Logging in the Streamside Management Zone: Effects of Harvesting System and Intensity on Visual Soil Disturbance

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Forestry

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September 29, 2006
Blacksburg, Virginia

Keywords: • SMZ, harvesting, system harvesting intensity, visual soil disturbance

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ABSTRACT

Streamside management zones (SMZs) are a common and effective mechanism used to protect and maintain water quality during timber harvesting operations. In the southeastern United States timber harvesting is typically allowed inside the SMZ, but there is little information regarding suitable types of harvesting systems and the acceptable amount of canopy cover. The effects of two harvesting systems and harvesting intensities on visual soil disturbance were evaluated throughout Virginia and eastern West Virginia. The harvesting systems were a chainsaw/cable-skidder system (manual) and a feller-buncher/grapple-skidder system (mechanized). A total of 118 unique SMZ plots were measured at 50 different harvest sites, split evenly between manual and mechanized operations. Analyses of variance (ANOVA) at the $p < 0.10$ significance level indicated that there was no significant difference in visual indices of soil disturbance levels between the two systems. However, the manual system had significantly more “rutted” disturbed area and slash cover than the mechanized system. Harvesting intensity was found to be a significant factor in the occurrence of total visual soil disturbance (slight, deep, rutted classes). Slope gradient was evaluated and revealed that slope percentages had no significant effect on percent soil disturbance for this study. Based on the parameters measured, the general occurrence and frequency of soil disturbance generally depends on the specific site conditions.

ACKNOWLEDGEMENTS

This study would not have been possible without the collaborative help from local and state agencies, private and industry forestry companies, private landowners, and university personnel and colleagues.

I would first like to thank the timber industrial companies that aided in this research. Georgia-Pacific Corporation in the Rupert office, West Virginia provided help with assisting in collecting fieldwork and the use of their timberland and harvest sites. Specifically John Montague, Randall Johnson, Gary Crawford, and Bill Haver. Also thanks to MeadWestvaco in Appomattox, Virginia for allowing me to conduct my research on their lands. My appreciation extends to the private companies and their foresters that assisted in providing research sites. The two foresters were John Perry of Turman Lumber Company and Matt Pace of Ridge Runner Forestry. I would like to thank the foresters of the Virginia Department of Forestry in Campbell (Jim Jarvis), Nottoway (Hylton Haynes), Montgomery (Jim Clark) and Sussex (Zach Dowling, Jay, David Powell) counties and the Salem region (Bob Boeren, Kem Pace).

In the university arena, I would like to thank professors Dr. Rien Visser, Dr. W. Michael Aust, and Dr. Robert Shaffer for their continued support and patience. I would also like to thank Andy Horcher, Ph.D. candidate for providing me with guidance and the tools used to measure canopy cover in the field. I am grateful to the departmental secretaries, Tracy Sherman and Sue Snow for showing me the way and answering all of my questions. And finally I would like to thank, a fellow graduate student and friend, Mary Yonce, who helped collect a lot of my fieldwork. Mary has helped me get through the “graduate experience” and make it a memorable one. In general, I want to thank The College of Natural Resources for the most gratifying and rewarding experience of my life. Everyone has been great!

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DECLARATION

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.”

Christine Lamb Hodges

Date

1.0 INTRODUCTION

Forestry is recognized as a science and art for attaining desired forest conditions and benefits. Forests provide many resources to our nation in the form of raw materials, clean air, drinking water, soil protection, wildlife habitat and the overall enhancement of life. However, there is a concern regarding the potential impacts of forestry activities, specifically harvesting, on water quality. If proper forestry management practices are implemented during and after harvest, the negative impacts on stream water quality will be greatly minimized (Kochenderfer, et al., 1997; Kochenderfer and Hornbeck, 1999; Lynch and Corbett, 1990; Lynch et al., 1985; Wynn et al., 1999). These practices are better known as Best Management Practices (BMPs). BMPs were created by individual states to maintain and improve water quality by decreasing non-point source pollution from agriculture, urbanization, and silviculture. One particular practice, streamside management zones (SMZs) or riparian area, is generally recognized as an important and useful BMP for protecting water quality and ecosystem health (Vowell, 2001 and Phillips, 1989). SMZs have the ability to filter excess sediment and nutrients from the overbank stream flow and overland runoff, provide shade and moderate water temperatures for aquatic wildlife, decrease erosion and stabilize stream banks, and provide additional wildlife and aquatic habitat.

There have been numerous studies that address the impacts of forest harvesting on water quality from a large-scale approach. However, there is limited research and data collected that pertains specifically to the streamside management zone and the implications of harvesting within this area. Presently, there are few regulations or sets of standards relevant to harvesting in riparian areas for maintaining water quality (Dissemeyer, 1994; and USDA, 1978). In the South, most states have somewhat vague non-regulation guidelines for the riparian areas. These recommendations vary by state; not just in the recommended widths, but also in suggested allowable harvest practices. More detailed information about the potential impact of harvesting on SMZ integrity and function is needed in order to evaluate whether these recommendations are appropriate, too lenient, or too restrictive.

1.1 Economic Considerations

Forestry, an important component of local and regional economies in the south, provides employment, income, eco-tourism through recreation, hunting, and fishing, capital for landowners, wood furniture, pulp and paper, and other tangible products. On southern rural land, forestry is one of the two largest land uses present, and combined with agriculture represents over 6% over the total southern economy (SGSF, 2002). Also in the southern United States, there are 4.9 million private forest landowners who own 187.1 million acres of forestland (Moulton and Birch, 1995). Employment in the wood products industry continues to increase and concentrate in the South to meet the increasing demand for fiber, holding 39.3% of the forestry jobs in the U.S. Through both public and private forest harvests, forestry in the south has contributed 2.2 million jobs and $104.6 billion in gross regional product (SGSF, 2002; Wear and Greis, 2002).

