. Shaffer et al. (1998) concluded the reduction in BMP implementation cost on larger size tracts were a result of fixed BMP related costs for haul roads, landings, and stream crossings which can be often spread over a large number of harvested acres. From this data, it is estimated (in 1998 dollars) that \$3.5 million were spent annually for implementing BMPs in Virginia. Further, Shaffer et al. (1998) suggested that this number does not include the associated costs of lost production during wet weather when the ground may cause a BMP violation or for larger wood inventories at industry mills to cover BMP related wood flow shortages.

A study by Aust et al. (1996) examined both costs and benefits of forestry BMPs in Virginia. Through development of three nonregulatory scenarios and one regulatory scenario, Aust et al. (1996) were able to determine with the increase in regulatory BMP implementation caused a decrease in the benfit:cost ratio. This indicated a greater expenditure for BMPs, which resulted in less benefits per dollar expended. Virginia nonindustrial private landowners (NIPF) paid a higher percentage for water quality protection, yet derive few direct benefits. Aust et al. (1996) believed this is a result of the higher percentage of NIPFs in Virginia that choose to harvest their timber. The primary loss to the landowner is the opportunity cost of forgone revenue from lost timber volume within the SMZ, or the reduced stumpage payments due to increased harvesting costs as a result of BMP implementation (Aust et al. 1996). The lower benfit:cost ratio was most pronounced in the Coastal Plain area of Virginia, where large tracts of land are harvested with low erosion rates. Their results suggested a focused nonregulatory BMP program would be the most efficient approach towards water quality protection assuming that overall BMP compliance is sufficient.

2.11 Soil Erosion Estimates

There are numerous methods to predict soil loss from timber harvesting operations. Methods range from computer model simulation to on the ground predictions. Some of today's computer simulation models for erosion are the Water Erosion Prediction Project (WEPP) developed by the USDA Forest Service in Moscow, Idaho, and EPA's Better Assessment Science Integrating Point and Nonoint Sources (BASINS) model developed by Tetra Tech, Inc. in Fairfax, Virginia. Although both models predict erosion rates, they are fundamentally different.

WEPP is considered a complex erosion prediction model, which examines the physical parameters that describe processes that affect erosion (Morfin et al. 1996). WEPP can be applied to various forest applications such as roads, skid trails, forest fires, and forest vegetation at various ages (Elliot and Hall, 1997). Further, WEPP can model single storm events as well as annual precipitation and snowmelt effects on erosion. Although WEPP can be a detailed estimate for erosion from forest activities, it has not been widely implemented within the forestry community due to the complexity of the modeling process, the lack of sufficient validation on forested sites, and the fact that it does not work well on forest land.

The other primary soil loss prediction model is EPA's BASINS, which is a multipurpose environmental analysis based on watershed and water quality studies performed throughout the United States. BASINS models several land management activities through a Geographic Information System (GIS) database system (EPA, 2000). BASINS, is a watershed-based approach to understanding the amount of sediment as well as nutrients and other potential pollutants which enter a watershed from timber harvesting as well as other land management uses.

The most common method for predicting soil loss is the Universal Soil Loss Equation (USLE). Originally designed in 1965 as an empirical equation to estimate erosion from agricultural lands based on 10,000 plot years of data, the USLE has gone through numerous revisions (Brooks et al. 1997).   According to Brooks et al. (1997) the term “universal” was derived to indicate the functionality of the USLE, which prior to 1978, was limited to east of the Rocky Mountains. Today’s modern version of the USLE has been improved from the original with newer data and technology. The range of application of the USLE varies from 1) rangelands, 2) surface mining, 3) watersheds, 4) construction sites, and; 5) forest lands. There have been more recent changes to the USLE including a computer based software model the Revised Universal Soil Loss Equation (RUSLE), which is the third major revision since 1965 (Azola, 2001). The RUSLE is considered more appropriate for cropland and construction sites because of the lack of a forestland cover factor.

In 1980, Dissmeyer and Foster revised the USLE for forestland application, adjusting vegetation as well as for rill and gully erosion. Azola (2001) states that although the RUSLE is a more modern version, the original 1984 Dissmeyer and Foster method would be a preferred method of on the ground erosion estimates on forestlands. In addition, the Dissmeyer and Foster USLE is considered a more practical means of soil loss prediction since the complexity of WEPP and BASINS limits these models to those with engineering and computer science backgrounds and therefore not applicable to the on the ground forester who is inspecting BMP effectiveness.

3. Methodology

The objective of this study was 1) to quantify post harvest soil loss from VDOF biannual audits throughout Virginia, 2) to measure recovery times of harvested sites via erosion rates, and 3) to compare predicted erosion rates with VDOF audit classifications. Throughout Virginia, quantified erosion rates from timber harvesting operations were obtained by field data collection methods based on the VDOF's biannual audit classifications of active sedimentation, no active sedimentation, and "potential" sedimentation.

There is a difference between erosion and sedimentation, especially from a water pollution standpoint. This study examined quantified erosion losses from timber harvests, while the main goal of the VDOF audits are to subjectively examine for sedimentation problems. It is important to note that VDOF audits are a snapshot of sedimentation problems on a tract. This study provided a snapshot of erosion rates from each tract and did not predict sedimentation rates. Also, it was believed that if significant rain event occurred prior to tract erosion rate measurements, it might skew erosion rate calculations. However, field measurements were taken during a drought within the summer and early fall of 2001.

3.1 Site Selection and General Locations

Study tracts were randomly selected from a VDOF database containing all tracts visited for their random biannual audits since 1993. All biannual audits were lumped into one large database for random selection by using Excel's random number generator to acquire the proper number of needed locations. The selection process separated out those sites classified during the audit by the VDOF as 1) active sedimentation, 2) no sedimentation, and; 3) potential sedimentation. The selection was based on Boolean logic, which looks for simple yes/no responses to VDOF audit classifications when randomly selecting harvest tracts.

Tracts were separated by VDOF region and physiographic province and randomly chosen starting with the more recent harvests of 2000 and selecting backwards to 1993. In instances where VDOF classifications were not numerous in regions, random selection of tracts was forgone to acquire an adequate number of field sites.

Tract maps were acquired by contacting the county forester for each county where tracts were located. For those locations without a site map, general directions and other information were provided to locate the tract. In addition to randomly selecting sites in Excel, collected tract maps by VDOF classifications were also randomly selected. Each map per VDOF classification and region were shuffled, based on site classification, and randomly selected picking from the top of the pile downward until the statistical number required per classification was captured.

Post harvest BMP effectiveness sample tract locations were throughout the Commonwealth of Virginia. Figure 1 shows the distribution of sampled tracts throughout each of Virginia's physiographic provinces. It is important to note that some counties had several tracts visited while others had only one tract visited.

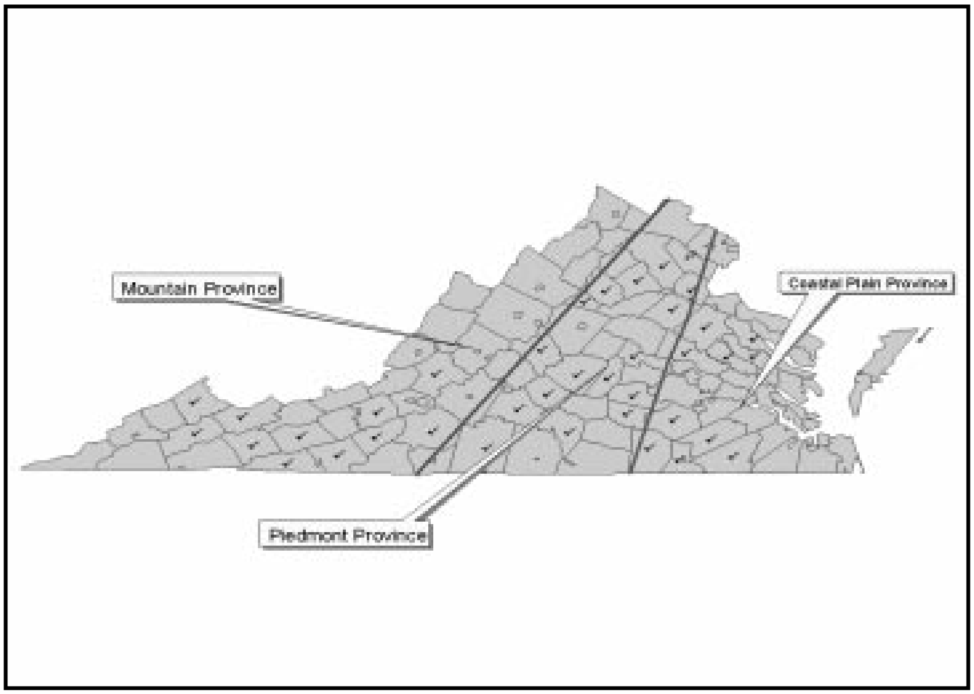

Figure 1. Field site locations throughout Virginia as indicated by check marks.

3.2 Categories

Sample tracts were blocked by physiographic province (Mountains, Piedmont and Coastal Plain) and split by VDOF audit classification (Active Sedimentation, Potential

Sedimentation, and No Sedimentation). This was done to compare and contrast erosion rates from sample tracts by physiographic province as well as from VDOF classification to determine if there was a statistical significant difference in soil loss among them. Field measurements were conducted according to the three VDOF classifications and were used as categories for this study since they are the basis of the current management strategy used by the VDOF. Table 8, provides a breakdown of sample size and location in Virginia.

Table 8. Number of Samples Recorded

VDOF Harvest Inspection Result	**Number of Sample Sites from Each VDOF Region**	**Number of VDOF Regions**	**Total Sample Size for Each BMP Classification**
Nonactive	3	6	18
Active	3	6	18
Potentially Active	3	6	18
		Total Number of Audited Sites Sampled	**54**
Control			9
On-going Operations			3
		Total Number of Samples	**66**

Post-harvest tract inspections were made at harvesting operations ranging from one to eight years old within each of the six VDOF regions, situated throughout the physiographic provinces of Virginia. Figure 2, depicts the boundaries of the six VDOF regions and was taken from the VDOF website (VDOF, 2001).

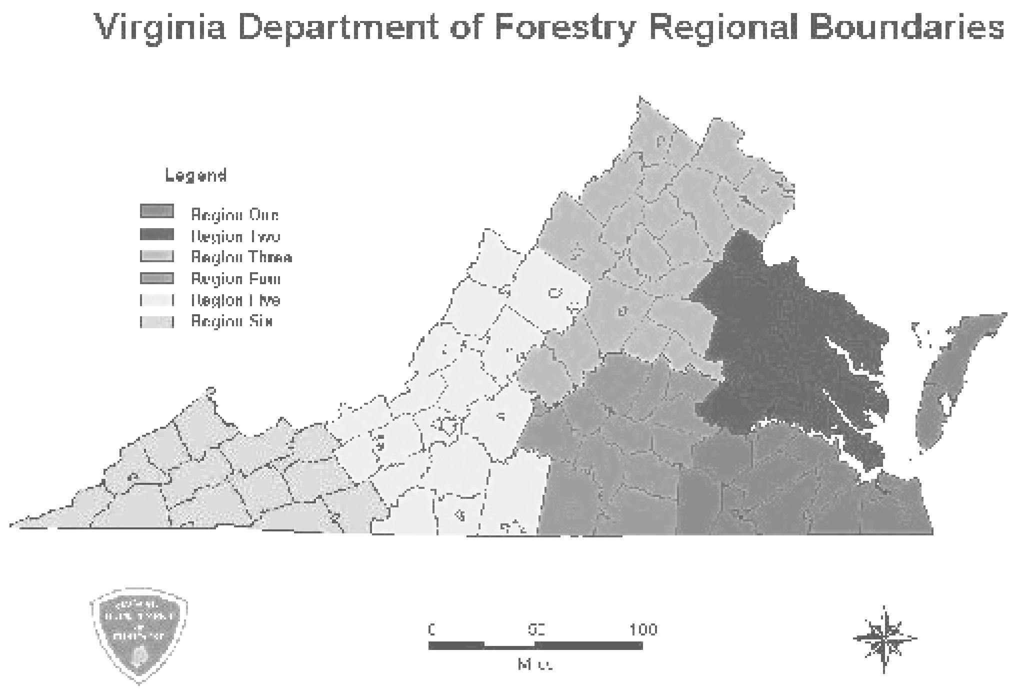

Figure 2. VDOF Regions (Taken from VDOF website, 2001).

3.3 Geography of Virginia

The main physiographic characteristics of Virginia are depicted in Figure 3 (taken from the College of William and Mary, “The Geology of Virginia” website, 2001): Note that the western portion of the state is separated into Appalachian Plateau, Valley & Ridge, and the Blue Ridge physiographic provinces and for the purpose of this study was combined into one class, “mountains.” The definitions below are adapted from Buol (1973).

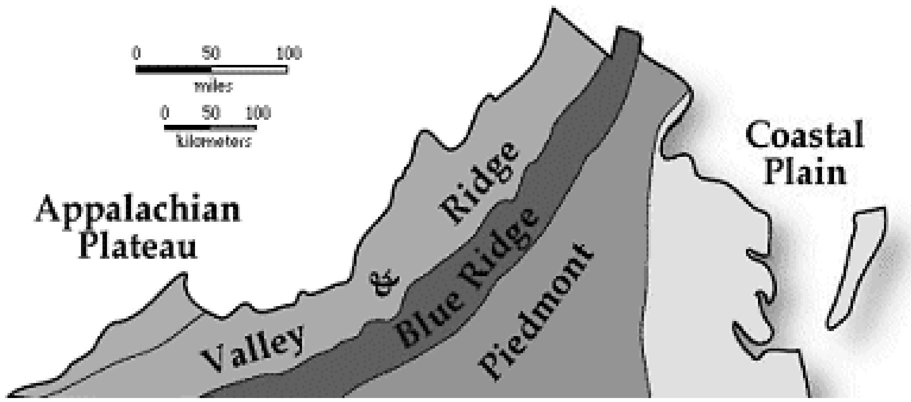

Figure 3. Pysiographic Provinces of Virginia (Taken from William and Mary Department of Geology website, 2001).

Mountains: The mountainous region of Virginia's westernmost physiographic provinces are separated into the Appalachian Plateau, Valley and Ridge, and Blue Ridge.

Appalachian Plateau is described as dendritic drainages with winding narrow crested ridges and deep narrow valleys. Described as steep in topography with narrow valleys.

Valley and Ridge is described as an area of valley floors separated by long, narrow, even-topped mountain ridges. Either of these elements may be the dominating factor of the landscape.

Blue Ridge is described as "subdued" in that the height and steepness of the mountains are very weathered.

Piedmont: In the United States, the Piedmont is a low plateau extending from New Jersey to Alabama and lying east of the Appalachian Mountains. The Piedmont has gently rolling hills, deeply weathered bedrock, and very little solid rock at the surface. The Piedmont region was and continues to be developed by erosion and slopes from the mountains to the Coastal Plain. The Piedmont tends to become steeper as it comes up to the Blue Ridge Mountains.

Coastal Plain: The Atlantic Coastal Plain is the easternmost of Virginia's physiographic provinces. The Atlantic Coastal Plain extends from New Jersey to Florida, and includes all of Virginia east of the Fall Line. The topography of the Coastal Plain is a terraced landscape that stair-steps down to the coast and to the major rivers, which forms broad swampy flats.

Geography can play an important role on erosion potential from forest operations. Logically, those tracts in the mountainous region of the state would have higher erosion potential than the Coastal Plain region. This is a direct result of topographical influence on water velocity and concentration. Water moves faster and it is concentrated more in the mountains as a result of slope. This increased erosion potential would indicate that there are more erosion and sedimentation problems in the mountains as well as in the Piedmont of Virginia.

Along with the variation of topography is the difference in soil type between physiographic provinces. Soil type may vary within each region as well as within each sample tract. However, the main soil feature remains similar within each physiographic province. For example, Coastal Plain soil has primarily a sandier texture, while the Piedmont is dominated by clay soils. Topography and soil type are the key differences between provinces and may affect erosion rates from timber harvesting activities.

3.4 Field Sampling

According to Summer et al. (2000), current erosion models are tools for helping experts devise possible conservation practices to reduce soil loss from land management activities and that they must be used with caution, bearing in mind that they are approximations.

Erosion estimates for each of the VDOF audit classifications were obtained using USDA Forest Service's "A Guide for Predicting Sheet and Rill Erosion on Forest Land" Technical Publication R8-TP 6.

This modification of the Universal Soil Loss Equation USLE by Dissemeyer and Foster (1984) was created to provide for a more realistic erosion rate from forestlands. This modified USLE was employed to establish estimates of erosion from forest access roads, skid trails, logging decks, stream crossings, harvest areas, controls, and ongoing operations.

The collection of data for the USLE transpired over several years from agricultural studies and was developed at the National Runoff and Soil Loss Data Center, established in 1954 by the Science and Education Administration (Wischmeier and Smith, 1978). The USLE is a widely used model to determine the erosion rates of land use practices across the country. Further, it is a fundamental baseline component to today's watershed models, such as EPA's BASINS. For this analysis, the USLE was used as an objective on the ground analysis for erosion prediction and could be used for everyday VDOF BMP inspections.

Although the USLE is one of the most widely used models to predict erosion, there are noted limitations when predicting erosion from forestland. For example, the water runoff is assumed to be uniform in nature, when typically water collects at the low point. Additionally, the USLE does not predict sediment-loading rates downstream from a site, nor does it estimate the deposition of sediment in the stream, only the net erosion from the site (Dillaha, 2000).

The USLE is founded on six principal components of erosion, which are multiplied together to achieve a predicted erosion rate for an area.

The USLE equation is:

A = R*K*LS*C*P

The following is what each letter represents in the USLE equation. This information is taken from the Dissmeyer and Foster (1984), which was taken from Wischmeier and Smith (1978).

- **A** Soil loss per unit area, usually as tons per acre per year.
- **R** Rainfall and runoff factor. The rainfall runoff factor for Virginia ranges from 125 EI units/yr to 300 EI units/yr
- **K** Soil erodibility factor. The soil erodability factor accounts for the variation in soils throughout Virginia with a range of .01 to 0.5 tons/acre/year/unit of R/subplot.
- **L** Slope length factor. Slope length factor accounts coincides with slope-steepnessto reflect the influence that both gradient and the distance of that gradient has on erosion.
- **S** Slope-steepness factor. Slope-steepness factor accounts for the effect of gradient on a uniform slope on erosion as well as convex and concave slopes.

- **C P** Vegetative cover or land management factor and support practice or BMP implemented to control erosion. Cover factor is based on the nine subfactors of 1) amount of bare soil, 2) canopy, 3) soil reconsolidation, 4) high organic content, 5) fine roots, 6) residual binding effect, 7) onsite storage, 8) steps, and 9) contour tillage, which in this field study was access road and skid trails on contour.

Rainfall Index (R)

The established rainfall index number in the ULSE (R factor) was used to assess the rainfall amount for each site visited throughout the Commonwealth of Virginia. The rainfall-runoff factor chart used in the field can be seen in Appendix B.

K Factor (Soil Erodibility)

The K-factor was identified using the USDA Natural Resource Conservation Service (NRCS) Soil Survey for those counties, which had a soil survey with a K-factor value. For those counties that do not have a USDA NRCS Soil Survey, the percent of organic matter and soil texture were established to conclude the soils K-factor by following the soil erodibility nomograph (Appendix B). A push tube was used to take a soil sample from each disturbance category to have an estimate of soil texture and percent organic matter. Location of each disturbance category influenced the index given for soil permeability. For example, those samples taken on skid trails, log decks, access roads, and stream crossings would receive a higher (which in this case indicates a slower permeability rate) ranking, where as harvest sites, and controls would receive a lower ranking.