In general, streamside management zones will yield high timber values due to the site characteristics specific to a riparian area (Kluender et al., 2000; Verry et al., 2000). The increased amount of nutrients and soil moisture found in these areas makes them highly productive sites. Landowners in the south rank increased income opportunities and aesthetic value from SMZs as being very desirable (Husak et al., 2004). However, forgoing the opportunity to harvest the timber will result in lost revenue for the landowner (Aust et al., 1996; Clinnick, 1985; Kluender et al., 2000). Despite land being taken out of production to minimize water quality impacts there are several federal and state programs that provide monetary assistance or tax relief to landowners practicing good stewardship, such as The Conservation Reserve Enhancement Program (CREP), The Forestry Incentives Program (FIP), The Forest Stewardship Program (FSP), the Stewardship Incentive Program (SIP), and The Conservation Reserve Program (CRP).

1.2 Laws and Regulations

Due to the growing concern for water quality and the need to protect our water resources, congress passed the 1972 Federal Water Pollution Control Act (PL 92-500). Also, known as the Clean Water Act of 1977 (CWA), its purpose is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Best Management Practices (BMPs) were developed following an amendment to the FWPCA, under Section 208, which identified forestry as a potential source of nonpoint pollution for water quality (AFPA, 1993; Lynch and Corbett, 1990; Wynn et al., 2000). Section 208 required that each state develop a plan that would assess and manage nonpoint source pollution (NPSP) for water quality purposes. It is important to note that the majority of the eastern states in the U.S. have voluntary BMP guidelines rather than laws that are regulated by local, state, and federal agencies (Brown et al., 1993; Stringer and Thompson, 2000). In conjunction with Section 208, in 1987 amendments were made to the CWA resulting in Section 319. Section 319 directed states to perform comprehensive assessments of all state's waters that had been significantly degraded from NPSP (Wynn et al., 2000). Following the amendment of the CWA in 1977 under section 404, "normal farming, silviculture, and ranching activities are exempted from regulation.

1.3 Forest Harvesting BMPs

Best Management Practice (BMP) guidelines for forestry are methods, measures, or practices that are designed to maintain or protect water quality. Most state BMP manuals address the following forestry activities: pre-harvest planning, forest roads, decks and landings, skid trails, harvest operations, sensitive areas, stream crossings, streamside management zones, site closure and site preparation (Aust, 1994). When BMPs are properly implemented, the effects of forest harvesting on water quality and productivity can be minimized (Aust et al., 1996; EPA, 1986, Kochenderfer and Hornbeck, 1999; Lynch and Corbett, 1990; and Wynn et al., 2000). Implementing BMPs during harvesting reduced sediment concentrations by 20% in Virginia (Park et. al, 1994). Kochenderfer and Hornbeck (1999) compared a site with BMPs to a site without BMPs in West Virginia to determine their values on soils and water quality. Their study concluded that during a logging operation on the site without BMPs, sediment yields increased significantly (1.4 t/ac/yr) (3.1 Mg/ha/yr) and temperature levels increased as much as 8^0F during the first year. The site with BMPs had only minor changes in sediment levels (0.05 t/ac/yr) and water temperatures remained below 75^0F. Kochenderfer and Aubertin (1974) concluded that turbidity levels were minimized to almost undisturbed forested levels of two Jackson Turbidity Units (JTUs) on a silvicultural clearcut with proper planning. In a study conducted by Kochenderfer and Wendel (1983), they discovered the importance of BMPs and specifically vegetation to the protection and recovery of forested streams.

1.4 Potential Harvesting Impacts on Water Quality

Forestry practices, if improperly implemented, can degrade water quality and the integrity of streams, through activities such as timber harvesting, skidding, landings and roads construction, and stream crossings. These activities have the potential to increase erosion, sedimentation, soil disturbance, temperature and turbidity levels and decrease dissolved oxygen levels and wildlife habitat and their impacts are described in greater detail below: (EPA, 1986; Kochenderfer and Edwards, 1991; Lynch and Corbett, 1990; McClurkin et al., 1987; Patric, 1976).

In forestry, sediment is considered to be the largest potential nonpoint source pollutant (Binkley and Brown, 1993; Golden et al., 1984; Kochenderfer et al., 1997; Lynch and Corbett, 1990; Phillips, 1989; Yoho, 1980). Nonpoint source pollution (NPSP) is defined as pollution that comes from many diffuse or scattered sources rather than from a concentrated point, known as point source pollution (Kentucky Department of Forestry, 1997). Nonpoint source pollution is considered to be a primary factor in affecting water quality and consists of 70% of all pollution from both point and nonpoint sources. Silvicultural activities contributed up to 8% of the total NPSP and on average, across the south percentages are closer to 5% and silviculture ranks 9th out of the 10 leading sources of impairments (Figure 1). In the Southeastern forest, average annual erosion rates range from .05 to .50 t/ac/year (0.11 to 1.2 Mg/ha/year) (Lynch and Corbett, 1990 and Patric, 1976) and specific to Virginia and West Virginia forestlands average erosion rates are estimated at 0.5 t/ac/year (1.2 Mg/ha/year) (Gianessi et al., 1986).

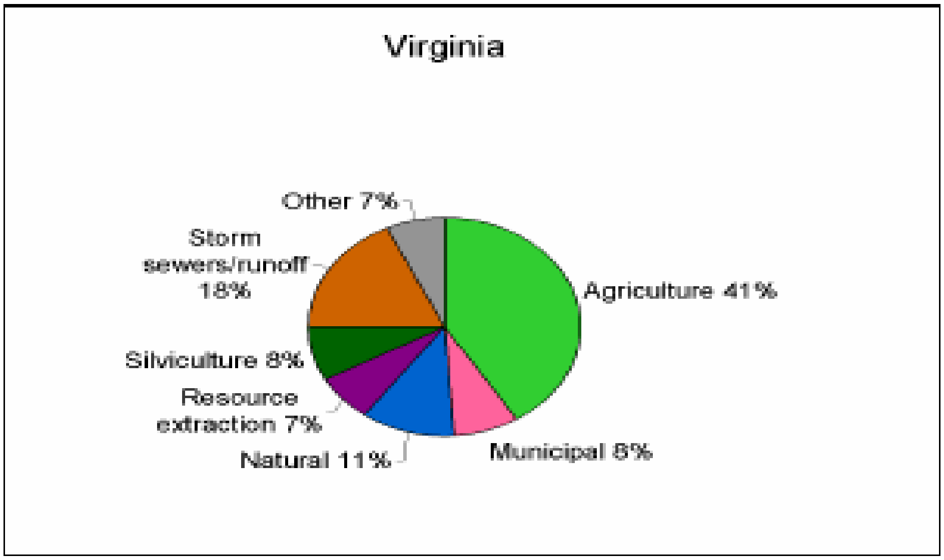

Figure 1. Leading sources of impairment of rivers and streams for Southern States from 1988 to 1998. Source: U.S. Environmental Protection Agency 1990, 1992, 1994, 1996, 1998a, 2000a.

Soil may be eroded by detachment and transported from its original location by forces such as water, wind, and gravity. Eroded soil may either be deposited on the site or it may be considered as stream sediment if it is transported to the stream. Forest harvesting activities have the potential to increase sediment yields from sources such as: the formation of gullies and rills, exposure of bare soil through harvesting, installation of roads and trails, skidding, and the use of equipment. Increased rain penetration to the forest floor due to lack of soil cover, and an increase in overland flow that may be the result of compaction are other potential sources of sediment. (Keim and Schoenholtz, 1999; Miller et al., 1988; Wear and Greis, 2002; Sopper, 1975; Yoho, 1980). In a study conducted by McClurkin et al. (1987), increases in sediment yields were found for three years following 0.002-ha plots that had been clearcut on pine covered ridges in 1976 in Oxford, Mississippi. Two replications were created with three plots per replication consisting of a control, thinning, and clearcut. Increases in sediment yields were found to be in magnitudes of two to three times and ranged from 0.003 to 0.054 Mg/ha, making it significantly larger than the control and thinning plots.

Sediment may potentially have a negative impact on water quality by also increasing turbidity and temperature levels, decreasing dissolved oxygen levels, and decreasing aquatic life habitat and the quality of drinking water**.** In a study conducted by Sopper (1975), turbidity levels increased by almost 500 JTUs on a commercial clearcut in West Virginia compared to an undisturbed forested control. The level of turbidity in a stream is directly linked to the presence of suspended sediment found. Turbidity levels greater than 35 NTU's may impair fish movement, vision, feeding, and survival of eggs and larvae (Wilber 1983). Lynch and Corbett (1990) stated that increases in sediment/turbidity yields are mainly from improper locations of skid trails, roads, and landings, inadequate drainage and erosion control devices, and stream crossings that are poorly designed. Excess nutrients, increased stream temperatures, decaying organic matter, and lack of dissolved oxygen also has the potential to adversely affect aquatic life and habitat through suffocation and a decrease in habitat and spawning areas (Baker et al., 1991; Vowell, J.L., 2001)

1.5 Streamside Management Zones (SMZs)

1.5.1 SMZ Description

"Streamside management zones (SMZs) are vegetated buffer strips adjacent to perennial or intermittent streams or other bodies of water (lakes, ponds, reservoirs, etc.) that should be managed with special considerations to protect water quality" (GFC, 1999). SMZs play an important role in protecting water quality and the riparian ecosystem. SMZs were developed to decrease erosion and sedimentation by stabilizing stream banks, decreasing overland flow and disturbance by protecting the forest floor, and filtering excess soil particles and nutrients before they reach the stream. They provide shade and carbon sources to the stream through canopy cover and the additions of organic matter in the means of leaf litter and other organic debris. They have the ability to increase aquatic and wildlife habitat by moderating stream temperatures and dissolved oxygen levels and providing cover for spawning and shelter. Finally, they have the potential to generate revenue to the landowner based on the landowner's objectives. A cross-sectional diagram of a SMZ is below in Figure 2; these areas may also be referred to as buffer strips, riparian areas, filter strips, and riparian management zones (RMZs).