Slope Length and Steepness Factors (LS)

The following equation was used to obtain an L value using Dissmeyer and Foster method:

$L = (\lambda/72.6)^m$
λ = slope length in feet
θ = angle of slope in degrees
$m = 0.5$ for slopes ≥ 5 percent (Dissmeyer and Foster, 1984).

A 100 ft. measurement tape determined field measurements of slope length. Each measurement was rounded up to the nearest foot. Measurements of slope were taken based on Dissmeyer and Foster (1984) procedures, which measures the point of origin for potential runoff to the location where the runoff either connects to a concentrated point and changes direction, or where the slope length ends. Those slopes that were irregular and changed in slope steepness throughout slope length as well as convex or concave at the base of the slope were separated into segments and calculated based on multiplying the products of Table 1 and 13 in Dissmeyer and Fosters (1984) (Appendix B).

Those slopes with failed BMPs, such as improperly constructed water bars, were considered to be a continuous slope and measured as if no BMPs were in place. One type of improperly constructed water bar is dirt simply pushed into a linear pile against the slope contour to trap water and to prevent water velocity increase. Further, those slopes with intact water control structures were measured from the structure to either the next structure or to the end of the slope. Throughout Virginia, slopes were measured to the end of each disturbance type or to the low point of that particular disturbance category.

The following Dissmeyer and Foster (1984) equation was used to determine an S value:

$$S= (65.41\sin^2\theta+4.65\sin\theta+0.065)$$

Slope steepness was measured to the nearest 1 percent by marking the end or break in the slope gradient with flagging tape at eye level and returning to the beginning of the slope with a clinometer to record slope percent. If two people were on site then one person would stand at the top of the slope while the other would stand at the end or break in the slope. Placing a Philadelphia Rod on site and flagging eye level was the method of recording slope percent in clearcuts.

To obtain LS, the Dissmeyer and Foster formula multiplies the two equations of L and S together:

$$LS = (\lambda/72.6)^m(65.41\sin^2\theta+4.65\sin\theta+0.065)$$

Cover-Management Practice Factor for Tilled and Untilled Forestland (CP)

The Cover-Management factor is divided into tilled and untilled forestland categories. There are five subfactors for untilled and six subfactors for tilled soils. Both untilled and tilled soils share the subfactors of a) bare soil and fine roots, b) canopy, c) steps, and d) onsite storage. Untilled soils also include evaluations of high organic matter content into the calculation while tilled soils evaluate the effects of invading vegetation and contour tillage practices. An example of a contour tillage practice for forestlands was access, skid trails, and log decks on contour.

Bare soil and fine roots subfactors differs slightly between tilled and untilled soils. Tilled soils typically do not have a fine root mat and therefore evaluate soil erodabililty through the soil residual binding capacity and soil reconsolidation. However, there is a USLE table designed for tilled soils, which accounts for a fine root mat possibility.

The percent of canopy cover over bare soil was visually estimated based on the guidelines of appendix B, which provides examples of the distribution of what bare ground and cover constitute over sample areas.

The cover factor was measured differently depending upon disturbance category type. For example, those tracts determined as access roads, skid trail, stream crossings, and log decks were measured as a “tilled soils.” Harvested areas and controls were considered “untilled soils.” This determination influenced two factors when calculating the C-factor value for tilled soils. The first was the measurement of fine roots, which was determined by employing a push tube on a representative sample of bare soil. If a fine root was found in a cubic inch of the top layer of soil, then it was determined that 100 percent of the site had fine roots. In disturbance categories that were seeded in one area and not in another, a fine root sample was taken among the newly established grass, which still had bare soil, and the area that was not seeded or did not yield a grass cover. The results were averaged to represent the entire site. The second additional factor for tilled soils was the management practice factor of contour tillage. Contour tillage for this study was a measurement to determine if access roads, skid trails, stream crossings, and log decks were on contour.

Unlike tilled soils, the C-factor for untilled soils included an evaluation of organic matter content. Following the suggestion of Wischmeier and Smith (1978) for untilled soils, those disturbance category locations with a organic matter content above 4 percent were multiplied by 0.7. These areas were typically represented with a one-inch thick organic horizon to qualify.

Onsite storage was measured in the same manner for both tilled and untilled soils. As seen in appendix B, various disturbance types constitute the onsite storage subfactor. Values range from 0 to 1 with zero indicating that the land has no bare soil, and one stating that there is no storage capacity. The zero value was never given because there is always some bare soil on site. Those disturbance categories with rock cover, such as access roads, would receive a value between 0.5 and 0.9 depending upon the rock size. Rock size on access roads is a substitute for the USLE storage classification of soil clods.

The step subfactor was the measurement of the percentage of debris dams, root clumps, depressions, and other obstacles throughout a slope gradient. The step acts as a trapping mechanism to stop or slow down runoff, which has washed away from the upslope. Steps may be both natural or can be caused by logging equipment moving up and down slopes. Steps act as breaks in slope grade.

The invading vegetation subfactor was the measurement of the percent bare soil with fine roots. This subfactor is only for tilled soils and was used for access roads, skid trails, log decks, and stream crossing disturbance categories. A push tube was used to collect a soil sample situated within a bare soil area within a disturbance category. The soil was then gently separated to examine for fine roots in the top cubic inch of the soil layer. If one fine root was found in this sample then it was concluded that there are fine roots throughout the disturbance category. For those disturbance categories that had a significant vegetative cover in one area and not another, two soil samples were taken. For example, if a log deck was seeded, but only half of the disturbance category area was partially covered, as seen in Figure 4.

Figure 4. A log deck in Botetourt County, with approximately 505 of the log deck successfully seeded with grass.

In the instance, as depicted in Figure 4, where one sample had fine roots and the other sample did not the fine root subfactor value was divided by two to suggest that 50 percent of the site had a fine root mat of invading vegetation. For those disturbance categories that were not easily divided received either 100 percent in fine root mats or 0 percent in fine root mats.

3.5 Parameters Evaluated Outside of the USLE

Several parameters were measured in addition to the variables needed to complete the Dissmeyer and Foster USLE. These parameters were considered because of their potential to influence BMP failure or success. Parameters studied were the type of harvest, post harvest vehicle usage, BMP/SMZ as a system, whether a tract was gated, and slope aspect.

Harvest Type

Harvest practice was identified by the method of regeneration as described on the VDOF BMP inspection form (see appendix A). Because some harvest types such as shelterwood, were not easily identified, all harvest types other than clearcuts were classified as selective harvests. Further, the total acreage of the timber harvest area was calculated as well as for the all disturbance categories based on VDOF maps. Through measuring the area represented by each of disturbance category and comparing to the total acres of the harvested tract, weighted estimates of erosion from each disturbance category and the overall tract were calculated. This weighted average and maps identified locations on the harvest site that posed the greatest risk to water quality, and those areas that do not represent water quality concerns.

Post-harvest use

Post-harvest use evaluated the level of vehicle traffic that has occurred since harvest. This primarily addressed off-road vehicle (ORV) use throughout each site and determined if ORV use has caused a water quality problem that would otherwise have not occurred.

Evaluations of ORV use were categorized as follows:

- Apparent use: Light
  Medium
  Heavy (Figure 5)
- No use

Figure 5. Heavy off road vehicle usage in Buckingham County is often detrimental to established BMPs.

Aspect

Aspect of the slope was considered because it dictates the amount of potential sunlight received by the harvest/road area. Sunlight directly influences the drying time of surfaces as well as the potential for new vegetative growth. Elliott et al. (1999) examined numerous independent variables to discover their effects on vegetation growth at the Coweeta Hydrologic Laboratory in Otto, NC. Elliott et al. (1999) hypothesized that temperature, which is related to sunlight, can be estimated by elevation, terrain shape and aspect. Their results claimed that 8 percent of the vegetation's distribution patterns variability was explained by aspect. Further, they suggest that vegetation composition is usually influenced by climatic, edaphic, and physiographic variation. Therefore, the physiographic variation of aspect within each disturbance category was examined as a potential explanation of percent vegetative cover.

Aspect was measured by establishing the bearing of the slope face. For north facing disturbance category with a bearing of 270 to 90 degrees, a value of zero was given. For those sites with a bearing of 91 to 269 degrees a value of one was given.

BMPs and SMZs (as a system)

An examination of SMZ failure and success was included in the field inspection. The objective was to discover whether or not the topographic low-point on the SMZ had become an end-of-pipe source for runoff or if any other failures occurred. Visual inspections took place to determine if 1) yes, sedimentation in the surface water is occurring, or 2) a sedimentation problem may occur.

A visual survey of appropriate BMP and SMZ implementation was used to evaluate BMPs and SMZs as a system. If either the BMP or SMZ were insufficient then the site received an unsatisfactory classification.

3.6 Site Impacts

Erosion Occurrence

The focus of this study was to identify those areas in the tract causing water quality degradation as well as measure representative samples of roads, skid trails, logging decks, stream crossings, harvest sites, and controls (if present on the tract) and then estimate the tons/acre/year of erosion, which was then converted to Mg/ha/year from each disturbance category.

Figure 6. Stream crossing sample sites, such as this one in Faquier County, were always measured and visually inspected for active erosion.

Disturbance categories within the tract was established in representative areas in addition to the representative disturbance category samples, erosion measurements were also taken at locations that were obviously eroding at a higher rate than the remaining site. These disturbance categories were classified as high-erosion samples and their erosion rate was averaged with a more representative sample within the tract. An example of a high-erosion disturbance category was typically where BMPs were absent or not implemented properly. Figure 7 provides an example of a high-erosion classification on a skid trail disturbance category on a tract in Grayson County, Virginia.

Figure 7. An example of a poorly constructed skid trail from a 1999 harvest in Grayson County, VA.

Obvious signs of erosion were used to indicate whether active or potential erosion was occurring. Field indices were rill, gullies, sediment plumes, bare soil around the stream surface, and mass wasting of a slope.

Sampling of stream crossings took place at intermittent and perennial streams. Both sides of the stream crossing were measured to establish the total Mg/ha/year from the disturbance category. There was an average of five disturbance categories of log deck, access road, harvested area, skid trails, and controls per site depending upon the availability. To compare the effects of time on harvesting sites, an inspection of one active logging site in each of the three physiographic regions (Mountain, Piedmont, Coastal Plain) of Virginia was conducted.

In addition to sampling ongoing harvesting operations, nine control tracts ranging from 10 to 20 years old were measured to create a representative sample of how harvested sites recover over the long-term. Three control tracts were evaluated in each of the classified physiographic provinces of Virginia. These tracts were not VDOF audited and therefore do not have a classification of active, nonactive, or potential for sedimentation. Otherwise, each site was sampled in same fashion as the VDOF classified tracts.

3.7 BMP Effectiveness Examination

The BMPs, as presented in the VDOF BMP manual, were evaluated on each tract. The purpose was to examine if the proper BMPs were installed as a system to control erosion from each disturbance category and to identify BMP needs. Additionally, BMP effectiveness was determined through estimated erosion rates calculated by the USLE and the previously mentioned parameters measured outside the USLE. All disturbance categories measured were accompanied with photographs of effective or non-effective BMPs. The erosion rates from the various disturbance categories within Virginia’s Physiographic Province were compared and contrasted based on their physiographic location and VDOF field audit classifications.

3.8 Statistical Analysis

The overall statistical design of this study was observational, blocked by Virginia’s physiographic provinces of Coastal Plain, Piedmont, and Mountains. Each of the six VDOF regions had 3 treatment samples for each of the VDOF random audit classification of 1) active, 2) nonactive, and 3) potential for sedimentation. There were two VDOF regions per physiographic province, providing a total of six samples for each classification per province and 18 samples throughout Virginia (Table 9).

Table 9. Analysis of Variance table of statistical design.

	Source of Variation	df
	Block	2
	Classification	2
	Error A	4
	Region	5
	Region x Class	10
Error B:	Region x Block	10
	Region x Class x Block	20
	Total Corrected	53

In addition, three control plots as well as one ongoing timber harvesting operation were taken within each of the physiographic provinces. Both the control and ongoing harvesting sample tracts were not used in the statistical analysis, however, they were used as both a baseline erosion rate at time zero as well as a long term predicted erosion rate. Table 10 provides the categories and numbers of samples.

		VDOF Classifications				
		Active	**Nonactive**	**Potential**	**Controls**	**Ongoing**
Physiopgraphic Province	**Mountain**	**6**	**6**	**6**	**3**	**1**
	Piedmont	**6**	**6**	**6**	**3**	**1**
	Coastal Plain	**6**	**6**	**6**	**3**	**1**
TOTAL		**18**	**18**	**18**	**9**	**3**

Table 10. Field Plot Sample Design

Potentially each harvest site could have six disturbance categories of 1) access roads, 2) skid trails, 3) log decks, 4) stream crossings, 5) harvest area, and; 6) controls.

Whole tract sample sizes were equal with a total of 54 tracts. However, disturbance category numbers vary as a result of their presence or absence within the tract (Table 11).

Table 11. Number of field samples for each disturbance category by province and VDOF audit classification.

		Disturbance Categories					
Physiographic Province	**VDOF Classification**	**Log Deck**	**Skid Trail**	**Access Road**	**Harvest**	**Control**	**Stream Crossings**
Coastal Plain	**Potential**	5	6	3	6	2	1
	Non Active	4	5	4	6	0	2
	Active	4	6	4	6	4	2
Piedmont	**Potential**	5	6	5	6	2	3
	Non Active	6	6	5	6	3	1
	Active	6	4	6	6	1	3
Mountains	**Potential**	5	6	6	6	3	1
	Non Active	6	6	5	6	5	2
	Active	6	6	6	6	3	4
	Total	**47**	**51**	**44**	**54**	**23**	**19**

After field sampling was completed, estimated erosion rate data were analyzed to determine if there was a significant soil loss between disturbance category and tracts by physiographic provinces. Additionally, erosion rates for disturbance categories were compared based on the VDOF random audit classifications were compared by province.

A statistical frequency test for estimated erosion rates was used to test for a Gaussian distribution among the data in Excel. The data distribution had skewness to the right, which is more common with biological data (Schabenberger, 2000). Upon determining that the data was Gaussian distributed, the statistical software package SPSS was used to perform ANOVAs, multiple linear regression, Pearson's correlations, and 2-Sample T Tests. The One-way ANOVA test was used to compare erosion rate means for disturbance categories between physiographic provinces and for VDOF classifications by physiographic provinces.

Scatter plots were incorporated to show erosion trends over time by disturbance category and physiographic province. Pearson's correlation analysis was used to determine which outside USLE erosion prediction parameters were linearly correlated to explain variability for each disturbance category.

Multiple Linear Regression was used to determine if time was a significant predictor for erosion parameters as well as to test which outside the USLE variables were the most significant determinant for soil erosion. Backward elimination, forward elimination, and stepwise elimination were all used for this task however stepwise elimination was considered the best model to use for the results. In addition, interaction between variables as well as variance inflation factors (VIF) for each regressor was tested to find if colinearity was a problem for each subplot type in each model. T-Tests were used to determine the significance of outside USLE parameters on erosion rates for each tract. All tests were run at an alpha level of 0.10.

3.8.1 Estimated Erosion Rate Procedure

Erosion data from each tract and disturbance category went through the following calculations for comparing the summed total erosion:

- USLE Erosion Rate x Percent disturbance category x Tract Size in Hectares = Mg/Year for that subplot on the site

- Summed USLE Erosion Rate x Ratio of disturbance category to Entire Tract Size/Summed Tract Size in Hectares =Weighted Mg/Ha/Year

By calculating the Mg/year for each disturbance category, a summed expected erosion rate by disturbance category for each physiographic province as well as VDOF classification was performed. Further, erosion rates, in reference to tract size sampled, were calculated to obtain a weighted Mg/Ha/Year for each of the 54 plots.

Erosion rates from timber harvesting operations, in association to other land uses in Virginia, were determined by calculating the average hectares harvested each year for each of the determined physiographic provinces. This information was obtained through U.S. Forest Service Field Inventory Analysis (FIA) data for Virginia, (Johnson, 1992, Thompson, 1992, Thompson, 1991). More recent FIA data for Virginia was not available.

The annual harvested hectares were multiplied with the average weighted Mg/ha/year of erosion coming for each physiographic province to obtain the Mg/year of estimated erosion taking place. The erosion rates for each physiographic province were then given as a percentage of the estimated total annual erosion from timber harvesting in Virginia.

4. Results

The overall objective of this study was to gain a better understanding about timber harvesting, BMPs, and erosion in Virginia. The data collected from the sample tracts also provided interesting supplemental information about the distribution of 1) average number of years since harvest, 2) average timber harvest area, 3) adequate BMPs and SMZs as a system, and 4) the most predominate type of harvest.

The average year since harvest for the sampled plots was 3.7 for the Coastal Plain, 3.6 for the Piedmont, and 3.3 for the Mountains. The average harvest area in hectares was 30 ha in the Coastal Plain, 38 ha in the Piedmont, and 23 ha within the Mountains. The distribution of harvest size may be related to the dominant landowner type. The larger landholdings by the forest products industry in the Piedmont and Coastal Plain, may be reflected in the average size of harvested tracts from those regions. The Mountains showed a much smaller averaged size timber tract, which suggested that these holdings were dominated by small private nonindustrial landowners.

For further information on the breakdown of all basic information, the raw data can be found in Appendix C., which provides tracts description information while Appendix D., provides the USLE values for each disturbance category. Appendix E, gives the estimated erosion rates for each disturbance category when the USLE and ratio of disturbance category to total area were multiplied.

4.1 Erosion Rates by Physiographic Province

A primary purpose of this study was to quantify BMP effectiveness by estimating erosion rates over time for each of the defined physiographic provinces. Knowledge about erosion rates will aid field personnel in focusing their BMP evaluation efforts. Analysis of erosion rates were achieved by comparing soil erosion rates for each disturbance category by physiographic provinces in Mg/ha/year as well as a summed Mg/year and the weighted average for each tract in Mg/ha/year.

4.1.1 Comparison of Erosion Rates by Physiographic Province

Soil erosion rates were estimated using the Dissmeyer and Foster method for each of the representative disturbance categories (log deck, skid trail, access road, stream crossing, harvest, and control) within each harvested tract. Results from the calculated weighted erosion rates indicated that there were large variations in soil loss between and within provinces (Figure 8).

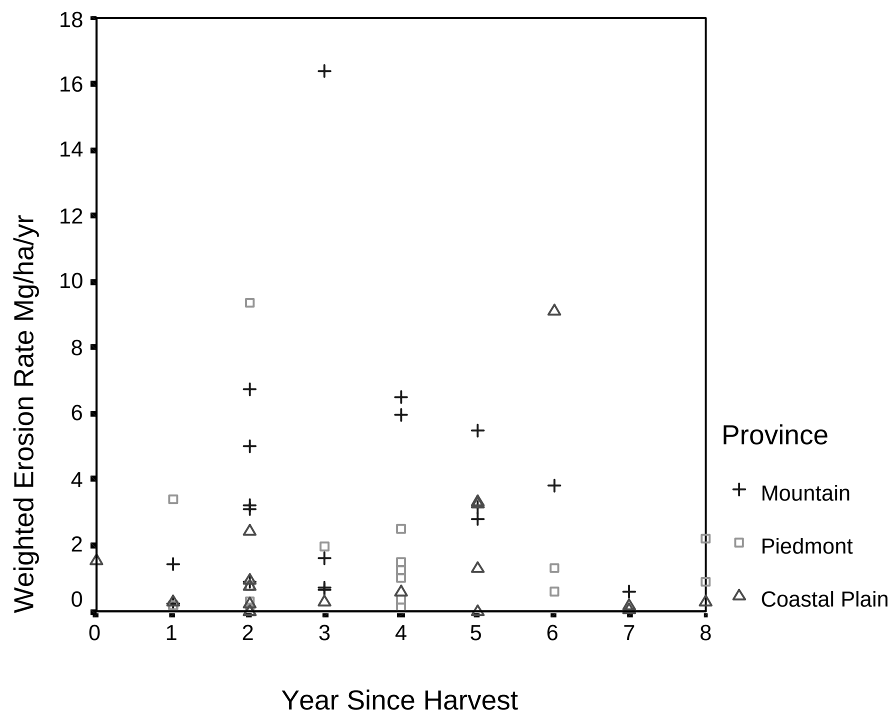

Figure 8. Weighted Erosion Rate Distribution by Physiographic Province.