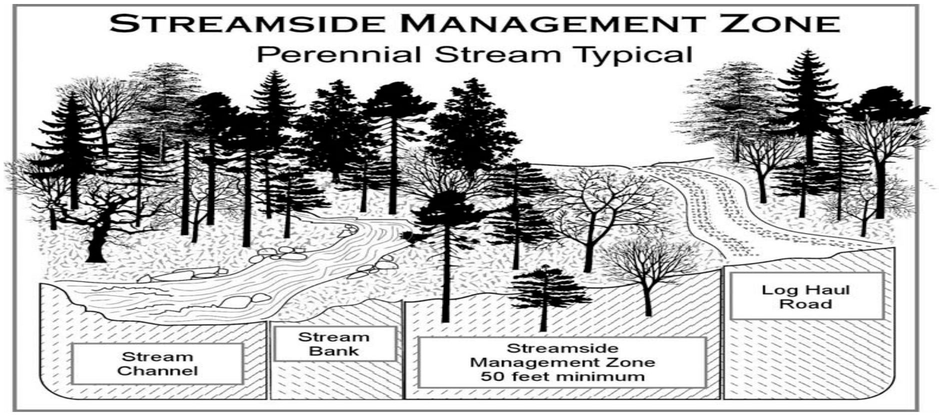

Figure 2. Cross-section diagram of a streamside management zone (Virginia BMP manual, 2002).

SMZ guidelines can be found in a best management practice manual designed and specific for each state. SMZ guidelines are designed as practical measures for protecting the integrity and health of the stream and minimizing site impacts from harvesting operations by serving as management tools that are intended to reduce nonpoint source pollution from agriculture, urbanization, and silviculture practices (Welsch, 1991). These reductions are made by slowing and decreasing overland flow and maintaining vegetative cover, which affects infiltration and interception rates (Kochenderfer and Edwards 1991; Swift, 1986). They are also designed to reduce equipment traffic and the amount of erodible ground next to streams (Stringer and Thompson, 2000).

1.5.2 SMZ Studies

Partial harvesting is a practice that is generally allowed in the SMZ in order to allow landowners to generate income from the riparian area while producing minimal or non-significant impacts to water quality. In a SMZ effectiveness study, Kochenderfer and Edwards (1991) concluded that careful harvesting yields only minor increases in sediment. This study included three watersheds where there was a control, a SMZ that was partially cut with the remaining area clearcut to a 14-inch stump diameter, and a 3.5 ac SMZ that was not cut with the remaining area clearcut and treated with mechanical site preparation.

SMZs are an effective means used to filter sediment, decrease soil disturbance and decrease turbidity levels (Hubbard and Lowrance, 1994; Keim and Schoenholtz, 1999; Kochenderfer and Edwards, 1991). Keim and Schoenholtz (1999) found that SMZs were effective in preventing significant increases of streamwater total suspended sediments (TSS) from logging during 15 months following harvest with TSS mean grab-samples of 541.6 mg/l in the cable-only SMZ and 298.0 mg/l in the no-harvest SMZ in Mississippi.

SMZs, if installed properly will help moderate stream temperatures to allow for the optimal temperature ranges that most fish species desire and need to survive (Hornbeck et al., 1984; Kochenderfer and Edwards, 1991; Kochenderfer et. al, 1997; Lynch et at., 1985; Swift and Baker, 1973). In a SMZ study conducted by Koechenderfer et al. (1997), stream temperatures remained within their biological limiting levels after the completion of a forest harvesting operation. Kochenderfer et al., (1997) implemented BMP guidelines from 1979 to 1989 in West Virginia on a 39 ha watershed to evaluate their effectiveness. They concluded that removing approximately 50% of the basal area in stems 2.54 cm dbh and larger within a SMZ resulted in non-significant increases in stream temperature. Kochenderfer and Edwards, (1991) also concluded that when harvesting with adequate riparian buffers increases in stream temperature, erosion, and sediment yields would be minimal and below the aquatic sensitivity threshold. Riparian buffers were a minimum of 66 feet on each side and road building and machinery were prohibited from the buffer.

Lynch and Corbett (1990) also evaluated the efficacy of BMPs by evaluating an area harvested using BMPs. Their findings concluded that BMPs were effective in controlling non-point source pollution and protecting water quality even though there was the increase in stream nitrogen and phosphorus, turbidity, and temperature were statistically significant, the increases were relatively small and met the standard drinking levels. In 1999, Keim and Schoenholtz published data from six different watersheds with slope gradients ranging from 30 to 45 percent and having harvest sizes ranging from 3.4 hectares to 13.4 hectares in the Deep Loess region of Mississippi. The study concluded that streamside management zones that were not harvested or only allowed removal of timber by cables were beneficial in decreasing the exposure of mineral soil near the stream where erosion and gullies are most likely to deliver sediment to the stream.

1.6 Harvesting Systems

Generally, forest operations are limited by terrain, piece size, productivity, or costs and the type of harvesting system that is chosen depends largely on these factors. In most management activities, the individual machines are grouped into systems. A forest operation system is more than just the work of the equipment it also incorporates the implementation of sound, researched methods and human work (Wear and Greis, 2002). The two most common harvest systems used in the southeast are (a) the feller-buncher combined with a grapple skidder, also known as a 'mechanized' system and (b) chainsaw felling followed by cable skidder extraction, also known as a 'manual' system. These conventional ground-based systems can easily be used on slopes greater than 30 percent without significantly impacting water or site quality (Stuart and Carr, 1991). Both systems are highly productive and flexible for typical situations, therefore they are economically appealing to contractors (Verry et al., 2000; Rollerson, 1989). While differences in impacts between systems can be expected, it is acknowledged that operator's knowledge and expertise significantly contributes not only to productivity, but also the level of environmental impact (Wear and Greis, 2002). For SMZ partial harvesting, state forestry agencies have not agreed as to which system is best suited for minimizing disturbances, but the manual system is most frequently recommended. Advantages and disadvantages of these systems are described below.