An ANOVA with Fisher's LSD was used to compare weighted erosion rates between physiographic provinces (Table 12). Further, disturbance category erosion rates were provided as a percent contribution to the total weighted average to indicate those disturbance categories contributing the greatest amount of soil loss for each province.

Table 12. Estimated Contribution of Erosion Rates to the Weighted Erosion Rate Average by Disturbance Category and Physiographic Province.

	Access Road	Skid Trail	Log Deck	Stream Crossing	Harvested Area	Control	Weighted Average
	Percent Soil Loss Contribution to Weighted Average						Mg/ha/yr
Coastal Plain	15	9	1	2	74	0.03	2.7b
Piedmont	39	14	4	3	39	0.03	2.5b
Mountain	27	54	7	2	0.1	0.001	4.4a*

*Different lower case letters within a column represent a significant difference at the 0.10 level.

There was a significant difference in the weighted erosion averages between the Mountains and other provinces. Within the Coastal Plain, the disturbance category of harvested area contributed the greatest amount of erosion to the weighted soil loss average. In the Piedmont both the harvested area and access road contributed the same amount of erosion to the weighted soil loss average, while skid trails contributed over half the soil loss in the Mountains.

It is important to point out that there were no significant differences between disturbance categories by physiographic province. The USLE is a widely accepted measurement of expected soil loss. Therefore, the insignificant differences in estimated erosion rates were believed to be a result of tract variability between and within regions.

A T-test was performed for estimated erosion rate averages for disturbance categories within each province. Results indicated that there are significant differences between some disturbance categories (Table 13).

Table 13. Comparison of disturbance categories average erosion rates within their respected province.

		Access Road	Skid Trail	Log Deck	Stream Crossing	Harvest Area	Control
Coastal Plain	Access Road					✓ p=0.002	
	Log Deck					✓ p=0.090	
	Skid Trail						✓ p=0.092
	Stream Crossing	No significant differences					
	Harvest	✓ p=0.002		✓ p=0.090			✓ p=0.031
Piedmont	Access Road			✓ p=0.079		✓ p=0.037	
	Log Deck	✓ p=0.079				✓ p=0.016	
	Skid Trail						
	Stream Crossing	No significant differences					
	Harvest	✓ p=0.037		✓ p=0.016			
Mountains	Access Road					✓ p=0.044	✓ p=0.077
	Log Deck					✓ p=0.016	✓ p=0.080
	Skid Trail					✓ p=0.032	✓ p=0.085
	Stream Crossing	No significant differences					
	Harvest						✓ p=0.034

Estimated erosion rates from all the Piedmont and Mountains are considered within the expected range for soil loss from active construction sites and the Coastal Plain soil loss was similar to a carefully cultivated field (Yoho, 1980). The erosion loss tolerance classification for the weighted averages by physiographic province is presented in Table 15. Classification of erosion loss tolerances for disturbance categories by physiographic province was derived for Table 14. Erosion loss tolerance classifications, based on Yoho (1980) were produced to provide a range of soil loss tolerance in Virginia (Table 15). There are four classifications; 1) essentially recovered < 1 Mg/ha/yr was derived from undisturbed mixed forest erosion rates, 2) acceptable <5 Mg/ha/yr was derived from the classification of soil loss from pastureland, 3) problem 5-10 Mg/ha/yr was derived from the classification of mechanical site preparation, and 4) severe erosion >10 Mg/ha/yr was derived from carelessly cultivated or steep sloped fields in conjunction with active construction.

Table 14. Erosion loss tolerance classification for the weighted average erosion rates by physiographic province.

	Weighted Average Mg/ha/yr	**Erosion Loss Tolerance Classification**
Coastal Plain	2.7	Acceptable <5
Piedmont	2.5	Acceptable <5
Mountain	4.4	Acceptable <5

Table 15. Classification of erosion rates by disturbance categories and VDOF audits.

	VDOF Classifications	Erosion Loss Tolerances	Access Road	Skid Trail	Log Deck	Stream Crossing	Harvest Area	Control
Coastal Plain	No Active Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5		✓	✓			
		Problem 5-10						
		Severe Erosion >10	✓			✓		
	Potential Sedimentation	Essentially Recovered <1				✓	✓	✓
		Acceptable <5			✓			
		Problem 5-10	✓	✓				
		Severe Erosion >10						
	Active Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5				✓		
		Problem 5-10						
		Severe Erosion >10	✓	✓	✓			
Piedmont	No Active Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5			✓			
		Problem 5-10						
		Severe Erosion >10	✓	✓		✓		
	Potential Sedimentation	Essentially Recovered <1						✓
		Acceptable <5		✓			✓	
		Problem 5-10						
		Severe Erosion >10	✓		✓	✓		✓
	Active Sedimentation	Essentially Recovered <1					✓	
		Acceptable <5						
		Problem 5-10			✓			
		Severe Erosion >10	✓	✓		✓		
Mountain	No Active Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5						
		Problem 5-10						
		Severe Erosion >10	✓	✓	✓	✓		
	Potential Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5						
		Problem 5-10						
		Severe Erosion >10	✓	✓	✓	✓		
	Active Sedimentation	Essentially Recovered <1					✓	✓
		Acceptable <5						
		Problem 5-10						
		Severe Erosion >10	✓	✓	✓	✓		

The separation of average erosion rates into tolerance classifications suggested that the majority of disturbance categories are either a problem or a severe erosion problem approximately three years after timber harvest. However, when compared to soil loss ranges from active construction sites (according to Yoho, 1980) the average access road erosion was four times less. Further, log deck erosion rates were around one-half the soil loss expected from a carelessly cultivated agriculture field (according to Yoho, 1980).

A ONE-Way ANOVA with a multiple comparison was performed on measured percent slopes for each disturbance category by physiographic province. The purpose was to evaluate the percent slope parameter. Disturbance category average percent slope with the multiple comparisons is in Table 16.

Table 16. Average percent slope for subplots by physiographic province.

Disturbance Categories	Coastal Plain	Piedmont	Mountain
	Slope (Percent)		
Log Deck	3 c	5 b	8 a
Skid Trail	6 b	9 b	18 a
Access Road	4 b	6 b	8 a
Stream Crossing	8 a	12 a	18 a
Harvest	6 b	13 b	26 a
Control	4 b	19 b	30 a

* Different lowercase letters, within a row, indicate a significant difference at the 0.10 level.

Slope percentages for stream crossings are the average of the two approaches, therefore, a nonparametric test of stream crossing medians were performed. A significant difference in slope percent medians was detected among physiographic provinces p=0.096.

4.1.2 Erosion Rates for Disturbance Categories by Ratio and Physiographic Province

The previous estimated soil loss values presented annual erosion in Mg/ha/yr, but these values do not account for the ratio or percentage, which are not the same for disturbance category area or percent relative to the total tract size. The erosion amount, by disturbance category in Mg/ha/yr accounts for the area that each disturbance category occupies within a tract. This erosion rate calculation provides the average erosion rate by multiplying the USLE erosion value by each disturbance categories percent of area within the total tract by physiographic province (Figure 9).

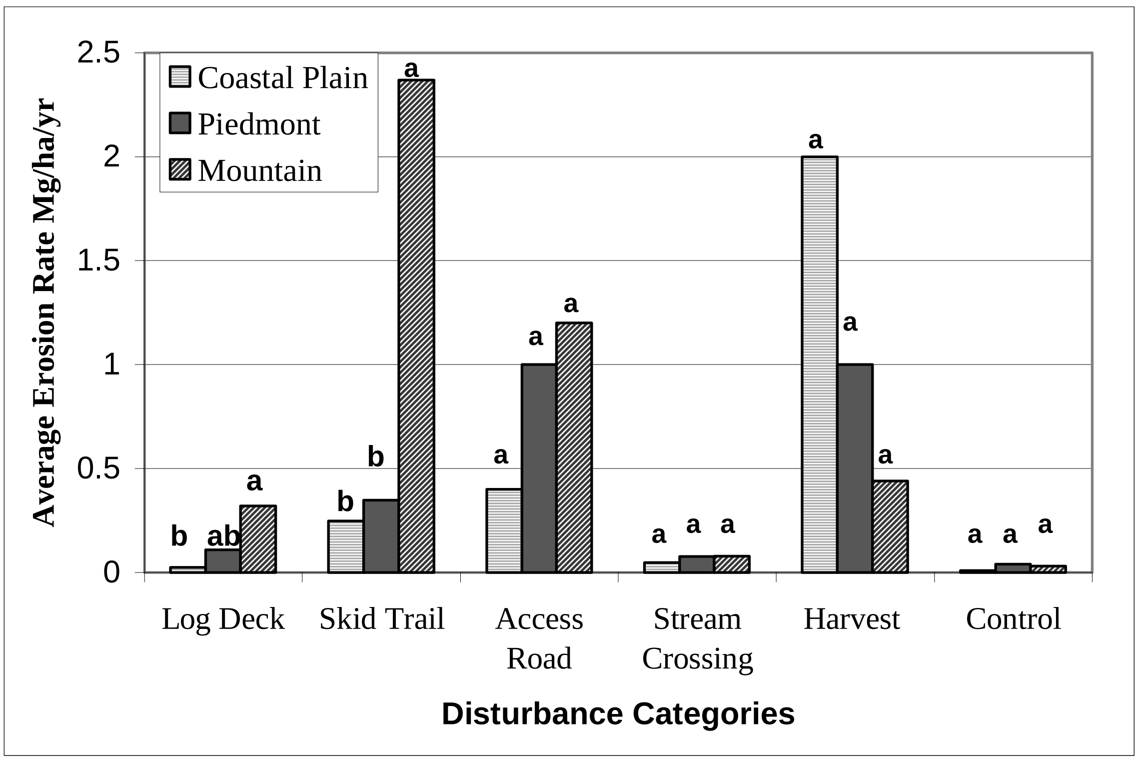

Figure 9. Average erosion rates from each disturbance category by physiographic province when extrapolated to the ratio of land that each disturbance category occupies.

From the results of the multiple comparisons test, the obvious interpretation is that the average estimated erosion rates from all disturbance categories were far less than that from traditional agricultural practices. Mountain skid trails, which contributed the greatest amount of estimated erosion have approximately half the erosion rate expected from pastureland (Yoho, 1980).

There were significant differences in erosion for log decks and skid trails disturbance categories. Skid trail erosion rates in the Mountains might be a result of the higher erosion values combined with the greater ratio of skid trails, which were 5% of total tract area compared to the 2% found in the other provinces.

According to Figure 9, the harvest area disturbance category contributed the greatest amount of erosion in the Coastal Plain. However, in the Piedmont the erosion rates from the access roads to the entire tract erodes more than the harvest area. This repeats earlier claims by studies that state the access road is the leading contributor to erosion from timber harvesting operations.

4.1.3 Evaluation of Time on Erosion

Because BMP inspections represent only a single point in time, it is important to understand soil loss over time. Erosion rates are expected to decline with time, but uncertainty exists regarding the length of recovery for the tract, disturbance categories, and regions. For example, Golden (1984) and Dissmeyer (1980) cited in Aust et al. (1996) found that the average recovery time for harvests in all three physiographic provinces was four years. However, this was the harvest as a whole and not separated into disturbance categories.

Overall, the influence of time was not the most significant factor for estimated erosion rates in the Coastal Plain, Piedmont, and Mountains. However time did influence some variables (Table 17).

Table 17. Predictor variables of erosion where year since harvest had a significant effect.

	Disturbance Category	Predictors	R^2 %	P-Value
Coastal Plain	**Access Road**	Access Road Ratio	57	p=0.052
Piedmont	**Skid Trail**	Slope Percent	52	p=0.039
	Harvest Area	Slope Percent and Slope Length	50	p=0.032
Mountains	**Log Deck**	Amount of Cover	75	p=0.001
	Harvest Area	Amount of Cover	42	p=0.04

The result indicated that time was a significant factor on access road ratio in the Coastal Plain. This was believed a combination of road closure practices as well as natural recovery. Time's influence on slope percent in the Piedmont might be a result of vegetation establishment over time. It was clear that time is a significant influence on vegetation establishment over bare soil in the Mountains.

To better understand how timber harvest sites recover, a scatter plot was created to show erosion rate distributions for each disturbance category. Ongoing timber harvesting operation erosion rates as well as control tract erosion rates was included to illustrate erosion rates from of time of harvest to 20 years since harvest. Overall, erosion rate trends over time either indicated soil loss reduction or an increase (Figures 10).

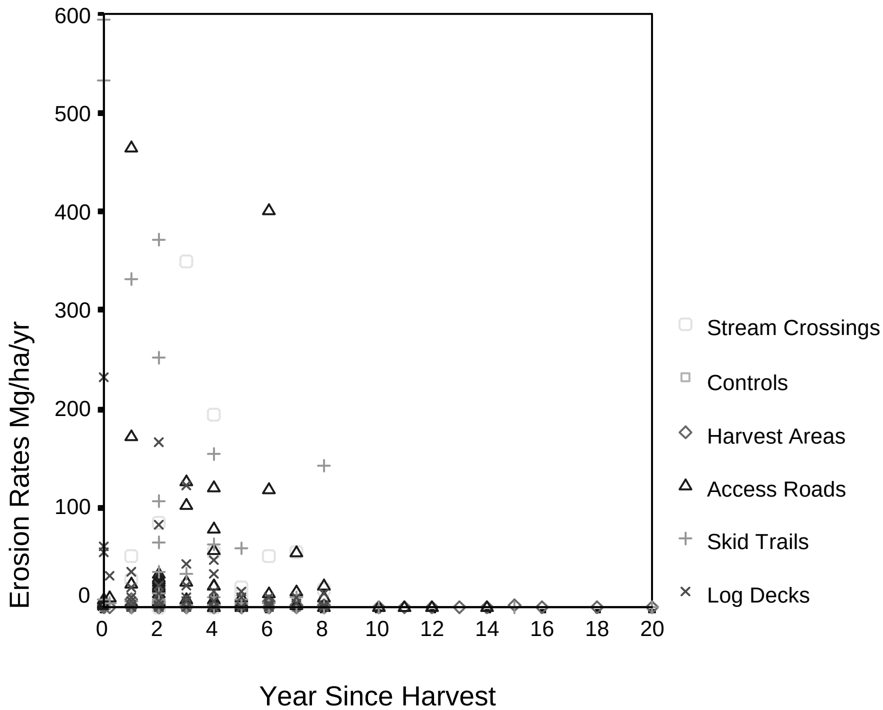

Figure 10. Disturbance category estimated erosion trends over time.

Erosion trends decrease for the majority of disturbance categories over time. An erosion trend line was not produced for Figure 10 as a result of the data variability. Overall, all disturbance categories seemed to essentially recover between six and 10 years since harvest. Although there are some disturbance categories which exhibited higher values, they are still within the range of erosion rates found from other land uses.

An increase in erosion rate for log decks was believed a result of a slightly greater log deck erosion rate value at year eight as well as a small sample size in later years which was believed to have manipulated the erosion trend for this disturbance category. Additionally, it was believed the skid trail trend was due to a 100-year storm event that occurred the summer before the study in the southwestern Virginia (where the control tracts were), which caused large-scale erosion in this region. Site recovery time differs for each disturbance category, for example the access road erosion trend reaches a minimal erosion rate between around 10 to 12 years after harvest, while harvest erosion remains around a constant low level from time zero to 20 years after harvest.

5. Erosion Rates by VDOF Audit Classifications

An additional goal of this study was to determine whether the subjective VDOF biannual audit inspections and more quantitative USLE estimates provide similar results. This goal was achieved by comparing USLE soil erosion rates for each disturbance category by physiographic province based upon the VDOF audit classifications of the sampled tracts. It is important to note that the VDOF look for evidence of sedimentation to a water body at stream crossings and do not examine erosion rates. Therefore, there may not be a correlation between USLE erosion rates and observed water quality threats during VDOF audits. Regardless, it is believed that erosion and sedimentation are directly correlated; therefore, a comparison of erosion rates and VDOF classifications was performed.

5.1 Comparison of Erosion Rates Classified by VDOF Audits

Each tract that is evaluated through the VDOF's biannual random audit received one of three classifications of 1) active, 2) potential, or 3) no sedimentation. An ANOVA was used to compare the weighted erosion rate average in Mg/ha/yr, based upon these classifications by physiographic province (Table 18).

Table 18. Estimated weighted erosion rate averages of tracts by VDOF Classification and Physiographic Province.

	VDOF Classifications			
	Active	**Potential**	**Nonactive**	
Physiographic Province	**Mg/ha/yr**			**P-Values**
Coastal Plain	13	1.5	4.5	p=0.251
Piedmont	3	8.8	6.5	p=0.414
Mountains	6.2	10.3	12.5	p=0.450

There were no significant differences in the tracts average erosion rates by physiographic province and VDOF classification. Therefore, each disturbance category was evaluated separately to identify differences in the mean estimated erosion rates by VDOF classification (Table 19).

Table 19. Estimated Average Erosion Rate From Each Disturbance Category by VDOF Classification.

	Mg/ha/year					
	Access Road	**Skid Trail**	**Log Deck**	**Stream Crossing**	**Harvest Area**	**Weighted Average**
Nonactive	16	7	7	35	0.5	1.4
Potential	13	6	9	11	0.5	2.4
Active	8	9	14	24	0.6	2.9

The highest estimated erosion average throughout the study tracts was for VDOF classified nonactive stream crossings at 35 Mg/ha/yr with the classification of active sedimentation average being second with 24 Mg/ha/yr.

When displaying the data in graph form, the distribution of the average estimated erosion rate can clearly show which areas the VDOF are accurate in predicting water quality problems, and those areas that need further examination during the audit (Figure 11).

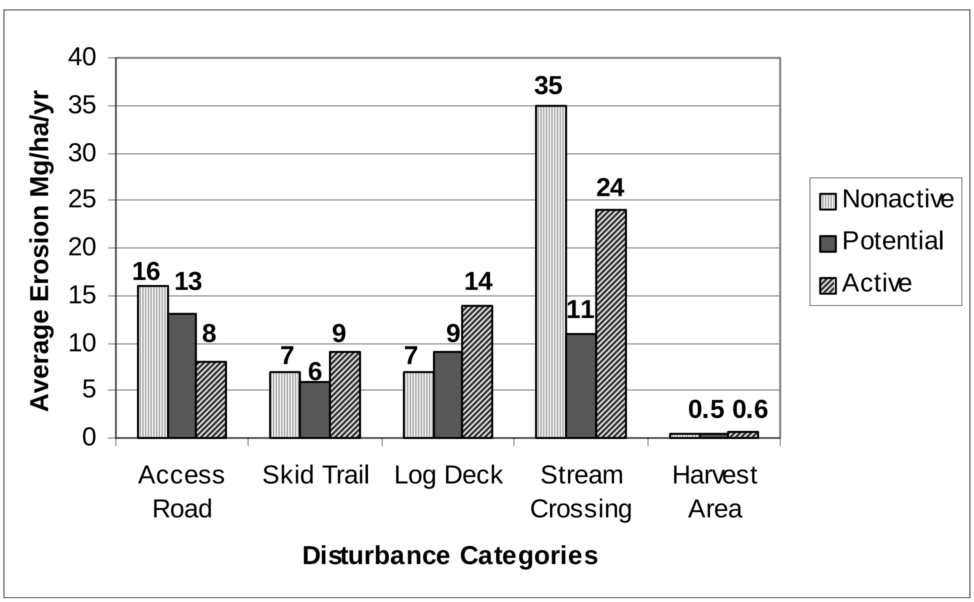

Figure 11. The average estimated erosion rates from each disturbance category by VDOF classification.