1.6.1 Mechanized System

Advantages to operating with a mechanized system (feller-buncher/grapple-skidder) in the SMZ include a higher productivity rate because trees are cut mechanically. The machine severs the trees using a shear or sawhead, accumulates a bunch, and then either swings or moves outside of the SMZ to place the trees on the ground for loading (Wear and Greis, 2002). There is increased safety for the workers because the operator is not required to leave the machine to secure the harvest load. Ground disturbances can also be minimized; generally, operations where logs are carried to their location and not dragged result in less soil disturbance to the forest floor (Verry et al., 2000, Wear and Greis, 2002). Possible disadvantages of this system are the need to introduce heavy machinery into the SMZ which can lead to soil compaction, increased erosion rates, and a decrease in soil productivity and infiltration rates (Clinnick, 1985; Keim and Schoenholtz, 1999; Kochenderfer et al., 1997; Kochenderfer and Edwards, 1991; Verry et al., 2000, Nicholas et. al., 1994; Yoho, 1980). Damage to the residual stand is also a factor for forest health and future merchantability. Residual stand damage levels ranging from 10-40% were found from a feller-buncher/grapple skidder operation in northern hardwood forests (Cline et al., 1991; Bruhn, 1986).

1.6.2 Manual System

Manual systems (chainsaw/rubber-tired cable skidder) are less expensive to operate and the felling machine is kept out of the SMZ while harvesting, therefore reducing compaction, soil disturbance, and rutting from wheels. In a study which tested the harvesting impacts of conventional ground based skidding systems on steep slopes in Virginia, between 70 and 80 percent of the surface soil in all tracts were found to be in an undisturbed condition and only six to 15 percent of the area in all tracts had been slightly disturbed (Stuart and Carr, 1991). However, even though the machine is located out of the SMZ, when logs are felled and skidded through the SMZ there is the potential for soil disturbance, residual stand damage and the creation of channelized flow that may transport upslope materials to the stream (Patric 1976). Residual stand damage may occur with these manual operating systems. In a study conducted by Nyland and Gabriel (1971) they found stand damage levels ranging from 20-30%. These systems also require more time and labor because cable skidder operators have to stop and attach a choker to each tree when extracting logs from the SMZ.

2.0 SMZ GUIDELINES REVIEW

As part of this study, a comprehensive review was completed on the SMZ guidelines that were found in 11 southeastern states of the United States using the published best practice management guidelines for each state (referenced below). Comparisons were made on SMZ width, the amount of harvesting allowed in the SMZ, and the type of harvesting equipment that is permitted in the SMZ.

- Alabama Forestry Commission. 1993. Best management practices for forestry
- Arkansas Forestry Commission. 2002. Arkansas best management practices for water quality protection
- Florida Division of Forestry. 2003. Silviculture best management practices
- Georgia Forestry Commission. 1999. Best management practices for forestry
- Kentucky Department of Forestry. 1997. Field guide to best management practices for timber harvesting
- Louisiana Department of Agriculture and Forestry. 1997. Recommended forestry best management practices
- Mississippi Forestry Commission. 2000. Best management practices for forestry
- North Carolina Division of Forest Resources. 1989. Forestry best management practices manual
- South Carolina Forestry Commission. 1994 Best management practices.
- Tennessee Department of Agriculture Division of Forestry. 2003. Guide to forestry best management practices
- Virginia Department of Forestry. 2002. Forestry best management practices for water quality in Virginia

2.1 SMZ Width Recommendations

States have created guidelines pertaining to SMZ widths using several different parameters such as slope gradient, stream width, stream order, special concern areas, or using a universal value. A summary for all recommended SMZ widths based on their parameter classifications is shown in Table 1. Kentucky, South Carolina, Georgia, Mississippi, Tennessee, Arkansas, and Florida have SMZ requirements for perennial and intermittent streams that are slope dependant. Their widths range from 25-300 feet. Louisiana, Virginia, North Carolina, and Alabama, are the remaining states that have SMZ widths for perennial and intermittent streams that are not slope dependant, however Alabama suggests that SMZs should be widened depending on slope and erodibility. Arkansas, Virginia, North Carolina, and Alabama have the same SMZ widths for perennial and intermittent streams, whereas the other states have separate specifications. Florida and Louisiana are the only states that have different widths depending on the width of the perennial stream. Kentucky, South Carolina, North Carolina, Virginia, and Georgia have set guidelines for special concern areas such as cold water fisheries with widths ranging from 40-200 feet. Georgia, Virginia, and Florida are the only states that have assigned SMZ widths of 50-200 feet for municipal water supplies. Kentucky, Virginia, and Florida have also set 50 feet to wetland areas.

Table 1. Comparison of recommended SMZ widths in the southeast region, 2004.