An expected erosion distribution would be a trend showing that nonactive tracts erode far less than potential, which erode far less than active. However, erosion rates vary regardless of VDOF classification. The erosion distribution from Figure 11 showed that VDOF audits did not correlate with the predicted erosion rates.

The estimated average erosion rates from the VDOF audits, based on the ratio of each disturbance category to the total tract area, were broken out by physiographic province (Figure 12).

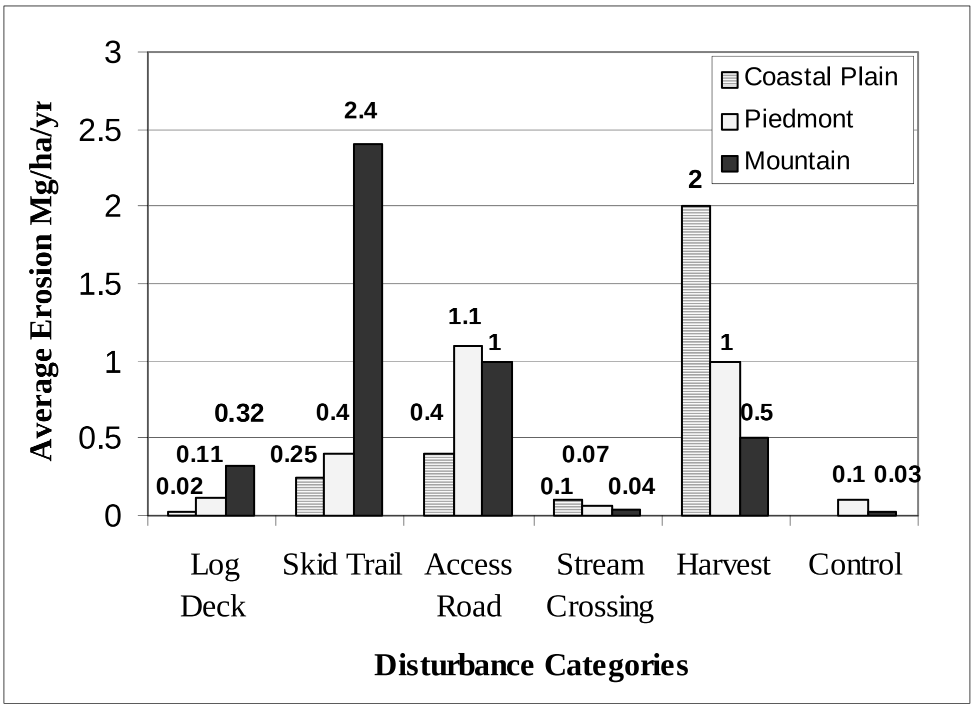

Figure 12. Average erosion rates by disturbance category and physiographic province based on VDOF classifications.

The differences in erosion rates were assumed a result of erosion rate variability as well as the sample size for each disturbance category. For example, the harvest disturbance category is based upon 18 samples per province, while the stream crossing erosion rates were based upon five samples in the Coastal Plain and seven samples in the Piedmont as well as the Mountains.

Harvest tracts classified as nonactive sedimentation were eroding at the highest level, based upon the ratio of the disturbance category to the total tract. The VDOF clearly identifies those access roads and skid trails that are a concern towards water quality.

Although the USLE harvest area soil loss was much lower than the access road or skid trail erosion rates, when compared to the ratio of the total tract area, the harvest area contributed the greatest amount of erosion in the Coastal Plain.

Access road erosion, although much smaller in the ratio to the total tract area, contributes much erosion to the overall site erosion rate. This indicated that although the access road ratio can be significantly less than the harvest area, it might contribute the same amount of erosion. For example, an access road with a ration of 10% can contribute as much as a harvest area that comprises of 89% of the total tract area.

Within the Piedmont the VDOF audit classification of potential indicated that field personnel accurately depict the potential for sedimentation. However, similar to the Coastal Plain, there were still differences in the distribution of estimated erosion and VDOF classification. For example, log deck active and nonactive classifications erode, based upon ratio of disturbance category to total tract size, the same. Additionally, nonactive classified sites erode at the highest level for skid trails.

5.2 VDOF Audit Classification Discussion

The erosion rates over time from these audits show discrepancies between disturbance category soil loss and audit results. The differences found in the estimated erosion rates relative to VDOF classification indicated certain areas for improvement of the auditing process.

The enforcement authority behind the random audits is Virginia's water quality laws and therefore stream crossings receive the greatest attention. However, stream crossing erosion rates were considered low when compared to agriculture. Nonactive sedimentation disturbance categories for some disturbance categories were eroding greater than those classified as active. Although these erosion rates are a function of time and closeout BMPs, the difference between erosion rates and VDOF classifications encourage modification of current auditing procedures.

Sedimentation of a waterbody was the key <u>visual</u> indicator for whether or not a site received an active sedimentation evaluation. The data indicated that the classification of potential sedimentation was where VDOF officials were the most accurate when examining for water quality degradation. It was considered easier to identify a potential for water quality degradation rather than active as a result of erosion indicators, such as rills or gullies.

6. Evaluation of Other (Non-USLE) Erosion Estimate Parameters

To account for other potential causes of erosion from disturbance categories, parameters were measured to determine additional factors other than the USLE values. T-Tests were used to compare erosion rates from 1) gated vs. not gated timber tracts, 2) ORV usage vs. no usage, 3) properly implemented BMPs with adequate sized SMZs vs. not properly implemented BMPs and SMZs, and 4) slope aspect.

The percentage of those timber tracts that were gated by physiographic province can be seen in Table 20.

Table 20. The percentage of sampled tracts with gates.

Physiographic Province	Percent of Tracts Gated
Coastal Plain	33%
Piedmont	38%
Mountain	50%

Whether or not a harvested site was gated may influence the amount of ORV traffic and therefore it was assumed that reduced ORV traffic would mean a reduction in additional erosion potential. The percent distribution of gated vs. nongated tracts differs by physiographic province and the T-Test indicated that there was sufficient evidence to conclude an insignificant difference in the weighted erosion rates if the tract was gated tract vs. nongated ($p=0.105$). However, there was a significant difference in erosion rates for log decks ($p=0.065$) if a tract was not gated.

Because all tracts visited with road gates were not equal in their ability to keep out unwanted traffic, ORV usage was determined, in conjunction with recording whether or not a tract was gated (Table 21). From the subjective field evaluations the heaviest amount of ORV usage occurred in the Piedmont.

Table 21 Percent distribution of ORV usage throughout the sampled tracts.

	No ORV Usage Detected	Light ORV Usage	Medium ORV Usage	Heavy ORV Usage
Coastal Plain (gated)	86%	14%	12%	0%
Coastal Plain (not gated)	55%	9%	36%	0%
Piedmont (gated)	20%	80%	0%	0%
Piedmont (not gated)	30%	30%	20%	20%
Mountain (gated)	13%	75%	12%	0%
Mountain (not gated)	55%	22%	12%	11%

Similar to percent distribution pattern for gated timber tracts, ORV impacts also varied by province. It was discovered that stream crossing erosion was influenced significantly by moderate ORV usage (p=0.011) versus no ORV usage and access road erosion was influenced significantly by heavy ORV usage (p=0.038) versus no ORV usage.

From section 4, the percent distribution of harvest types from the sample plots showed that the clearcut method was preferred. Using a T-Test, the type of timber harvest, either clearcut or selective cut, indicated a significant affect on the estimated weighted erosion rate throughout Virginia (p=0.025). However, the aspect of the slope was not significant factor of erosion from all five, disturbance categories types.

These parameters provided further explanation of contributing factors of erosion on post harvest sites. From the water quality law standpoint, both gated tracts and ORV usage would need more stringent requirements, since stream crossing erosion has shown to be a significant factor with ORV traffic.

Each sample tract was evaluated for BMPs and SMZs working together as a system, based upon BMP subjective examinations (see section 3.5). From those field evaluations a percent distribution by physiographic province of those sites believed to have sufficient BMPs and SMZs as a system to control erosion, was created (Table 22).

Table 22. Percentage of tracts sampled with adequate BMPs and SMZs as a system by physiographic province.

Physiographic Province	Adequate BMPs and SMZs as a system
Coastal Plain	54%
Piedmont	75%
Mountain	71%

The Coastal Plain had the least amount of timber tracts with adequate BMPs and SMZs as a system while the Piedmont had the highest percentage. This would suggest that within the Coastal Plain, BMPs as a system are not as rigorously followed than within the other provinces, which was a result of inadequate SMZs.

The harvest type for all sample tracts were placed into one of two categories, 1) clearcut, or 2) selective cut. From these field classifications, the more frequent harvest type by physiographic province can be seen (Table 23).

Table 23. General Harvest Type Distribution in Virginia

	Harvest Type	
	Selective	**Clearcut**
Coastal Plain	11%	89%
Piedmont	39%	61%
Mountain	44%	56%

Harvest type appears to be related to topography and landowner type. For example, the Coastal Plain has the highest percentage of clearcutting and the lowest percentage of selective harvests. This may be because the gentle slopes of the Coastal Plain, coupled with industrial ownerships, and favored clearcutting more so than in the terrain limiting mountains.

6.1 Correlation of Erosion Parameters by Disturbance Categories and Physiographic Province

Pearson's correlation coefficient tests evaluated erosion parameters linear relationships for each disturbance categories by physiographic province. Parameters tested for each disturbance category were 1) disturbance category erosion rates, 2) aspect, 3) ratio of disturbance category, 4) total tract area, 5) year since harvest, 6) gated vs. nongated, 7) ORV use, 8) BMPs and SMZs used as a system and 9) harvest type (clearcut or selection).

COASTAL PLAIN

The evaluation of disturbance categories in the Coastal Plain identified those parameters that were either significantly negatively or positively correlated (Appendix F). The Coastal Plain exhibited a significant negative correlation between year since harvest and total tract area. This correlation indicated that as time increased total tract area decreased in the Coastal Plain, which might indicate a trend for recent harvest sizes.

A significant negative correlation between year since harvest and access road ratio to the total tract existed. This result indicated that an increase in time decreases the road ratio on tracts. This may be a result of closeout BMPs and site recovery.

Whether a tract was gated had a significant positive correlation to the total tract area in the Coastal Plain. This result was believed to be a function of landowner type because the larger tracts may indicate industrial timber industry ownership in this region.

The evaluation of stream crossings in the Coastal Plain showed a significant positive correlation between stream crossing erosion rates and stream crossing ratio. This suggested that erosion increases with an increase in the total road area hydrologically connected to stream crossing.

The control disturbance category estimated erosion rates showed a significant positive relationship with ORV traffic. Therefore, as ORV traffic increases, so does the erosion rate. Harvest type had a significant positive correlation with the control ratio, suggesting that either clearcut or selective cut allowed for a greater control ratio on a tract. Logic suggested that the selective cut harvest method would allow for a greater control ratio within a tract.

PIEDMONT

The evaluation of disturbance categories in the Piedmont identified those parameters that were either significantly negatively or positively correlated (Appendix G). The evaluation of skid trail erosion rates with BMPs and SMZs as a system showed a significant positive correlation, which suggested BMPs and SMZs as a system explained much of the variability in estimated skid trail erosion rates.

Access road erosion showed a significant negative correlation with BMPs and SMZs as a system, which implied when access road erosion increases, BMPs and SMZs as a system decrease. Harvest area estimated erosion rates and ORV usage showed a positive correlation implying that when ORV usage increases so does erosion rates.

MOUNTAINS

The evaluation of the disturbance categories in the Mountain province identified those parameters that were either significantly negatively or positively correlated (Appendix H). Log deck erosion evaluation identified that whether a tract was gated significantly negatively correlated with erosion rates. This suggested that erosion rates increased on log decks when tracts are not gated. A significant negative correlation existed between year since harvest and BMPs and SMZs as a system. This was believed to represent the natural recovery process of skid trails and not inadequate BMPs.

BMPs as a system and access road ratio had a significant negative correlation, which suggested, as access road ratio increase in the Mountains then BMPs and SMZs as a system decrease.

Harvest area correlations in the Mountains suggested when a tract was gated it had a significant negative correlation on the amount of harvest erosion. Therefore, additional erosion is avoided if a tract is gated.

An assessment of stream crossings ratio showed a significant negative correlation with ORV usage in the Mountains. This suggested that wider streams inhibited ORV passage. Further, as with the majority of disturbance categories in the Mountains, year since harvest had a significant negative correlation with BMPs and SMZs as a system. This result was assumed to indicate BMPs on a tract decrease as a result of the tract natural recovery process.

6.2 Evaluation of Erosion from Ongoing Harvest Operations and Controls

ONGOING HARVEST OPERATIONS

Soil loss from ongoing operations is expected to occur on average higher than those areas that have had the benefit of time to establish vegetation and for BMPs to be implemented. Erosion rates vary among the physiographic provinces. However, because of the small sample size (one per province), statistical analysis was not performed on the erosion data.

Estimated erosion rate comparisons from ongoing harvest operations to the sampled post harvest tracts showed a dramatic decline in average erosion rates in access roads, log decks, and skid trials (Table 24). However, access road estimated erosion rates were greater in the post harvest tracts. This was believed a function of several possible factors including improper closeout BMPs and ORV usage. Further, ongoing harvest operations typically maintain access roads including controlling runoff, to ensure that production would not be impeded by inadequate roads.

Table 24. Ongoing Timber Harvest Estimated Erosion Rates [values in brackets are the average USLE estimated erosion rates].

	Log Deck	Skid Trail	Access Road	Harvest Area
Coastal Plain	31 (9)	3 (11)	9 (10)	0.5 (1.7)
Piedmont	232 (22)	533 (61)	3 (53)	2 (1)
Mountain	56 (35)	593 (74)	5 (55)	2 (0.6)

- Stream crossings were not present within the randomly chosen ongoing sample tracts.
- Statistics were not performed on ongoing operations due to the small sample size

The ongoing operations soil loss from skid trails shows the effects that slope percent; soil type, percent cover, and working BMPs can have on erosion rates, when compared to the average USLE erosion rates for the sampled post harvest tracts. Overall, the ongoing harvest operation in the Piedmont produced the greatest amount of estimated soil loss.

Piedmont erosion rates on average tend to be consistently greater or as great as erosion from the Mountains, even though the average slope in the mountains is greater than the Piedmont. Additionally, log deck erosion rates were higher in the Piedmont than both the Coastal Plain and Mountain provinces. This may be a result of a combination of the soil types found in the Piedmont as well as the high compaction that log decks receive. As a result, vegetation may have a difficult time with establishment and soil loss is greater.

CONTROL PLOTS

The three randomly selected control tracts by physiographic province, ranged in years since harvest and therefore an average erosion rate and average year since harvest was calculated to provide an overall expected mean soil loss (Table 25). Because these tracts ranged from 10 to 20 years old, several of the disturbance categories were no longer visible and could not be included. Additionally, since there were fewer than two samples for certain disturbance categories, a statistical analysis could not be performed. It is important to note that for the control disturbance categories of access roads and skid trails had just one disturbance category present and therefore not averaged. However, the control disturbance category of harvest area was averaged and provided a range of year since harvest.

Table 25. Erosion rate in Mg/ha/yr from the nine randomly selected control plots, three per province.

	Coastal Plain	Piedmont	Mountain
Year Since Harvest	13	11	10
Access Road	0.1	0.2	0.02
Year Since Harvest	N/A	N/A	15
Skid Trail	N/A	N/A	0.3
Range of Year Since Harvest	12-14	11-18	10-20
Averaged Harvest Erosion	0.02	0.04	0.9

The estimated erosion rate from the mountain region indicated that access roads in the mountains eroded less than harvest areas found in the same province. A possible reason for this may be the site specifics of the mountain control tracts, which were in the Appalachian Plateau and received a 100-year storm event the summer before field sampling. When comparing the same disturbance categories for the other provinces, an expected pattern of erosion distribution rates was presented.

6.3 Erosion Rate Discussion

Estimated erosion rates across Virginia varied. The insignificant difference found between these erosion rates was in itself significant. Although erosion rates were more for some disturbance categories than others, overall, the weighted average was well within the acceptable limits of erosion for other land uses.

COASTAL PLAIN EROSION DIFFERENCES

There was less erosion rate variability in the Coastal Plain as in the other provinces. There were also notable differences in skid trail and access road erosion averages, which might be a result of the significant slope percent difference from the Mountain province.

Average erosion rates were higher in the Piedmont than Coastal Plain, however, the weighted erosion average in the Coastal Plain were almost equal to that of the Piedmont. This was interpreted as a function of the tract sizes and the contribution of soil loss of each disturbance category.

Access road ratio with year since harvest exhibited a significant negative correlation, which suggested that as time progressed the percentage of access road on a tract decreases. This was believed a combination of natural site recovery as well as proper closeout BMPs.

Harvest areas in the Coastal Plain eroded more than skid trails and access roads, based on the ratio of disturbance category to total tract size. Harvest area erosion rates found in Figure 8., were almost three times higher than skid trails and access roads, which suggest that further consideration to harvest area BMPs is warranted.

PIEDMONT EROSION RATE DIFFERENCES

Erosion rate variability in the Piedmont province showed that certain areas such as stream crossings and access roads need closer attention for proper BMP installation upon closeout of timber harvesting.

Stream crossings ratio in the Piedmont showed a significant positive correlation with estimated erosion rates. This was believed to indicate that an increase in the total hydrologically connected approaches to a stream crossing would increase erosion rates. This can be avoided with proper BMPs such as turnouts, waterbars, and broad-based dips.

From the averaged erosion rate based on disturbance category ratio size, forest access roads produced the greatest amount of erosion in the Piedmont. This coincides with statements from EPA (1993), which stated that access roads were the largest single contributor to erosion from timber harvesting operations. Because this average erosion rate accounts for the ratio of access roads to the entire tract it suggested that a small portion of access road may contribute more erosion than the much greater harvested area.

According to the outside USLE parameters, log decks were impacted if a timber tract was not gated, to restrict access. Overall, erosion trends showed that tracts recover between six and eight years after harvest. However, for certain disturbance categories the erosion trend over time took longer to recover or did not recover under the specific time frame examined for this study. There can be several factors as to why this occurred. For example, parameters measured outside the USLE showed that moderate ORV use significantly increased erosion rates at stream crossings. In addition, access road erosion rates significantly increased with heavy ORV usage in the Piedmont, which ties into stream crossing erosion. Eliminating or discouraging access to reduce erosion from ORV traffic should be a target priority when exiting a tract (Moll, 1996).

Piedmont soil is predominately clayey soil types and clays may recover slower from heavy logging traffic since they are subject to compaction. In turn, this effect might reduce vegetation ability to establish itself without the assistance of being sown into the ground or having the compacted areas ripped to reduce soil bulk density.

MOUTAIN EROSION DIFFERENCES

In the Mountain province the access roads and skid trails were the largest contributors of erosion, based on ratio of these disturbance categories to total tract size. This was probably as result of a combination of several factors: 1) average skid trail and access road ratio was higher in the Mountains, 2) steeper slopes, and 3) longer slope lengths.

Overall, disturbance category recovery time in the Mountains took longer than the other provinces. This was believed a result of the site-specific parameters such as slope percent and length. To increase site recovery time in the Mountains, correlations indicted that gating tracts would significantly decrease estimated erosion rates from log decks and the harvest area. From the erosion rate data, all tracts essentially recovered between years six and ten since harvest.

The likely driving force behind the erosion rate in the Mountains at stream crossings was the apparent lack of vegetation and the slope of the stream crossing approaches. Bare soil and slope are reasons for sedimentation over time and although BMPs might be present at stream crossings, they might not be sufficient. Revegetation is paramount in healing disturbed areas (Moll, 1996). Therefore, maintaining vegetative cover on eroding sites is an effective management tool.

The erosion rates for the Mountains suggested that breaking up slope grade and slope length, in combination with seeding log decks, skid trails, stream crossings, and leaving more slash debris on harvest sites would significantly reduce erosion in the Mountains. Further, tracts visited exhibited poorly constructed water bars within this region more common than the other provinces and needs to be corrected.

7. Estimated Erosion Rates from Timber Harvesting in Virginia

7.1 Evaluation of Erosion Rates by Physiographic Province.

An extrapolation of erosion rate data was performed to better understand the amount of annual soil loss in Virginia from timber harvesting operations. The analysis allowed calculation of the expected percentage of erosion for any given year from post harvest sites by physiographic province. This erosion percentage was broken out by VDOF classification to provide a picture as to what VDOF audited sites are contributing the most soil loss.

The first step was to sum erosion rates for disturbance categories in Mg/yr for each tract and dividing this number by the total area of all the sampled tracts by physiographic province. This provided an average estimated erosion rate Mg/ha/yr. Using USFS 1992 FIA data, an annual timber removal area in hectares for each physiographic province was obtained. From the FIA data, the annual hectares harvested were multiplied with the average soil loss/ha/yr by physiographic province, to obtain the percent contribution of annual soil loss related only to timber harvesting and not other land management practices, by physiographic province in Virginia (Table 26).

Table 26. Annual harvest hectares by province with estimated annual soil loss contribution.

Physiographic Province	Annual Harvested Ha/year	Estimated Annual Soil Loss Contribution From Those Hectares Harvested Annually
Coastal Plain	36,570 Ha/year	35%
Piedmont	42,537 Ha/year	32%
Mountains	25,509 Ha/year	33%
	Total	100%

The annual hectares of timber harvested, was multiplied with the average Mg/ha/yr of estimated erosion rates to obtain Mg/yr of estimated soil loss. All province soil losses were summed and each broken out into a percentage of the total contributing forest harvesting operations erosion rates for Virginia.

The distribution of annual estimated erosion rates throughout Virginia is relatively equal in percent soil loss contribution (Table 26). It was believed that the erosion distribution was the factors of total hectares harvested and the topography within each province. For example, the Mountainous region of Virginia is contributing roughly 2% less in erosion from the Coastal Plain although the annual harvested acres in the Coastal Plain is approximately 11,000 more hectares or 27,000 more acres harvested. The Piedmont province, which harvests the largest land area, is approximately 1% lower in total erosion from the Mountain provinces. This would be a result of the steep topography in the Mountains.

7.1.2 Evaluation of Estimated Erosion in Virginia, by VDOF Classification

To further understand the distribution of erosion rates in terms of VDOF audit classifications, the estimated sample tract erosion rates, which were extrapolated to the total annual harvested acres in Virginia, were used to separate out what percentage of annual erosion falls into what VDOF category (Table 27). The following calculation processes was used to determine the percent estimated annual contribution of erosion separated by VDOF classifications.

1) Totaled Hectares of those sample tracts classified as active, potential, and nonactive.

2) Calculated percentage breakdown of VDOF classifications based on the sum of audit inspections since 1993.

3) Multiplied the VDOF classification percents of active, potential, and nonactive to the average erosion (Mg/yr) for each province.

4) Summed the erosion values to obtain the total average erosion in Mg/y by physiographic province.

5) Divided the total average into the individual erosion values based on VDOF classifications, which provided the percent erosion rate for that regions contribution of VDOF audited plots.

Table 27. Estimated average annual contribution of soil loss by VDOF classifications by physiographic province.

	Active	Potential	Nonactive	TOTAL
Coastal Plain	4%	58%	38%	100%
Piedmont	36%	34%	30%	100%
Mountains	10%	54%	36%	100%

Table 28, indicated that the area contributing the most erosion, with the estimated erosion rate percentage (58%) in the Coastal Plain, potential. The Mountain province had the second highest erosion percentage under the potential classification (54%). The contribution to overall erosion from active sites is less than the other classifications. Further, the variation in erosion contribution percentage is greater under the active classification.

The overall percent distribution of erosion in Virginia was not as varied under the nonactive classification, which indicates that the VDOF was more accurate in their field audits when predicting a site to be nonactive for sedimentation.

Although, erosion and sedimentation are two separate processes, they are a connected system of aggradation and degradation and this discrepancy shows a need for improvement in the auditing process.

7.1.3 Comparison of Estimated Erosion from Timber Harvesting to Other Land Uses

Soil loss from timber harvesting practices has been a continued source of concern for potential water quality sedimentation problems in Virginia. However, the level of sediment that timber harvesting contributes to statewide water quality degradation is well documented. When compared to the significant amount of vegetation residue covering the ground surface after timber harvesting, erosion rates from timber harvesting are deemed to be one to two orders of magnitude less than that from cropland (Brown, 1985, cited in Novtony, 1994).

According to Robinson (1979) sediment yield from Agricultural lands can range from 11 to 29 Mg/ha/yr. The average estimated erosion from this study was 2.7 Mg/ha/yr in the Coastal Plain, 2.5 Mg/ha/yr in the Piedmont, and 4.4 Mg/ha/yr of erosion in the Mountains. Approximate annual timber harvesting occurs on 104,616 ha/yr while it is believed that agriculture occurs sums to a much larger area in Virginia. Thus the upper range of expected total sediment yield contribution from timber harvesting would be much lower than that of the other traditional land management practices (Table 28).

Table 28. Sediment losses due to natural and human-made erosion (adapted from Dillaha 2000).

Sediment Source	Sediment Yield Mg/ha/yr
Natural erosion	0.4
Timber harvesting erosion	0-4.4 Weighted Erosion Average
Agriculture erosion (pasture, cropland etc.)	0.1-100
Urban erosion	0-500
Highway erosion	0-500

8. Southeast BMP Monitoring Needs

The variability in BMP monitoring among the southeastern states gives rise to a need for creation of minimum standard BMP monitoring and reporting process (Vowell, 2001). Although a minimum standardized monitoring process had been introduce in the mid-90s, it was not embraced by various states, for previously mention reasons (see section 2.7). States should create a standard reporting procedure, which would present findings based upon a uniform BMP language and monitoring procedures, in like format.

The results from this study identified the inherent difficulty associated with BMP monitoring. Expected erosion rates differ within tract as well as within and between provinces. Estimated erosion rates for each disturbance category exhibited no significant difference among provinces and by VDOF classification.

The minimum monitoring standard is a goal with which states would aspire to meet. There would be no ranking of state BMP effectiveness/compliance levels because it would be unfair to compare the achievements in erosion control between, for example, Louisiana and Virginia. There is too much variability between these two states to compare erosion/sedimentation, however, regulatory officials could examine their measurable achievements of the minimum standards. If states do not meet the minimum standard within "N" number years, then regulatory action can be recommended.

The creation of a minimum BMP monitoring standard will allow for a true understanding as to level with which states are monitoring and implementing BMPs. Further, with a similar reporting and monitoring process, southeastern states can have a common ground to convey ideas on what avenues of improvement work and don't work.

The federal government has relied on states to ensure that effective programs are implemented to prevent water quality degradation. If a state has proven unable to perform the task successfully, then the federal government has the responsibility to take over a program through regulations. Therefore, if all southeastern states were on a minimum standard of BMP monitoring and reporting it would provide credible indicators of success. The following list provides the general overall need for southeastern states continuity for monitoring BMP effectiveness.

Basic Standards

1. Common definition of compliance and implementation standards.
2. Common random sample selection criteria for BMP audits.
3. Common monitoring (recording) and presentation of data and results.

State Needs

1. Proper notification "several days/weeks" to a logging operation, to allow field personnel time to arrange work schedual.
2. Right to trespass on property to assess BMP implementation/effectiveness.
3. Adequate funding to implement BMP programs and monitoring.

Effectiveness

1. Standard methods for testing BMP effectiveness.
2. Less expensive objective "on-the-ground" procedure to assess effectiveness and compliance.

Baseline Studies

1. Only a handful of states monitor control watersheds for background data on natural loading rates for sediment and nutrients.
2. Compare and Contrast monitoring results by blocking study areas by region/physiographic province/landowner type.

EPA is focusing more on TMDLs as a solution to water quality problems from timber harvesting and believe that the next step is effectiveness studies to back high BMP compliance rates. However, some southeastern states have not begun to monitor BMP effectiveness for the previously mention reasons.

There is a need for continuity in reporting and monitoring to provide a more accurate picture. The above list are suggestions to remedying a current southeastern state need and suggest future examination of both mandatory and voluntary BMP monitoring nationwide.

9. Conclusion

The results from this study showed that erosion rates for timber harvesting between physiographic provinces were not significantly different. This finding in itself was significant because it identified that erosion rates vary greatly between and with provinces.

Each province had a disturbance category which contributed the greatest amount of soil loss when multiplied by its' area ratio. For example, this study showed that erosion from access roads was single largest contributor of erosion on harvesting sites in the Mountains. However, the harvest area in the Coastal Plain contributed the most erosion out of all disturbance categories, but according to the erosion loss tolerance table, harvest areas are not eroding at problem levels.

The lack of vegetative cover on skid trails, access roads, log decks, and stream crossings in conjunction with slopes with long slope lengths will increase erosion potential. From the field observations and results, it became obvious that harvesting closeout BMPs were often not effective in breaking slope lengths and establishing sufficient cover for many of the tracts sampled.

Anecdotal information observed during sample tract measurements was that the highest percentage of quality BMPs implementation was often found in areas closest to a road. Further, sites in the Coastal Plain and Piedmont tend to have seeded log decks and skid trails more than tracts in the Mountains. However, the majority of those lands owned by forest products companies in the Mountains did seed and use proper BMPs, with less of an occurrence on non-industrial private landowners property.

A possible solution for post harvest BMP effectiveness is the development of a minimum standard of estimated erosion rates for each physiographic province. The current VDOF BMP manual addresses the universe of applicable BMPs in a broad manner to cover all possible erosion control situations. However, additional studies would need to take place to establish proper recommendations for vegetative cover percentages for close out BMPs.

Disturbance category correlations outside the USLE parameters by physiographic province suggested that ORV usage and tract gates are needed to reduce additional erosion potential on post harvested tracts. Visual observations suggested that gate functionality vary among tracts. Therefore, the greatest care is need when gating a tract to ensure that trespassers are not permitted to drive ORV on the property. Estimated erosion rate trends over time showed a decrease of soil loss for all disturbance categories in Virginia.

A recommendation to the VDOF is to not consider poorly constructed water bars (often referred to as “tank traps”) as a viable BMP. There were numerous cases throughout Virginia where these improperly constructed water bars were installed near stream crossings with erosion evidence indicating their subsequent failure. Although there are no statistics on how often this BMP type was installed, the visual observation of poorly constructed water bars showed that “tank traps” fail repeatedly. In addition to stream crossings, poorly constructed water bars on steep slopes for access and skid roads failed repeatedly and warrant future scrutiny on their implementation as a BMP. This might be a good option for on the ground improvements, but this does not consider the VDOF audit process.

The random audit process conducted by the VDOF is intended to be a more in-depth evaluation of timber harvest effects on water quality rather than erosion. However, the variability of erosion rates based upon VDOF classification suggest, that a more quantifiable objective field audit process be developed based on the predictor variables and other findings from this study. It is recommended that the water quality auditing process be modified to include quantifiable erosion rates. Because there is a likely relationship between erosion rates and sedimentation, the VDOF might consider using the Dissmeyer and Foster USLE during their random audits as well as during harvest inspections to provide personnel with quantitative evaluations for making BMP recommendations.

Additional findings suggested that proper gating of tracts is an effective way to reduce ORV influences on erosion, especially for access roads and at stream crossings. Although results indicated that the subjective visual observation of BMPs and SMZs working as a system proved not to be statistically significant, alone this finding indicated that a visual subjective observation might not always be the most appropriate method of determining BMPs and therefore a quantifiable data collection system (USLE) is needed for BMP recommendations.

There has been a great emphasis placed on regulating timber harvesting operations as a point source of pollution as well as to have voluntary BMPs made mandatory. Overall, it was observed that the majority of tracts visited during this study attempted to employ the broad management measures of Virginia and EPA's BMP guidelines. The forestry community is adequately taking steps to reduce and prevent soil runoff. There are only a few bad actors in the state that attract regulatory attention and place pressure on the rest of the industry. The overall average estimated erosion rates from timber harvesting in Virginia are well within the acceptable limits of erosion from agricultural practices. This suggests that it would be more constructive to evaluate those land management practices that are responsible for the majority of water quality problems.

The results from this project demonstrate the need for further inquiry into the correlation between erosion and sedimentation from timber operations as well as a comparison between erosion from voluntary BMP programs and mandatory BMP programs.

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Appendix A: VDOF Harvest Inspection Form

Form 30
08/11/2000
f030_po.dot

VIRGINIA DEPARTMENT OF FORESTRY
HARVEST INSPECTION FORM

TRACT NUMBER:	PARCEL:	LANDOWNER NAME:
SUBMITTED BY: SSN NAME		DATE SUBMITTED:
LOGGER NAME: (for reference only)		INSPECTION: OPEN ☐ FINAL ☐

TRACT INFORMATION

TYPE OF HARVEST: CLEAR CUT ☐ SELECT CUT ☐ THINNING ☐

ACRES IN SALE ________ ACRES CUT TO DATE ________ TOTAL ACRES SPB IN SALE AREA ________

FUTURE LAND USE: FOREST ☐ AGRICULTURE ☐ DEVELOPMENT ☐

REGENERATION: NATURAL ☐ TO PLANT ☐ NOT KNOWN ☐

HARVESTED AT THE RECOMMENDATION OF: DOF ☐ CONSULTANT ☐ INDUSTRY FORESTER ☐ OTHER ☐

1. N/A
2. YES ☐ NO ☐ Was DOF notified prior to or not later than 3 working days after the start of harvest?
3. N/A
4. YES ☐ NO ☐ Does this tract comply with the Seed Tree Law?
5. YES ☐ NO ☐ Is there a stream/ditch channel present or adjacent to the harvest?
6. YES ☐ NO ☐ Is there water in the channel?
7. YES ☐ NO ☐ Any other water bodies present or immediately adjacent to the harvest?

IF ANY OF QUESTIONS 5, 6, OR 7 IS MARKED "YES", ANSWER THE FOLLOWING:

8. YES ☐ NO ☐ Was there any harvesting done in the SMZ?
9. YES ☐ NO ☐ Was the SMZ properly maintained?

BMP/WATER QUALITY LAW INFORMATION

DOES ACTIVITY IN ANY OF THE FOLLOWING CATEGORIES REPRESENT A:

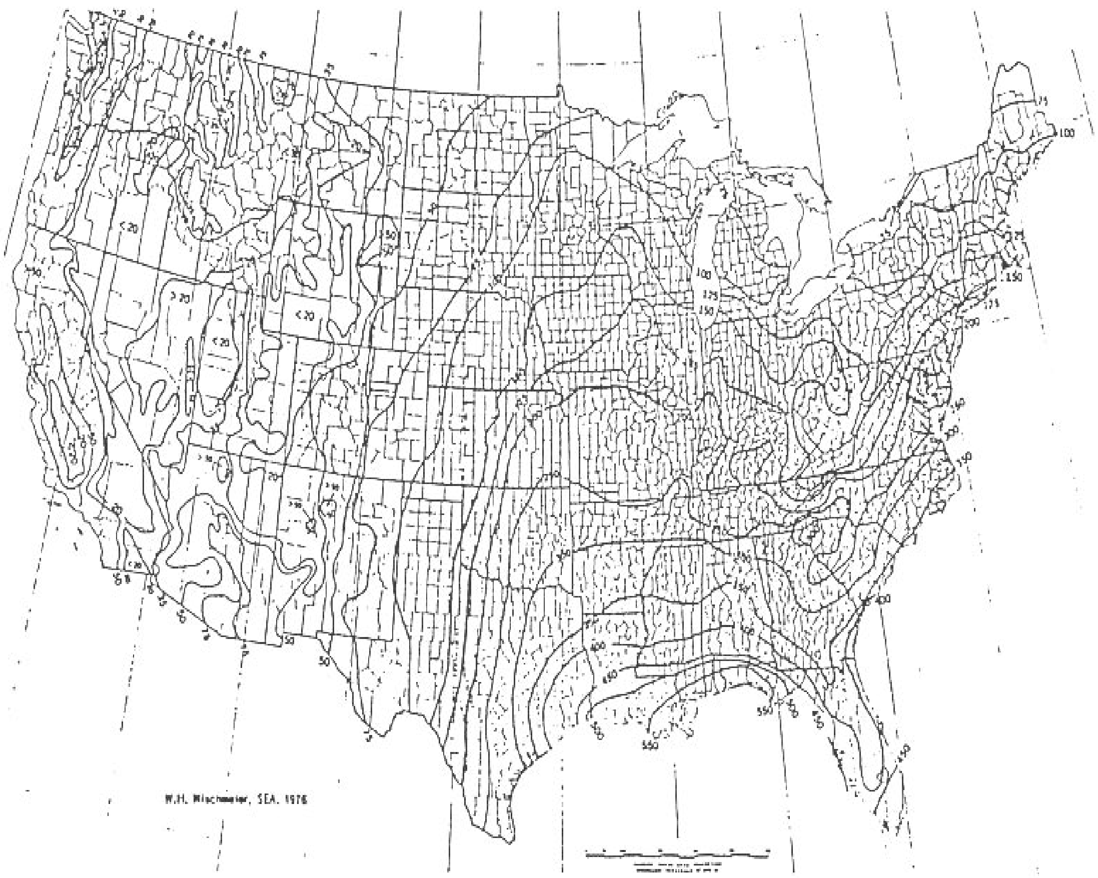
BMP's (see comments below)	WATER QUALITY DEFICIENCY	CATEGORY
10. See Comments Below	16. YES ☐ NO ☐	HAUL ROADS?
11. See Comments Below	17. YES ☐ NO ☐	SKID TRAILS?
12. See Comments Below	18. YES ☐ NO ☐	IMPROPER SMZ?
13. See Comments Below	19. YES ☐ NO ☐	LANDINGS?
14. See Comments Below	20. YES ☐ NO ☐	STREAM CROSSINGS?
15. See Comments Below	21. YES ☐ NO ☐	OTHER (SPECIFY) ________

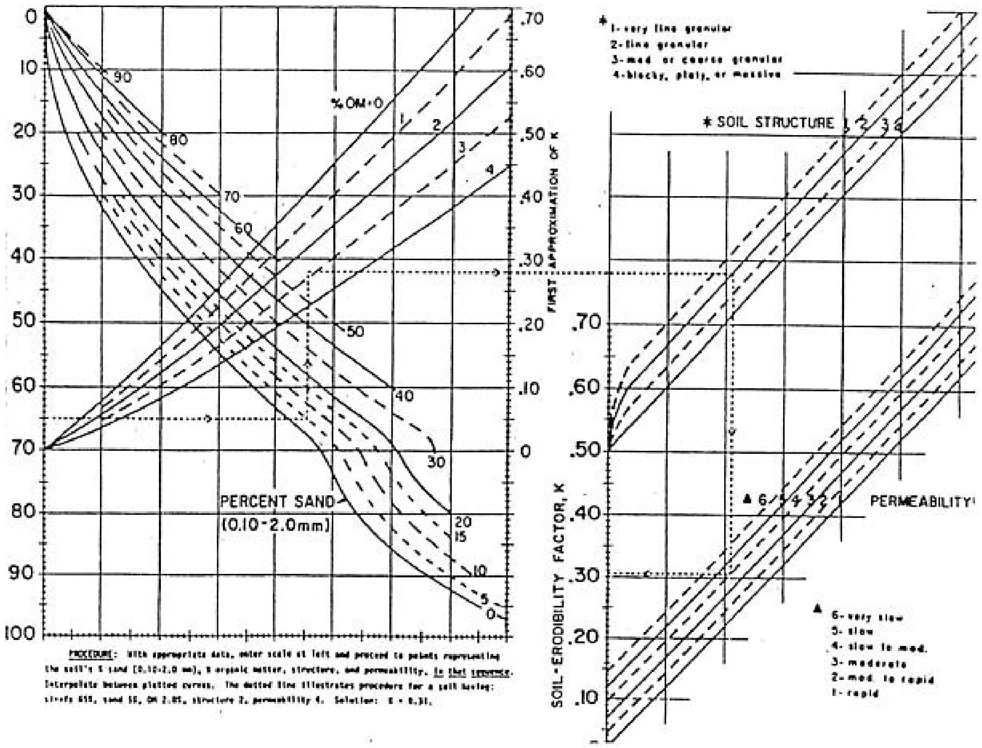
COMMENTS/RECOMMENDATIONS: ________

IF ANY ANSWER TO THE WATER QUALITY DEFICIENCY QUESTIONS IS "YES", PROCEED TO WATER QUALITY ENFORCEMENT FORM.