State	**Perennial**			**Intermittent**	**Cold Water Fisheries***	**Wetlands**	**Municipal Waters**
	(All widths ft)	*(0-20 ft)*	*(20-40 ft)*	(ft)	(ft)	(ft)	(ft)
Alabama	35			35			
Arkansas	35-80sc			35-80sc			
Florida		35	75-300sc	35-300sc		50	200
Georgia	40-100sc			25-50sc	100		50-150
Kentucky	25-55sc			0	60	50	
Louisiana		50	100	35			
Mississippi	30-60sc			30			
North Carolina	50			50	50-125sc		
South Carolina	40-160sc			40-160sc	40-200sc		
Tennessee	25-145sc			25-145sc			
Virginia	50			50	60-120sc	50	100-200sc

sc: slope class dependant

2.2 SMZ Harvesting Intensity Recommendations

All southeastern states allow timber harvesting in SMZs, with recommended residual density guidelines and specific harvesting treatments. A summary of these requirements are given in Table 2. Overall, states suggest leaving 50-75% canopy cover or 50 ft^2/ac basal area on perennial streams and cold water fisheries. On perennial streams South Carolina, Georgia, Mississippi, and Arkansas require residual stand density of 50 ft^2/ac that is evenly distributed throughout the area. Kentucky, Tennessee, and Georgia set separate specifications for cold water fisheries ranging from 50-75% canopy cover. On intermittent streams, states suggest 25-50% canopy cover or basal area (ft^2/ac). Kentucky, South Carolina, and Louisiana do not specify any requirements within SMZs of intermittent streams. Kentucky, Georgia, Tennessee, Virginia, and Alabama specify that 50% of canopy cover must be left in the stand. Kentucky and Virginia mention harvesting in wetlands and set the same specifications as allowed in perennial zones and 50% canopy cover on wetland areas.

There are some states that set no harvesting restrictions in these streamside management zones and one state measures harvesting levels by bare ground disturbance. North Carolina specifies that no more than 20% evenly distributed, bare ground should result from harvesting operations in perennial zones. Florida doesn't allow any harvesting within 35 feet of a perennial stream, however, they are allowed to clearcut 25% of the SMZ, excluding the first 35 feet. They also require a residual stand density of 50 ft^2/ac in perennial zones if exceptions do not apply. There are also very few states that specify what type of harvest (selective, partial or regeneration) is allowed in the SMZ, even though most states suggest that the residual stand will remain evenly distributed.

Table 2. Comparison of the harvesting SMZ requirements in the southeast region. Guidelines are typically based on either the amount of canopy cover (CC) or the basal area (ft^2/ac) that should be retained after harvest.

State	Perennial	Intermittent	Cold Water Fisheries	Wetlands
Alabama	50% CC	Partial/Regeneration		
Arkansas	50 ft^2/ac	50% CC		
Florida	50 ft^2/ac	leave stringer *		
Georgia	50 ft^2/ac or 50% CC	25ft^2/ac or 25% CC	50 ft^2/ac	
Kentucky	50% overstory	N/A	75% CC	50% CC
Louisiana	N/A	N/A		
Mississippi	50 ft^2/ac selective harvest	regeneration harvest		
North Carolina	<20% bare ground or 75% CC	40% CC		
South Carolina	50 ft^2/ac	N/A		
Tennessee	50% CC	50% CC	50% CC	
Virginia	50% BA or 50% CC	50% CC		50% CC

* stringer – Narrow strip of trees left on and/or near the banks of intermittent streams.

2.3 SMZ Harvesting System Recommendations

Since harvesting is allowed in SMZs in the southeastern United States, there are guidelines set by each state denoting what type of harvesting equipment or system should be used within the streamside management area. Kentucky, North Carolina, and Tennessee recommend that harvesting equipment operate outside of the SMZ and logs are cabled and winched out. Georgia and Kentucky allow equipment in the SMZ, but not within 25 feet of the stream. Florida and Mississippi allow harvesting equipment inside the SMZ without any stipulations. Georgia, Alabama, Arkansas, and Virginia allow harvesting equipment as long as the forest floor is protected and soil disturbance is minimized. South Carolina and Louisiana also allow equipment in the SMZ, but recommend that the machines have wide tires or tracked wheels (Table 3).

Table 3. **Comparison of the harvesting equipment allowed in the southeast region found in state BMP manuals.**

State	BMP Harvesting Guidelines in SMZs
Alabama	Harvesting equipment is allowed in SMZs; the forest floor should be protected
Arkansas	Harvest as to minimize the disturbance level to the forest floor
Florida	Harvesting equipment is allowed in SMZs
Georgia	Harvesting equipment is allowed in SMZs as long as there is no significant impact; no equipment operation within 25’ of perennial stream
Kentucky	No harvesting equipment or vehicles are allowed within SMZ, the preferred method is winching. No equipment operation within 25' of perennial stream.
Louisiana	Harvesting equipment is allowed in SMZs, suggested equipment includes wide-tire and cable skidders, forwarders, and tracked equipment.
Mississippi	Harvesting equipment is allowed in SMZs
North Carolina	No harvesting equipment or vehicles are allowed within an SMZ that has a confluence, the preferred method is winching. Other SMZs remove timber with extreme care and leave forest floor essentially undisturbed.
South Carolina	Harvesting equipment is allowed in SMZs, secondary zone suggests using wheel or tracked vehicles
Tennessee	No harvesting equipment or vehicles are allowed within SMZ, the preferred method is winching
Virginia	Harvesting equipment is allowed in SMZs; the forest floor should remain essentially undisturbed

After reviewing BMP guidelines and research from several southeastern states (Blinn and Kilgore, 2004 and Stringer and Thompson, 2000); it is apparent that states set SMZ recommendations based on several different factors such as slope, stream width, stream type, and land use (cold water fisheries, municipal waters, wetlands). Therefore, we wanted to design a study that focused on these differences and determine which factors have more of an impact on soil disturbance. Specifically, we wanted to address the impacts of harvesting intensity, and testing the difference between the two primary harvesting systems on soil disturbance in various physiographic regions. Both of these parameters have been documented as having an effect on soil disturbance, but there have been few evaluations within SMZs. We also wanted to document the level of soil disturbance, erosion, and harvesting that has occurred in SMZs on lands throughout Virginia and the eastern part of West Virginia.

3.0 STUDY OBJECTIVES

3.1 Objectives

Our specific objectives are:

(1) To evaluate the impact of using two different harvesting systems: feller-buncher/grapple skidder vs. chainsaw/cable-skidder system on visual soil disturbance within a SMZ.

(2) To determine the impact on visual soil disturbance from different harvesting intensities within a SMZ.

These objectives will be met by testing the following alternative hypotheses.

3.2 Hypotheses

Ha_1: Cable winching systems (manual) used in SMZs will have higher visual soil disturbance levels than the feller-buncher/grapple-skidder system (mechanized).

Ha_2: As harvesting intensities increase, the amount of visual soil disturbance will also increase

4.0 METHODOLOGY

4.1 Study Area

The study sites were located on forest land throughout Virginia (Montgomery, Botetourt, Buckingham, Sussex, Nottoway, Faquier, Campbell, and Tazewell counties) and in the eastern part of West Virginia (Greenbriar, Summers, Fayette, and Mercer counties) (Figure 3).

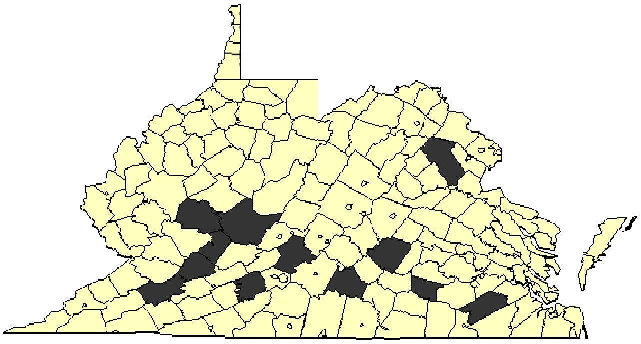

Figure 3. The location of counties in Virginia and the eastern part of West Virginia where study sites were evaluated.

Forestlands were owned and managed by various private, and industry companies, private landowners, and state agencies. Sites occurred in the Coastal Plain, Piedmont, Ridge and Valley, and Appalachian Plateaus physiographic regions (Table 4).

Table 4. The number of sampled sites, tracts, and average slope found in each of the physiographic regions of Virginia and West Virginia, 2004.

Physiographic Province	# Sites	# Tracts	Average Slope (%)
Coastal Plain	20	10	6
Piedmont	28	12	19
Ridge and Valley	52	19	35
Appalachian Plateaus	18	9	35

The Coastal Plain is made up of mainly plateaus, terraces, and broad swampy flats at lower elevations. This is the least weathered of Virginia's physiographic regions with parent material being deposited by Atlantic Ocean began or sediments being deposited by the erosion from the Appalachian Highlands. Slope gradient within the SMZ averaged six percent across the study area and ranged between 3 and 13 percent (Table 4). Normal annual total precipitation range from 48 to 56 inches. The Coastal Plain borders and extends along the Piedmont region with the fall line separating the two areas (Buol, 1973). Due to the generally level terrain mechanized harvesting systems are common in this region.

The Piedmont region consists of gently rolling hills with rounded summits and shallow valleys that were created by the converging and folding of metamorphic rocks of various origins and plates. Topography in this region is generally steeper with an average 19% slope gradient found on study sites and ranging anywhere between 2 and 50 percent slope. Normal annual total precipitation equals 48 inches. The Piedmont Plateau surface is approximately 200 feet to 1000 feet above sea level. Erosion has played a major role in developing this region and generally the older soils are stratified above the younger coastal deposits. Although the Piedmont is steeper than the coastal plain, mechanized systems are still commonly used.

The Ridge and Valley region is 65 miles wide is located west of the Blue Ridge province. The topography is made up of long, narrow, even mountain ridges and valleys formed by folding due to plate tectonics followed by differential erosion. Slopes averaged 35 % in the study area and percentages ranged between 8 and 18 percent. These landforms were created from differential weathering and the process of sedimentary rocks eroding. Normal annual total precipitation equals 48 inches.

The Appalachian Plateau lies just west of the Ridge and Valley region and is characterized as winding, narrow-crested ridges and deep, narrow valleys with sandstone rock that is underlain in a horizontal pattern. Areas of high relief have been caused by the eroding of soils due to stream action that has taken place over millions of years. Our plateau sites are in West Virginia and the average slope was also 35 % with slope gradients ranging from 15 to 54 %. Normal annual total precipitation equals 40 inches. Manual systems are more common on the steeper areas in the Ridge and Valley and the Appalachian Plateau.

4.1.1 Soil Characteristics

Soils in these regions have formed from lava flows, hard crystalline, metamorphic, and sedimentary rock, and in unconsolidated sands, silts, and clays of fluvial, marine, and eolian origin (Buol, 1973). The two main soil orders that characterize these eastern forests are the alfisols and ultisols. Alfisols are acidic soils with high fertility levels and the diversity and activity of soil biota are high. Ultisols are characteristic of the southern part of the region. These areas are non-glaciated, older, and highly weathered soils that are more acidic than the alfisols and lower in fertility.