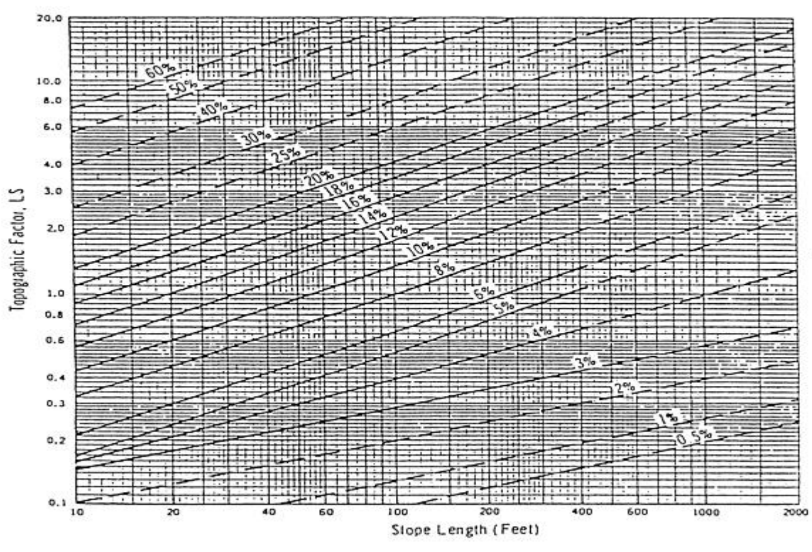
Appendix B: USLE Tables and Charts Used in the Field

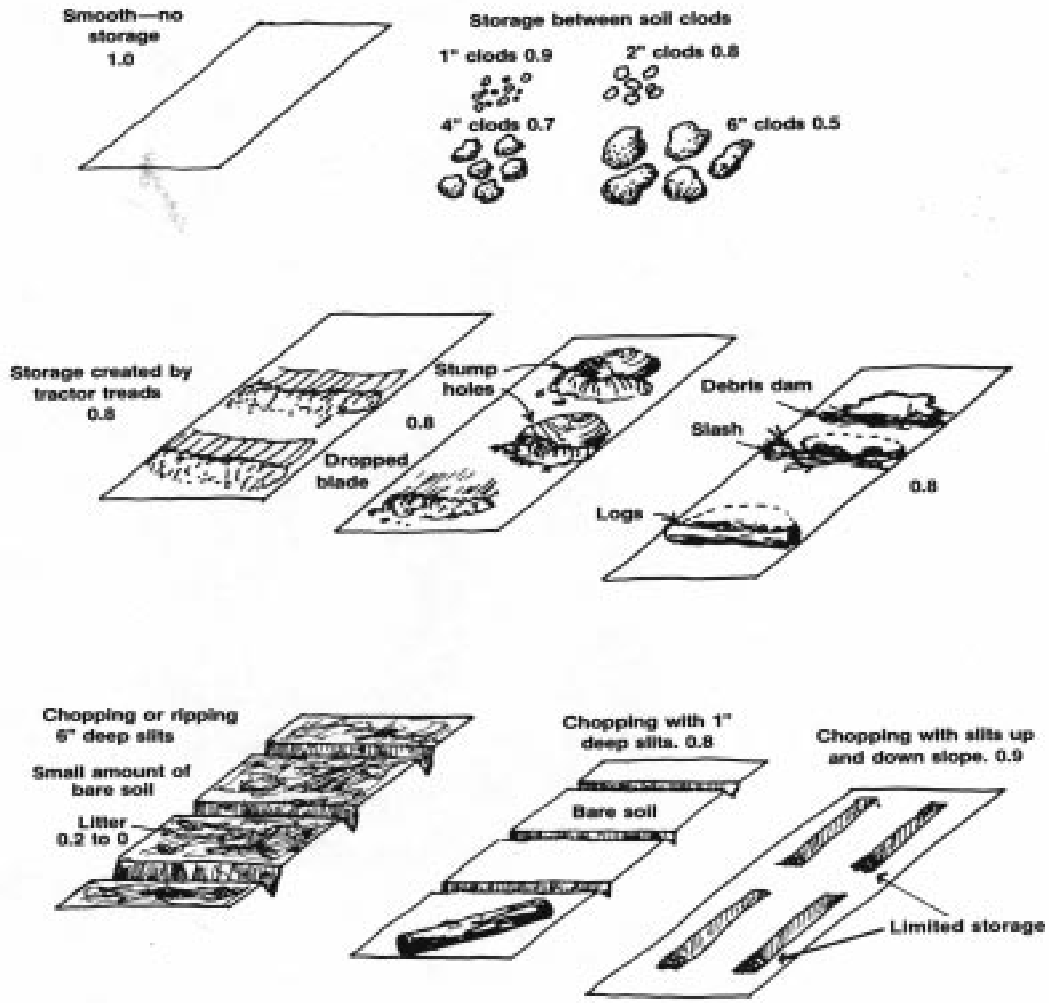
Rainfall Index





Soil Nomograph (K Factor) and LS Factor Graph





Storage Capacity Graphic

Appendix C: Tract Descriptions

Plot Number	Physiographic Provience	VDOF Classification	Year Since Harvest	Harvest Type	Hectares	Adequate SMZ/BMPs	ORV	Gated
1	Coastal Plain	P	5	0	24	0	0	0
2	Coastal Plain	G	2	0	34	1	0	0
3	Coastal Plain	A	2	0	40	1	0	0
4	Coastal Plain	P	0	0	41	0	0	0
5	Coastal Plain	A	2	1	13	1	0	0
6	Coastal Plain	A	5	0	8	0	2	0
7	Coastal Plain	A	6	0	11	0	1	0
8	Coastal Plain	G	2	0	76	1	1	1
9	Coastal Plain	G	2	0	6	.	0	1
10	Coastal Plain	P	7	0	21	0	0	1
11	Coastal Plain	A	5	0	6	0	0	1
12	Coastal Plain	P	3	0	59	0	2	0
13	Coastal Plain	G	5	0	4	.	0	0
14	Coastal Plain	P	2	1	71	1	0	1
15	Coastal Plain	G	1	0	5	1	0	0
16	Coastal Plain	P	7	0	87	.	0	1
17	Coastal Plain	G	4	0	24	1	0	0
18	Coastal Plain	A	8	0	4	1	1	0
19	Piedmont	P	1	0	6	1	1	0
20	Piedmont	B	2	0	73	1	3	0
21	Piedmont	P	4	0	8	1	0	0
22	Piedmont	P	4	0	13	.	2	0
23	Piedmont	B	4	0	64	1	2	0
24	Piedmont	B	6	0	18	0	0	0
25	Piedmont	G	4	1	13	1	1	0
26	Piedmont	B	8	1	142	1	1	1
27	Piedmont	P	2	1	34	1	1	0
28	Piedmont	G	3	0	26	0	1	1
29	Piedmont	G	4	1	60	1	0	0
30	Piedmont	G	1	1	16	1	0	1
31	Piedmont	P	2	1	8	1	0	1
32	Piedmont	P	2	1	12	1	1	1
33	Piedmont	B	8	1	6	.	0	0
34	Piedmont	G	1	0	81	0	0	1
35	Piedmont	B	6	0	54	0	3	0
36	Piedmont	G	4	0	41	1	1	1
37	Mountains	G	3	0	17	0	0	0
38	Mountains	B	2	1	68	1	2	0
39	Mountains	G	4	0	14	0	1	1
40	Mountains	P	2	1	12	1	0	0
41	Mountains	G	1	1	10	1	0	0
42	Mountains	P	7	1	8	0	3	0
43	Mountains	P	6	0	11	0	1	1
44	Mountains	B	5	0	11	1	0	1
45	Mountains	B	3	0	8	1	0	0
46	Mountains	G	3	1	8	.	0	0

47	Mountains	G	2	0	6	.		0	1
48	Mountains	B	3	1	36		1	2	1
49	Mountains	B	5	1	17		1	1	1
50	Mountains	G	2	0	12	.		1	1
51	Mountains	P	1	0	68		1	1	1
52	Mountains	B	5	0	8		1	1	1
53	Mountains	P	2	0	41	.		1	0
54	Mountains	P	4	1	20	.		1	0

Appendix D: Disturbance Category Data USLE Values in Mg/ha/yr

Plot Number	Access Road	Log Deck	Skid Trail	Stream Crossings	Harvest Area	Control
1		0.01	0.00		0.02	
2			14.54		20.62	
3	28.07	2.31	108.01	0.61	0.04	
4	7.57	62.38	7.57		2.24	0.03
5	.	.	0.11		1.31	0.01
6	9.34*	15.68	4.86		1.79	0.22
7	.	0.02	0.00		0.03	0.09
8	10.66	1.25	0.09		6.45	.
9	12.99	2.46	7.21		0.9*	.
10	1.77	3.32	9.90		1.12	0.02
11	.	.	0.09		0.00	0.04
12	3.56	8.96	34.05*		0.02	
13	.	0.03	0.0224*		0.04	
14	3.9	0.07	3.88	0.47	0.47	
15	24.57	5.51	.	27.71	1.55*	
16	14.96	.	0.49	.	1.28*	
17	0.22	.	2.67	0.07	0.26*	
18	21.44	0.22	0.36	2.15	0.04	
19	3	10.48	0.38	.	8.11*	
20	8.04	1.43	5.15	2.49	0.22	
21	80.12	47.13	1.60	195.52	0.00	
22	7.01	0.38	0.07	.	2.98	0.63
23	3.72	32.88	0.00	.	0.01	.
24	119.97	4.7	.	51	0.01	.
25	0.25	15.3	10.75	.	0.01	.
26	10.91	14.56	143.49	.	1.41	0.67
27	26.49	6.27	0.01	0.7	0.02	.
28	25.85	6.23	0.23	.	0.05	0.03
29	56.96	0.72	0.02	.	0.10	.
30	.	0.02	6.68	.	0.22	0.54
31	17.85	13.98	5.49	2.15	0.02	.
32	.	.	0.07	.	0.02	0.03
33	0.22	1.77	0.45	17.88	0.09	.
34	173.24	1.28	331.30	.	0.22	0.01
35	401.79	9.18	.	.	6.27	.
36	21.73	0.11	0.01	55.57	0.81	.
37	127.01	42.78	2.016*	.	0.45	0.03
38	6.72	82.63	36.06	86.42	0.25	.
39	22.18	5.02	155.77	.	0.07	0.03
40	29.37	20.88	253.12*	0.4	0.01	.
41	4.55	20.56	0.06	51.52	2.53	0.21
42	54.92	10.62	0.07	55.69	0.34	.
43	13.44	1.34	3.44	.	0.22	0.02
44	1.79	9.43	7.77	11.83	0.22	0.02

45	103.44	122.19	66.29*	.	1.52	0.04
46	.	0.36	1.40	.	0.73	0.58
47	33.6	.	4.93*	.	0.22	0.45
48	7.01	21.28	0.01	350.11	0.19	.
49	4.73	0.49	59.23*	20.79	0.54	.
50	19.71	1.12	0.22	.	0.09	.
51	464.49	35.08	6.94	.	0.31	0.03
52	0.02	0.01	4.14	.	0.45	0.04
53	22.18	166.5	371.9*	.	0.94	.
54	122.1	.	64*	.	0.81	0.08

* represent those values that were the average of muliplte subplot samples

Appendix E: Erosion rates by disturbance category ratio to total tract size

Plot Number	Geographic Province	Tract Area (hectares)	Access Road	Log Deck	Skid Trails	Stream Crossings	Harvest Area	Control
1	Coastal Plain	24		0.00004	0.00003808		0.0194	
2	Coastal Plain	34			0.3489024		20.2076	
3	Coastal Plain	40	0.014035	0.000231	3.240384	0.00061	0.0384	
4	Coastal Plain	41	0.047691	0.12476	0.1287104		2.128	0.0009
5	Coastal Plain	13			0.0028		0.6419	0.0047
6	Coastal Plain	8	0.11208	0.06272	0.0097216		1.3246	0.0528
7	Coastal Plain	11		0.00008	0.0000896		0.0288	0.0018
8	Coastal Plain	76	0.1066	0.00125	0.0011648		6.321	
9	Coastal Plain	6	0.2598	0.0246	0.0793408		0.855	
10	Coastal Plain	21	0.022125	0.00664	0.198016		1.0192	0.0012
11	Coastal Plain	6			0.0011648		0.0078	0.008
12	Coastal Plain	59	0.004984	0.0448	0.14301101		0.0196	
13	Coastal Plain	4		0.00093	0.00056		0.0372	
14	Coastal Plain	71	0.078	0.00014	0.0542528	0.000282	0.4512	
15	Coastal Plain	5	0.36855	0.0551		0.2771	1.426	
16	Coastal Plain	87	0.2992		0.0019712		1.2544	
17	Coastal Plain	24	0.0088		0.0106624	0.00007	0.2522	
18	Coastal Plain	4	3.216	0.00396	0.036288	0.00215	0.0288	
19	Piedmont	6	0.03	0.257808	0.0151424		7.5423	
20	Piedmont	73	0.01608	0.00286	0.05152	0.000249	0.2178	
21	Piedmont	8	8.012	0.56556	0.0319424	0.39104	0.0074	
22	Piedmont	13	0.02103	0.0057	0.002016		2.384	0.0945
23	Piedmont	64	0.01488	0.06576	0.00002037		0.0099	
24	Piedmont	18	4.19895	0.0235		0.051	0.0096	
25	Piedmont	13	0.00075	0.153	0.505344		0.0094	
26	Piedmont	142	0.03273	0.1456	1.434944		1.2972	0.067
27	Piedmont	34	0.31788	0.01254	0.00007392	0.0007	0.0194	
28	Piedmont	26	0.007755	0.0623	0.00535808		0.045	0.003
29	Piedmont	60	0.8544	0.00144	0.0000672		0.098	
30	Piedmont	16		0.00008	0.0801024		0.1606	0.135
31	Piedmont	8	0.58905	0.5592	0.1372	0.0215	0.018	
32	Piedmont	12			0.0007168		0.0184	0.0018
33	Piedmont	6	0.0088	0.0531	0.043456	0.03576	0.0819	
34	Piedmont	81	0.17324	0.00384	3.31296		0.2068	0.0005
35	Piedmont	54	1.60716	0.01836			6.2073	
36	Piedmont	41	0.6519	0.000275	0.0000672	0.05557	0.7776	
37	Mountain	17	2.5402	1.2834	0.06048		0.3735	0.003
38	Mountain	68	0.09408	0.33052	0.9016	0.034568	0.24	
39	Mountain	14	0.8872	0.0502	4.673088		0.0602	0.0018
40	Mountain	12	0.2937	0.08352	25.312	0.0012	0.0097	
41	Mountain	10	0.0455	0.08224	0.0056	0.05152	1.8469	0.042
42	Mountain	8	2.746	0.02124	0.0059136	0.05569	0.2958	
43	Mountain	11	0.1344	0.0134	0.3784		0.154	0.0036

44	Mountain	11	0.0537	0.2829	0.38864	0.03549	0.1804	0.0014
45	Mountain	8	2.0688	2.81037	0.0448		1.2312	0.004
46	Mountain	8		0.0036	0.07		0.5037	0.145
47	Mountain	6	1.008		2.6516		0.1738	0.0585
48	Mountain	36	0.0701	0.08512	0.000432	0.105033	0.1843	
49	Mountain	17	0.05676	0.00147	0.8291584	0.02079	0.5238	
50	Mountain	12	0.5913	0.00336	0.00224	0.304291	0.0855	
51	Mountain	68	4.6449	0.042096	0.118048		0.2852	0.0018
52	Mountain	8	0.0005	0.005	0.4144		0.2925	0.012
53	Mountain	41	0.04436	0.002	3.719		0.9212	
54	Mountain	20	4.884		3.2		0.6723	0.008

Appendix F. Coastal Plain Correlations

Log Deck Correlations

		Log Deck Erosion	Log Deck Aspect	Log Deck Ratio	Total Tract Area	Year Since Harvest	Gated vs. Nongated	ORV	BMP & SMZ as a system	Harvest Type
Log Deck Erosion	Pearson Correlation	1	.141	-.230	.113	-.456	-.248	-.027	-.376	-.138
	Sig. (2-tailed)	.	.646	.450	.713	.117	.413	.930	.255	.654
	N	13	13	13	13	13	13	13	11	13
Log Deck Aspect	Pearson Correlation	.141	1	-.553	.626	-0.053*	.141	-.102	.000	.207
	Sig. (2-tailed)	.646	.	.050	.022	.055	.630	.729	1.000	.478
	N	13	14	13	13	14	14	14	12	14
Log Deck Ratio	Pearson Correlation	-.230	-.553	1	-.557	.329	-.273	-.113	.278	.485
	Sig. (2-tailed)	.450	.050	.	.048	.272	.367	.713	.409	.093*
	N	13	13	13	13	13	13	13	11	13
Total Tract Area	Pearson Correlation	.113	.626	-.557	1	-0.47*	.396	.105	.234	-.179
	Sig. (2-tailed)	.713	.022	.048	.	.098	.181	.733	.489	.559
	N	13	13	13	13	13	13	13	11	13
Year Since Harvest	Pearson Correlation	-.456	-.523	.329	-.479	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.117	.055	.272	.098	.	.629	.421	.208	.262
	N	13	14	13	13	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.248	.141	-.273	.396	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.413	.630	.367	.181	.629	.	.355	.887	.621
	N	13	14	13	13	18	18	18	15	18
ORV	Pearson Correlation	-.027	-.102	-.113	.105	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.930	.729	.713	.733	.421	.355	.	.241	.420
	N	13	14	13	13	18	18	18	15	18
BMP & SMZ as a system	Pearson Correlation	-.376	.000	.278	.234	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.255	1.000	.409	.489	.208	.887	.241	.	.179
	N	11	12	11	11	15	15	15	15	15

* Correlation is significant at the 0.10 level (2-tailed).

Skid Trail Correlations

		Skid Trail Erosion	Skid Trail Aspect	Total Tract Area	Skid Trail Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Skid Trail Erosion	Pearson Correlation	1	.236	.155	-.078	-.295	-.225	-.005	.189	-.135
	Sig. (2-tailed)	.	.361	.551	.765	.250	.384	.984	.519	.607
	N	17	17	17	17	17	17	17	14	17
Skid Trail Aspect	Pearson Correlation	.236	1	.005	.184	-.302	-.368	.020	.429	.065
	Sig. (2-tailed)	.361	.	.984	.478	.238	.146	.938	.126	.803
	N	17	17	17	17	17	17	17	14	17
Total Tract Area	Pearson Correlation	.155	.005	1	-.234	-.270	.374	.023	.286	.150
	Sig. (2-tailed)	.551	.984	.	.365	.295	.140	.930	.322	.565
	N	17	17	17	17	17	17	17	14	17
Skid Trail Ratio	Pearson Correlation	-.078	.184	-.234	1	.287	-.299	-.122	-.058	-.086
	Sig. (2-tailed)	.765	.478	.365	.	.264	.244	.642	.844	.744
	N	17	17	17	17	17	17	17	14	17
Year Since Harvest	Pearson Correlation	-.295	-.302	-.270	.287	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.250	.238	.295	.264	.	.629	.421	.208	.262
	N	17	17	17	17	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.225	-.368	.374	-.299	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.384	.146	.140	.244	.629	.	.355	.887	.621
	N	17	17	17	17	18	18	18	15	18
ORV	Pearson Correlation	-.005	.020	.023	-.122	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.984	.938	.930	.642	.421	.355	.	.241	.420
	N	17	17	17	17	18	18	18	15	18
BMPs & SMZs as a system	Pearson Correlation	.189	.429	.286	-.058	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.519	.126	.322	.844	.208	.887	.241	.	.179
	N	14	14	14	14	15	15	15	15	15

Access Road Correlations

		Access Road Erosion	Access Road Aspect	Total Tract Area	Access Road Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Access Road Erosion	Pearson Correlation	1	.412	-.226	.238	-.059	-.263	-.145	.476	-.265
	Sig. (2-tailed)	.	.184	.481	.456	.855	.408	.654	.164	.406
	N	12	12	12	12	12	12	12	10	12
Access Road Aspect	Pearson Correlation	.412	1	.311	-.408	-.100	-.169	.436	.000	-.302
	Sig. (2-tailed)	.184	.	.325	.188	.757	.599	.156	1.000	.341
	N	12	12	12	12	12	12	12	10	12
Total Tract Area	Pearson Correlation	-.226	.311	1	-.367	-.106	.449	-.026	.085	.356
	Sig. (2-tailed)	.481	.325	.	.241	.743	.143	.935	.816	.255
	N	12	12	12	12	12	12	12	10	12
Access Road Ratio	Pearson Correlation	.238	-.408	-.367	1	0.57*	-.199	.093	.360	-.044
	Sig. (2-tailed)	.456	.188	.241	.	.052	.535	.775	.306	.892
	N	12	12	12	12	12	12	12	10	12
Year Since Harvest	Pearson Correlation	-.059	-.100	-.106	.572	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.855	.757	.743	.052	.	.629	.421	.208	.262
	N	12	12	12	12	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.263	-.169	.449	-.199	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.408	.599	.143	.535	.629	.	.355	.887	.621
	N	12	12	12	12	18	18	18	15	18
ORV	Pearson Correlation	-.145	.436	-.026	.093	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.654	.156	.935	.775	.421	.355	.	.241	.420
	N	12	12	12	12	18	18	18	15	18
BMPs & SMZs as a system	Pearson Correlation	.476	.000	.085	.360	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.164	1.000	.816	.306	.208	.887	.241	.	.179
	N	10	10	10	10	15	15	15	15	15

* Correlation is significant at the 0.10 level (2-tailed)

Harvest Area Correlations

		Harvest Area Erosion	Harvest Aspect	Total Tract Area	Harvest Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Harvest Area Erosion	Pearson Correlation	1	.178	.164	.168	-.289	-.059	-.083	.299	-.093
	Sig. (2-tailed)	.	.479	.515	.506	.245	.815	.743	.279	.713
	N	18	18	18	18	18	18	18	15	18
Harvest Aspect	Pearson Correlation	.178	1	-.295	.048	.099	.000	-.082	.196	.000
	Sig. (2-tailed)	.479	.	.235	.850	.697	1.000	.747	.483	1.000
	N	18	18	18	18	18	18	18	15	18
Total Tract Area	Pearson Correlation	.164	-.295	1	0.46*	-.183	0.553*	.054	.196	.165
	Sig. (2-tailed)	.515	.235	.	.054	.468	.102	.832	.484	.512
	N	18	18	18	18	18	18	18	15	18
Harvest Ratio	Pearson Correlation	.168	.048	.462	1	-.137	.169	-.111	-.095	-.474*
	Sig. (2-tailed)	.506	.850	.054	.	.589	.502	.661	.736	.047
	N	18	18	18	18	18	18	18	15	18
Year Since Harvest	Pearson Correlation	-.289	.099	-.183	-.137	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.245	.697	.468	.589	.	.629	.421	.208	.262
	N	18	18	18	18	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.059	.000	.397	.169	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.815	1.000	.102	.502	.629	.	.355	.887	.621
	N	18	18	18	18	18	18	18	15	18
ORV	Pearson Correlation	-.083	-.082	.054	-.111	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.743	.747	.832	.661	.421	.355	.	.241	.420
	N	18	18	18	18	18	18	18	15	18
BMPs & SMZs as a system	Pearson Correlation	.299	.196	.196	-.095	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.279	.483	.484	.736	.208	.887	.241	.	.179
	N	15	15	15	15	15	15	15	15	15

***** Correlation is significant at the 0.10 level (2-tailed).

Stream Crossing Correlations

		Stream Crossing Erosion	Stream Crossing Apsect	Total Tract Area	Stream Crossing Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Stream Crossing Erosion	Pearson Correlation	1	-.998*	-.511	.998*	-.431	-.266	-.188	.	-.266
	Sig. (2-tailed)	.	.000	.379	.000	.468	.665	.762	.	.665
	N	5	5	5	5	5	5	5	5	5
Stream Crossing Apsect	Pearson Correlation	-.998	1	.477	-.999*	.480	.250	.250	.	.250
	Sig. (2-tailed)	.000	.	.416	.000	.413	.685	.685	.	.685
	N	5	5	5	5	5	5	5	5	5
Total Tract Area	Pearson Correlation	-.511	.477	1	-.509	-.432	.846*	-.497	.	0.845*
	Sig. (2-tailed)	.379	.416	.	.382	.468	.071	.394	.	.071
	N	5	5	5	5	5	5	5	5	5
Stream Crossing Ratio	Pearson Correlation	.998	-.999	-.509	1	-.462	-.291	-.236	.	-.291
	Sig. (2-tailed)	.000	.000	.382	.	.433	.635	.702	.	.635
	N	5	5	5	5	5	5	5	5	5
Year Since Harvest	Pearson Correlation	-.431	.480	-.432	-.462	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.468	.413	.468	.433	.	.629	.421	.208	.262
	N	5	5	5	5	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.266	.250	.846	-.291	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.665	.685	.071	.635	.629	.	.355	.887	.621
	N	5	5	5	5	18	18	18	15	18
ORV	Pearson Correlation	-.188	.250	-.497	-.236	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.762	.685	.394	.702	.421	.355	.	.241	.420
	N	5	5	5	5	18	18	18	15	18
BMPs & SMZs as a system	Pearson Correlation	.	.	.	.	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.	.	.	.	.208	.887	.241	.	.179
	N	5	5	5	5	15	15	15	15	15
										1

* Correlation is significant at the 0.10 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

Control Correlations

		Control Erosion	Control Aspect	Total Tract Area	Control Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Control Erosion	Pearson Correlation	1	.488	-.399	-.016	.288	-.348	.973	-.383	-.383
	Sig. (2-tailed)	.	.326	.433	.976	.580	.499	.001	.453	.453
	N	6	6	6	6	6	6	6	6	6
Control Aspect	Pearson Correlation	.488	1	-.616	-.353	.929	.500	.463	-.632	-.632
	Sig. (2-tailed)	.326	.	.193	.493	.007	.312	.355	.178	.178
	N	6	6	6	6	6	6	6	6	6
Total Tract Area	Pearson Correlation	-.399	-.616	1	-.457	-.627	-.189	-.423	-.138	-.138
	Sig. (2-tailed)	.433	.193	.	.363	.182	.720	.404	.794	.794
	N	6	6	6	6	6	6	6	6	6
Control Ratio	Pearson Correlation	-.016	-.353	-.457	1	-.243	-.181	-.010	.849	.849*
	Sig. (2-tailed)	.976	.493	.363	.	.643	.732	.985	.032	.032
	N	6	6	6	6	6	6	6	6	6
Year Since Harvest	Pearson Correlation	.288	.929	-.627	-.243	1	.122	.202	-.345	-.279
	Sig. (2-tailed)	.580	.007	.182	.643	.	.629	.421	.208	.262
	N	6	6	6	6	18	18	18	15	18
Gated vs. Nongated	Pearson Correlation	-.348	.500	-.189	-.181	.122	1	-.232	-.040	.125
	Sig. (2-tailed)	.499	.312	.720	.732	.629	.	.355	.887	.621
	N	6	6	6	6	18	18	18	15	18
ORV	Pearson Correlation	.973	.463	-.423	-.010	.202	-.232	1	-.323	-.203
	Sig. (2-tailed)	.001	.355	.404	.985	.421	.355	.	.241	.420
	N	6	6	6	6	18	18	18	15	18
BMPs & SMZs as a system	Pearson Correlation	-.383	-.632	-.138	.849	-.345	-.040	-.323	1	.367
	Sig. (2-tailed)	.453	.178	.794	.032	.208	.887	.241	.	.179
	N	6	6	6	6	15	15	15	15	15

** Correlation is significant at the 0.10 level (2-tailed).

Appendix G. Piedmont Correlations

Log Deck Correlations

		Log Deck Erosion	Log Deck Aspect	Log Deck Area	Log Deck Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Log Deck Erosion	Pearson Correlation	1	-.279	-.045	.090	.104	-.224	-.025	.265	-.153
	Sig. (2-tailed)	.	.279	.862	.731	.691	.388	.923	.340	.557
	N	17	17	17	17	17	17	17	15	17
Log Deck Aspect	Pearson Correlation	-.279	1	.461	-.383	-.253	.410	.384	.075	.182
	Sig. (2-tailed)	.279	.	.063	.129	.326	.102	.128	.789	.484
	N	17	17	17	17	17	17	17	15	17
Log Deck Area	Pearson Correlation	-.045	.461	1	-.463	.251	.277	.287	-.030	.020
	Sig. (2-tailed)	.862	.063	.	.061	.331	.281	.264	.914	.939
	N	17	17	17	17	17	17	17	15	17
Log Deck Ratio	Pearson Correlation	.090	-.383	-.463	1	.057	.083	-.327	.220	.279
	Sig. (2-tailed)	.731	.129	.061	.	.829	.752	.200	.431	.278
	N	17	17	17	17	17	17	17	15	17
Year Since Harvest	Pearson Correlation	.104	-.253	.251	.057	1	-.249	.045	-.184	.204
	Sig. (2-tailed)	.691	.326	.331	.829	.	.319	.860	.496	.417
	N	17	17	17	17	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	-.224	.410	.277	.083	-.249	1	-.307	-.073	-.410*
	Sig. (2-tailed)	.388	.102	.281	.752	.319	.	.216	.789	.091
	N	17	17	17	17	18	18	18	16	18
ORV	Pearson Correlation	-.025	.384	.287	-.327	.045	-.307	1	-.037	.509*
	Sig. (2-tailed)	.923	.128	.264	.200	.860	.216	.	.891	.044
	N	17	17	17	17	18	18	18	16	16
BMPs & SMZs as a system	Pearson Correlation	.265	.075	-.030	.220	-.184	-.073	-.037	1	1
	Sig. (2-tailed)	.340	.789	.914	.431	.496	.789	.891	.	.
	N	15	15	15	15	16	16	16	16	18

* Correlation is significant at the 0.10 level (2-tailed).

Skid Trail Correlations

		Skid Trail Erosion	Skid Trail Aspect	Total Tract Area	Skid Trail Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Skid Trail Erosion	Pearson Correlation	1	.200	.582*	-.193	-.051	.396	-.234	-.591*	-.127
	Sig. (2-tailed)	.	.457	.018	.473	.850	.129	.382	.026	.640
	N	16	16	16	16	16	16	16	14	16
Skid Trail Aspect	Pearson Correlation	.200	1	.373	-.388	-.173	-.073	.421*	.284	.000
	Sig. (2-tailed)	.457	.	.154	.137	.522	.789	.104	.325	1.000
	N	16	16	16	16	16	16	16	14	16
Total Tract Area	Pearson Correlation	.582	.373	1	-.475	.310	.214	.238	-.128	-.036
	Sig. (2-tailed)	.018	.154	.	.063	.242	.426	.375	.662	.895
	N	16	16	16	16	16	16	16	14	16
Skid Trail Ratio	Pearson Correlation	-.193	-.388	-.475	1	.444*	-.333	-.208	.017	.180
	Sig. (2-tailed)	.473	.137	.063	.	.085	.208	.440	.955	.505
	N	16	16	16	16	16	16	16	14	16
Year Since Harvest	Pearson Correlation	-.051	-.173	.310	.444	1	-.249	.045	-.184	.087
	Sig. (2-tailed)	.850	.522	.242	.085	.	.319	.860	.496	.730
	N	16	16	16	16	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	.396	-.073	.214	-.333	-.249	1	-.307	-.073	-.410*
	Sig. (2-tailed)	.129	.789	.426	.208	.319	.	.216	.789	.091
	N	16	16	16	16	18	18	18	16	18
ORV	Pearson Correlation	-.234	.421	.238	-.208	.045	-.307	1	-.037	.509*
	Sig. (2-tailed)	.382	.104	.375	.440	.860	.216	.	.891	.044
	N	16	16	16	16	18	18	18	16	16
BMPs & SMZs as a system	Pearson Correlation	-.591	.284	-.128	.017	-.184	-.073	-.037	1	.204
	Sig. (2-tailed)	.026	.325	.662	.955	.496	.789	.891	.	.417
	N	14	14	14	14	16	16	16	16	18

* Correlation is significant at the 0.10 level (2-tailed).

Access Road Correlations

		Access Road Erosion	Access Road Aspect	Access Road Ratio	Total Tract Area	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Access Road Erosion	Pearson Correlation	1	.325	-.028	.144	.145	-.067	.238	-.679*	-.127
	Sig. (2-tailed)	.	.219	.917	.595	.593	.806	.374	.008	.640
	N	16	16	16	16	16	16	16	14	16
Access Road Aspect	Pearson Correlation	.325	1	.016	.060	-.206	.051	.126	-.228	.000
	Sig. (2-tailed)	.219	.	.953	.827	.445	.851	.642	.433	1.000
	N	16	16	16	16	16	16	16	14	16
Access Road Ratio	Pearson Correlation	-.028	.016	1	-0.431*	.168	-.135	-.515*	.196	-.036
	Sig. (2-tailed)	.917	.953	.	.095	.533	.617	.041	.502	.895
	N	16	16	16	16	16	16	16	14	16
Total Tract Area	Pearson Correlation	.144	.060	-.431	1	.213	.358	.260	.002	.180
	Sig. (2-tailed)	.595	.827	.095	.	.428	.174	.332	.995	.505
	N	16	16	16	16	16	16	16	14	16
Year Since Harvest	Pearson Correlation	.145	-.206	.168	.213	1	-.249	.045	-.184	.087
	Sig. (2-tailed)	.593	.445	.533	.428	.	.319	.860	.496	.730
	N	16	16	16	16	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	-.067	.051	-.135	.358	-.249	1	-.307	-.073	.204
	Sig. (2-tailed)	.806	.851	.617	.174	.319	.	.216	.789	.417
	N	16	16	16	16	18	18	18	16	18
ORV	Pearson Correlation	.238	.126	-.515	.260	.045	-.307	1	-.037	-.410*
	Sig. (2-tailed)	.374	.642	.041	.332	.860	.216	.	.891	.091
	N	16	16	16	16	18	18	18	16	18
BMPs & SMZs as a system	Pearson Correlation	-.679	-.228	.196	.002	-.184	-.073	-.037	1	.509*
	Sig. (2-tailed)	.008	.433	.502	.995	.496	.789	.891	.	.044
	N	14	14	14	14	16	16	16	16	16

* Correlation is significant at the 0.10 level (2-tailed).

Harvest Area Correlations

		Harvest Area Erosion	Harvest Aspect	Total Tract Area	Harvest Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs and SMZs	Harvest Type
Harvest Area Erosion	Pearson Correlation	1	-.320	-.045	.088	-.010	-.263	0.41*	-.133	-.356
	Sig. (2-tailed)	.	.195	.859	.728	.970	.292	.088	.623	.147
	N	18	18	18	18	18	18	18	16	18
Harvest Aspect	Pearson Correlation	-.320	1	.291	.081	.285	-.169	-.189	-.073	-.025
	Sig. (2-tailed)	.195	.	.242	.750	.252	.503	.452	.789	.920
	N	18	18	18	18	18	18	18	16	18
Total Tract Area	Pearson Correlation	-.045	.291	1	.400	.276	.206	.280	-.061	-.029
	Sig. (2-tailed)	.859	.242	.	.100	.267	.411	.260	.823	.910
	N	18	18	18	18	18	18	18	16	18
Harvest Ratio	Pearson Correlation	.088	.081	.400	1	.151	-.198	.373	-.188	-.072
	Sig. (2-tailed)	.728	.750	.100	.	.550	.430	.128	.485	.776
	N	18	18	18	18	18	18	18	16	18
Year Since Harvest	Pearson Correlation	-.010	.285	.276	.151	1	-.249	.045	-.184	.087
	Sig. (2-tailed)	.970	.252	.267	.550	.	.319	.860	.496	.730
	N	18	18	18	18	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	-.263	-.169	.206	-.198	-.249	1	-.307	-.073	.204
	Sig. (2-tailed)	.292	.503	.411	.430	.319	.	.216	.789	.417
	N	18	18	18	18	18	18	18	16	18
ORV	Pearson Correlation	.414	-.189	.280	.373	.045	-.307	1	-.037	-.410*
	Sig. (2-tailed)	.088	.452	.260	.128	.860	.216	.	.891	.091
	N	18	18	18	18	18	18	18	16	18
BMPs and SMZs	Pearson Correlation	-.133	-.073	-.061	-.188	-.184	-.073	-.037	1	.509*
	Sig. (2-tailed)	.623	.789	.823	.485	.496	.789	.891	.	.044
	N	16	16	16	16	16	16	16	16	16

* Correlation is significant at the 0.10 level (2-tailed).

Control Correlations

		Control Erosion	Control Aspect	Total Tract Area	Control Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Control Erosion	Pearson Correlation	1	.468	.251	.632	.588	-.468	.325	.669	-.127
	Sig. (2-tailed)	.	.349	.632	.178	.219	.349	.530	.217	.640
	N	6	6	6	6	6	6	6	5	16
Control Aspect	Pearson Correlation	.468	1	-.328	.211	.155	-1.000	0.759*	.	.000
	Sig. (2-tailed)	.349	.	.526	.689	.770	.	.080	.	1.000
	N	6	6	6	6	6	6	6	5	16
Total Tract Area	Pearson Correlation	.251	-.328	1	-.350	.672	.328	-.179	.031	-.036
	Sig. (2-tailed)	.632	.526	.	.497	.144	.526	.734	.960	.895
	N	6	6	6	6	6	6	6	5	16
Control Ratio	Pearson Correlation	.632	.211	-.350	1	-.132	-.211	-.114	.420	.180
	Sig. (2-tailed)	.178	.689	.497	.	.803	.689	.829	.482	.505
	N	6	6	6	6	6	6	6	5	16
Year Since Harvest	Pearson Correlation	.588	.155	.672	-.132	1	-.249	.045	-.184	.087
	Sig. (2-tailed)	.219	.770	.144	.803	.	.319	.860	.496	.730
	N	6	6	6	6	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	-.468	-1.000	.328	-.211	-.249	1	-.307	-.073	.204
	Sig. (2-tailed)	.349	.	.526	.689	.319	.	.216	.789	.417
	N	6	6	6	6	18	18	18	16	18
ORV	Pearson Correlation	.325	.759	-.179	-.114	.045	-.307	1	-.037	-.410*
	Sig. (2-tailed)	.530	.080	.734	.829	.860	.216	.	.891	.091
	N	6	6	6	6	18	18	18	16	18
BMPs & SMZs as a system	Pearson Correlation	.669	.	.031	.420	-.184	-.073	-.037	1	.509*
	Sig. (2-tailed)	.217	.	.960	.482	.496	.789	.891	.	.044
	N	5	5	5	5	16	16	16	16	16

* Correlation is significant at the 0.10 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

Stream Crossing Correlations

		Stream Crossing Erosion	Stream Crossing Apect	Total Tract Area	Stream Crossing Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs and SMZs as a system	Harvest Type
Stream Crossing Erosion	Pearson Correlation	1	.063	-.356	-.168	.169	-.173	-.362	.002	-.531
	Sig. (2-tailed)	.	.905	.433	.718	.718	.711	.424	.998	.220
	N	7	6	7	7	7	7	7	6	7
Stream Crossing Apect	Pearson Correlation	.063	1	.014	-.222	-.132	.730*	.091	.	-.091
	Sig. (2-tailed)	.905	.	.977	.633	.779	.062	.846	.	.846
	N	6	7	7	7	7	7	7	6	7
Total Tract Area	Pearson Correlation	-.356	.014	1	-.478	-.392	-.166	.924*	.180	-.459
	Sig. (2-tailed)	.433	.977	.	.231	.337	.695	.001	.699	.253
	N	7	7	8	8	8	8	8	7	8
Stream Crossing Ratio	Pearson Correlation	-.168	-.222	-.478	1	-.230	.512	-.439	.187	.463
	Sig. (2-tailed)	.718	.633	.231	.	.583	.195	.276	.688	.248
	N	7	7	8	8	8	8	8	7	8
Year Since Harvest	Pearson Correlation	.169	-.132	-.392	-.230	1	-.249	.045	-.184	.087
	Sig. (2-tailed)	.718	.779	.337	.583	.	.319	.860	.496	.730
	N	7	7	8	8	18	18	18	16	18
Gated vs. Nongated	Pearson Correlation	-.173	.730	-.166	.512	-.249	1	-.307	-.073	.204
	Sig. (2-tailed)	.711	.062	.695	.195	.319	.	.216	.789	.417
	N	7	7	8	8	18	18	18	16	18
ORV	Pearson Correlation	-.362	.091	.924	-.439	.045	-.307	1	-.037	-.410*
	Sig. (2-tailed)	.424	.846	.001	.276	.860	.216	.	.891	.091
	N	7	7	8	8	18	18	18	16	18
BMPs and SMZs as a system	Pearson Correlation	.002	.	.180	.187	-.184	-.073	-.037	1	.509*
	Sig. (2-tailed)	.998	.	.699	.688	.496	.789	.891	.	.044
	N	6	6	7	7	16	16	16	16	16

** Correlation is significant at the 0.10 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.

Appendix H. Mountain Disturbance Category Correlations

Log Deck Correlations

		Log Deck Erosion	Log Deck Aspect	Total Tract Area	Deck Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPS & SMZs as a system	Harvest Type
Log Deck Erosion	Pearson Correlation	1	.302	.418	.073	-.393	-.519*	-.036	.305	-.212
	Sig. (2-tailed)	.	.256	.107	.788	.132	.040	.894	.289	.431
	N	16	16	16	16	16	16	16	14	16
Log Deck Aspect	Pearson Correlation	.302	1	.517*	-.124	-.191	-.126	-.018	.000	-.016
	Sig. (2-tailed)	.256	.	.040	.646	.478	.642	.946	1.000	.953
	N	16	16	16	16	16	16	16	14	16
Total Tract Area	Pearson Correlation	.418	.517	1	-.335	-.491*	.016	.360	.338	.040
	Sig. (2-tailed)	.107	.040	.	.205	.053	.954	.171	.238	.883
	N	16	16	16	16	16	16	16	14	16
Deck Ratio	Pearson Correlation	.073	-.124	-.335	1	.177	-.085	-.547*	-.226	-.434*
	Sig. (2-tailed)	.788	.646	.205	.	.513	.755	.028	.437	.093
	N	16	16	16	16	16	16	16	14	16
Year Since Harvest	Pearson Correlation	-.393	-.191	-.491	.177	1	.200	.400	-.526*	.022
	Sig. (2-tailed)	.132	.478	.053	.513	.	.426	.100	.053	.930
	N	16	16	16	16	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	-.519	-.126	.016	-.085	.200	1	.067	.000	-.447
	Sig. (2-tailed)	.040	.642	.954	.755	.426	.	.793	1.000	.063
	N	16	16	16	16	18	18	18	14	18
ORV	Pearson Correlation	-.036	-.018	.360	-.547	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.894	.946	.171	.028	.100	.793	.	.429	.206
	N	16	16	16	16	18	18	18	14	18
BMPS & SMZs as a system	Pearson Correlation	.305	.000	.338	-.226	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.289	1.000	.238	.437	.053	1.000	.429	.	.433
	N	14	14	14	14	14	14	14	14	14
Harvest Type	Pearson Correlation	-.212	-.016	.040	-.434	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.431	.953	.883	.093	.930	.063	.206	.433	.

Skid Trail Correlations

		Skid Trial Erosion	Skid Trail Aspect	Total Tract Area	Skid Trail Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Skid Trial Erosion	Pearson Correlation	1	-.197	-.175	-.189	-.237	-.236	-.082	.136	-.050
	Sig. (2-tailed)	.	.434	.488	.452	.343	.346	.747	.642	.843
	N	18	18	18	18	18	18	18	14	18
Skid Trail Aspect	Pearson Correlation	-.197	1	.978*	.089	-.237	.067	.149	.251	.386
	Sig. (2-tailed)	.434	.	.000	.726	.343	.790	.556	.386	.113
	N	18	18	18	18	18	18	18	14	18
Total Tract Area	Pearson Correlation	-.175	.978	1	.055	-.344	.005	.145	.310	.399
	Sig. (2-tailed)	.488	.000	.	.827	.162	.984	.565	.281	.101
	N	18	18	18	18	18	18	18	14	18
Skid Trail Ratio	Pearson Correlation	-.189	.089	.055	1	.309	-.221	-.174	-.089	.103
	Sig. (2-tailed)	.452	.726	.827	.	.212	.378	.491	.763	.685
	N	18	18	18	18	18	18	18	14	18
Year Since Harvest	Pearson Correlation	-.237	-.237	-.344	.309	1	.200	.400	-0.526*	.022
	Sig. (2-tailed)	.343	.343	.162	.212	.	.426	.100	.053	.930
	N	18	18	18	18	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	-.236	.067	.005	-.221	.200	1	.067	.000	-0.447*
	Sig. (2-tailed)	.346	.790	.984	.378	.426	.	.793	1.000	.063
	N	18	18	18	18	18	18	18	14	18
ORV	Pearson Correlation	-.082	.149	.145	-.174	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.747	.556	.565	.491	.100	.793	.	.429	.206
	N	18	18	18	18	18	18	18	14	18
BMPs & SMZs as a system	Pearson Correlation	.136	.251	.310	-.089	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.642	.386	.281	.763	.053	1.000	.429	.	.433
	N	14	14	14	14	14	14	14	14	14
Harvest Type	Pearson Correlation	-.050	.386	.399	.103	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.843	.113	.101	.685	.930	.063	.206	.433	.
	N	18	18	18	18	18	18	18	14	18

* Correlation is significant at the 0.10 level (2-tailed).

Access Road Correlations

		Access Road Erosion	Access Road Aspect	Total Tract Area	Access Road Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Access Road Erosion	Pearson Correlation	1	-.220	.507*	-.082	-.315	.019	-.035	.038	-.217
	Sig. (2-tailed)	.	.396	.038	.754	.218	.941	.893	.896	.402
	N	17	17	17	17	17	17	17	14	17
Access Road Aspect	Pearson Correlation	-.220	1	-.248	-.159	-.103	-.169	-0.456*	.141	.029
	Sig. (2-tailed)	.396	.	.336	.541	.695	.517	.066	.630	.913
	N	17	17	17	17	17	17	17	14	17
Total Tract Area	Pearson Correlation	.507	-.248	1	-0.441*	-0.451*	-.069	.363	.338	.123
	Sig. (2-tailed)	.038	.336	.	.076	.069	.793	.152	.238	.638
	N	17	17	17	17	17	17	17	14	17
Access Road Ratio	Pearson Correlation	-.082	-.159	-.442*	1	.498*	.043	.252	-.550*	-.032
	Sig. (2-tailed)	.754	.541	.076	.	.042	.869	.329	.042	.904
	N	17	17	17	17	17	17	17	14	17
Year Since Harvest	Pearson Correlation	-.315	-.103	-.451	.498	1	.200	.400	-0.526*	.022
	Sig. (2-tailed)	.218	.695	.069	.042	.	.426	.100	.053	.930
	N	17	17	17	17	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	.019	-.169	-.069	.043	.200	1	.067	.000	-0.447*
	Sig. (2-tailed)	.941	.517	.793	.869	.426	.	.793	1.000	.063
	N	17	17	17	17	18	18	18	14	18
ORV	Pearson Correlation	-.035	-.456	.363	.252	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.893	.066	.152	.329	.100	.793	.	.429	.206
	N	17	17	17	17	18	18	18	14	18
BMPs & SMZs as a system	Pearson Correlation	.038	.141	.338	-.550	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.896	.630	.238	.042	.053	1.000	.429	.	.433
	N	14	14	14	14	14	14	14	14	14
Harvest Type	Pearson Correlation	-.217	.029	.123	-.032	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.402	.913	.638	.904	.930	.063	.206	.433	.
	N	17	17	17	17	18	18	18	14	18

Harvest Area Correlations

		Harvest Area Erosion	Harvest Area Aspect	Total Tract Area	Harvest Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Harvest Area Erosion	Pearson Correlation	1	-.210	-.153	-.329	-.286	-0.48*	-.323	.292	.187
	Sig. (2-tailed)	.	.404	.543	.183	.249	.041	.192	.311	.458
	N	18	18	18	18	18	18	18	14	18
Harvest Area Aspect	Pearson Correlation	-.210	1	.178	.244	.267	.111	.600	.000	.224
	Sig. (2-tailed)	.404	.	.479	.329	.285	.661	.008	1.000	.372
	N	18	18	18	18	18	18	18	14	18
Total Tract Area	Pearson Correlation	-.153	.178	1	0.541*	-0.43*	-.026	.387	.338	.073
	Sig. (2-tailed)	.543	.479	.	.020	.070	.918	.112	.238	.775
	N	18	18	18	18	18	18	18	14	18
Harvest Ratio	Pearson Correlation	-.329	.244	0.54*	1	-.287	-.021	.370	.270	.203
	Sig. (2-tailed)	.183	.329	.020	.	.249	.933	.131	.351	.419
	N	18	18	18	18	18	18	18	14	18
Year Since Harvest	Pearson Correlation	-.286	.267	-.436	-.287	1	.200	.400	-0.52*	.022
	Sig. (2-tailed)	.249	.285	.070	.249	.	.426	.100	.053	.930
	N	18	18	18	18	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	-.487	.111	-.026	-.021	.200	1	.067	.000	-0.447*
	Sig. (2-tailed)	.041	.661	.918	.933	.426	.	.793	1.000	.063
	N	18	18	18	18	18	18	18	14	18
ORV	Pearson Correlation	-.323	.600	.387	.370	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.192	.008	.112	.131	.100	.793	.	.429	.206
	N	18	18	18	18	18	18	18	14	18
BMPs & SMZs as a system	Pearson Correlation	.292	.000	.338	.270	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.311	1.000	.238	.351	.053	1.000	.429	.	.433
	N	14	14	14	14	14	14	14	14	14
Harvest Type	Pearson Correlation	.187	.224	.073	.203	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.458	.372	.775	.419	.930	.063	.206	.433	.
	N	18	18	18	18	18	18	18	14	18

* Correlation is significant at the 0.10 level (2-tailed).

Control Correlations

		Control Erosion	Control Aspect	Total Tract Area	Control Ratio	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Control Erosion	Pearson Correlation	1	-.063	-.293	.413	-.375	-.239	-.485	.334	.495
	Sig. (2-tailed)	.	.854	.383	.206	.256	.479	.131	.419	.122
	N	11	11	11	11	11	11	11	8	11
Control Aspect	Pearson Correlation	-.063	1	-.258	.366	0.68*	-.100	.100	-.258	.149
	Sig. (2-tailed)	.854	.	.444	.269	.020	.770	.770	.537	.662
	N	11	11	11	11	11	11	11	8	11
Total Tract Area	Pearson Correlation	-.293	-.258	1	-.432	-.428	.210	.421	.179	-.138
	Sig. (2-tailed)	.383	.444	.	.185	.189	.536	.197	.672	.685
	N	11	11	11	11	11	11	11	8	11
Control Ratio	Pearson Correlation	.413	.366	-.432	1	.172	-.108	-.011	.197	.337
	Sig. (2-tailed)	.206	.269	.185	.	.614	.753	.975	.640	.311
	N	11	11	11	11	11	11	11	8	11
Year Since Harvest	Pearson Correlation	-.375	.684	-.428	.172	1	.200	.400	-0.52*	.022
	Sig. (2-tailed)	.256	.020	.189	.614	.	.426	.100	.053	.930
	N	11	11	11	11	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	-.239	-.100	.210	-.108	.200	1	.067	.000	-0.447*
	Sig. (2-tailed)	.479	.770	.536	.753	.426	.	.793	1.000	.063
	N	11	11	11	11	18	18	18	14	18
ORV	Pearson Correlation	-.485	.100	.421	-.011	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.131	.770	.197	.975	.100	.793	.	.429	.206
	N	11	11	11	11	18	18	18	14	18
BMPs & SMZs as a system	Pearson Correlation	.334	-.258	.179	.197	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.419	.537	.672	.640	.053	1.000	.429	.	.433
	N	8	8	8	8	14	14	14	14	14
Harvest Type	Pearson Correlation	.495	.149	-.138	.337	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.122	.662	.685	.311	.930	.063	.206	.433	.
	N	11	11	11	11	18	18	18	14	18

*Correlation is significant at the 0.10 level (2-tailed).

Stream Crossing Correlations

		Stream Crossing Erosion	Stream Crossing Aspect	Stream Crossing Aspect	Total Tract Area	Year Since Harvest	Gated vs. Nongated	ORV	BMPs & SMZs as a system	Harvest Type
Stream Crossing Erosion	Pearson Correlation	1	-.268	-.594	.411	-.147	.347	.453	.097	.256
	Sig. (2-tailed)	.	.561	.159	.360	.752	.445	.308	.836	.580
	N	7	7	7	7	7	7	7	7	7
Stream Crossing Aspect	Pearson Correlation	-.268	1	.066	.264	.041	-.750	.403	-.471	.354
	Sig. (2-tailed)	.561	.	.888	.567	.930	.052	.370	.286	.437
	N	7	7	7	7	7	7	7	7	7
Stream Crossing Ratio	Pearson Correlation	-.594	.066	1	-.549	.072	.039	-0.68*	.149	-.624
	Sig. (2-tailed)	.159	.888	.	.202	.878	.934	.090	.750	.134
	N	7	7	7	7	7	7	7	7	7
Total Tract Area	Pearson Correlation	.411	.264	-.549	1	-.370	-.077	.399	.304	.244
	Sig. (2-tailed)	.360	.567	.202	.	.415	.869	.375	.507	.598
	N	7	7	7	7	7	7	7	7	7
Year Since Harvest	Pearson Correlation	-.147	.041	.072	-.370	1	.200	.400	-0.526*	.022
	Sig. (2-tailed)	.752	.930	.878	.415	.	.426	.100	.053	.930
	N	7	7	7	7	18	18	18	14	18
Gated vs. Nongated	Pearson Correlation	.347	-.750	.039	-.077	.200	1	.067	.000	-.447
	Sig. (2-tailed)	.445	.052	.934	.869	.426	.	.793	1.000	.063
	N	7	7	7	7	18	18	18	14	18
ORV	Pearson Correlation	.453	.403	-.684	.399	.400	.067	1	-.230	.313
	Sig. (2-tailed)	.308	.370	.090	.375	.100	.793	.	.429	.206
	N	7	7	7	7	18	18	18	14	18
BMPs & SMZs as a system	Pearson Correlation	.097	-.471	.149	.304	-.526	.000	-.230	1	.228
	Sig. (2-tailed)	.836	.286	.750	.507	.053	1.000	.429	.	.433
	N	7	7	7	7	14	14	14	14	14
Harvest Type	Pearson Correlation	.256	.354	-.624	.244	.022	-.447	.313	.228	1
	Sig. (2-tailed)	.580	.437	.134	.598	.930	.063	.206	.433	.
	N	7	7	7	7	18	18	18	14	18

VITA

Edwin A. Christopher, Jr. was born September 6, 1973 in Ft. Devens, Massachusetts. Edwin is the son of Gail and Edwin A. Christopher of Culpeper, Virginia. He has an older sister, Mary C. Nary of Warrenton Virginia. Edwin grew up in Ft. Devens, Massachusetts, Munich, Germany, and Manassas, Virginia. Upon graduation from Osbourn Park High School in 1992, Edwin spent two years at Northern Virginia Community College to complete the basic course work for an undergraduate degree. In the fall of 1994 Edwin became a student at Virginia Polytechnic Institute and State University in Blacksburg, Virginia. He pursued a degree in environmental resource management in the forestry department. In May of 1997, he completed the requirements for a Bachelor of Science degree in Forestry and Wildlife. Upon graduation he worked several different seasonal positions with the National Park Service at Jewel Cave National Monument in Custer, South Dakota. He worked eight months as a forester for the U.S. Forest Service out of Asheville, North Carolina as a member of the Field Inventory Analysis team. At the start of 1999 he took a job with Tetra Tech, Inc. in Fairfax, Virginia as an environmental scientist. As an environmental consultant, he worked on various national forestry BMP reports and documents for the U.S. Environmental Protection Agency. It was here that his interested sparked in BMP effectiveness from silvicultural activities. In August of 2000, Edwin returned to Virginia Polytechnic Institute and State University to undertake a Master's of Science degree in forestry under Dr. J.M. (Rien) Visser. Edwin was married to his college sweetheart, Samantha Connell Christie, on May 19, 2001.