4.1.2 Vegetation Characteristics

Forests in these regions are comprised of the oak/hickory, southeastern coastal plain, and mixed mesophytic deciduous vegetation types (Barbour et al., 1999). Species composition found in the research plots were dominated by tulip poplar (*Liriodendron tulipifera* L.),white oak (*Quercus alba*), chestnut oak (*Quercus prinus* L.), red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), mockernut hickory (*Carya tomentosa* Nutt.), and sweetgum (*Liquidambar stryaciflua*). Other hardwoods occasionally found at these sites included beech (Fagus grandifolia Ehrh.), American basswood (*Tilia americana* L.), black locust (*Robinia pseudoacacia*), black cherry (*Prunus serotina*) sourwood (*Oxydendrum arboretum*), northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muench.), American hornbeam (*Carpinus caroliniana* Walt.), and cucumber tree (*Magnolia acuminate* L.). The softwood component included eastern hemlock (*Tsuga canadensis* Carr.), eastern white pine (*Pinus strobes* L.), and Virginia pine (*Pinus virginiana).*

4.2 Site Selection

SMZ sites used in this research were located throughout Virginia and parts of West Virginia. To locate potential study sites, I began by calling state officials, private businesses, industries and consultants and asking them if they had recent harvesting sites that met the desired conditions for this study. If they did, I then spent one day with the forester of that company in the field to physically assess if the site would actually meet the requirements. The requirements were either active or recently active harvesting sites (within 6 months) where the SMZ had been harvested to some degree and was a minimum width of 50 feet. The harvesting system needed to be either the cable-skidder winching system or the feller-buncher/grapple skidder system. Once the site qualified, I then attained permission to include this site in the study by the landowners and company representatives

4.3 Harvesting Systems

Two types of conventional ground-based harvesting systems were evaluated in this study, a manual cable skidder system and a mechanized feller-buncher/grapple-skidder system (see section 1.6 for more information pertaining to harvesting systems). All sites were studied post-harvest, therefore a complete description of the actual harvest system is not available. Machine size and power varied depending on the size of the job and the company performing the harvest. Study plots were managed by different entities; public, private, and industrial companies. Some companies had employed their own logging crews while others contracted the jobs out to independent logging crews or timber agencies. Size of logging crews ranged from one to five employees per job and crews were unaware that this study was taking place. General descriptions of how each system operates are given below.

The manual system uses chainsaws to fell, top, and limb trees before extraction. The cable is then pulled from the winch of a rubber-tired skidder or bulldozer by either the skidder operator or another crew member to the log (Figure 4). Skidders may have winches, grapples, both or swing boom grapples attached depending on the harvesting operation. These logs are generally attached by three to five chokers and pulled to the skidder by the winch. They are then skidded, or dragged across the ground, out of the SMZ to a main skid trail or landing for loading and at no time during the operation are machines allowed to enter the SMZ. This type of system where cables are used is mainly for steep, wet, or broken terrain when it is unstable or unsafe for skidders to operate on or travel.

Figure 4. A manual harvesting system consists of manual felling of trees using a chainsaw (photo to left) and a cable skidder (photo to right) to drag logs to a loading or landing area. Photos taken from the College of Natural Resources at Virginia Tech website, www.cnr.vt.edu.

Mechanized systems generally include one feller buncher, two grapple skidders, a gate delimber, and a knuckleboom log loader (Figure 5). The mechanized system uses a feller buncher to fell, bunch, and remove the timber for further handling from the SMZ with a saw or shear. A grapple skidder is then used to transport timber to the landing or a processing area for delimbing by grasping a load of bunched timber with a large pincer that is located on the back of the machine. Mechanized systems do not require the operator to leave the machine at any time during the felling process or when the timber is transported to the landing. This system operated in the SMZ with minimal passes of the machine and roads and skid trails were located outside of the SMZ.

Figure 5. A general mechanized harvesting system consists of a wheeled feller-buncher (photo to left) to fell and bunch trees and then a grapple skidder (photo to right) transports the timber to the landing deck. Photos taken from the College of Natural Resources at Virginia Tech website, www.cnr.vt.edu.

4.4 Sample Plots

All sample plots were located within streamside management zones that were managed according to the state's BMP guidelines. Plots were first located by beginning at the boundary of the SMZ and then walking parallel to the stream for 4-5 chains, depending on the size of the SMZ. At that point, a 50'x50' (15.24m x 15.24m) random plot area was laid out with two of the corners starting at the streambank (Figure 6). Spacing between plots were roughly 1-2 chains depending on the size of the SMZ. The number of plots that were sampled at a given tract depended on the size of the SMZ.

Within the plot, data was collected to determine background information on slope, timber volume, Universal Soil Loss Equation (USLE) erosion estimates, and vegetative composition. Canopy cover, basal area, and soil disturbance measurements were taken to determine their effects from the harvest. There were five transects spaced at 10-foot (3.05m) intervals which ran perpendicular to the direction of the timber extraction and parallel to the stream. All transects were located completely within the SMZ and away from skid trails. Visual soil disturbance measurements were collected every two feet using a visual soil disturbance classification scheme. Canopy cover measurements were collected every 4 feet (1.22m) using a vertical densitometer along each of the five transects. The amount of erosion per year was estimated for the entire plot using the Universal Soil Loss Equation (USLE) in ton/acre/year. Slope measurements were taken in each plot using a clinometer and rounding to the nearest one percent. Finally, trees that were greater than five inches and all stumps greater than three inches in the plot were measured to attain information on the basal area and volume using a volume prediction from stump diameter equation before and after the selective harvest.

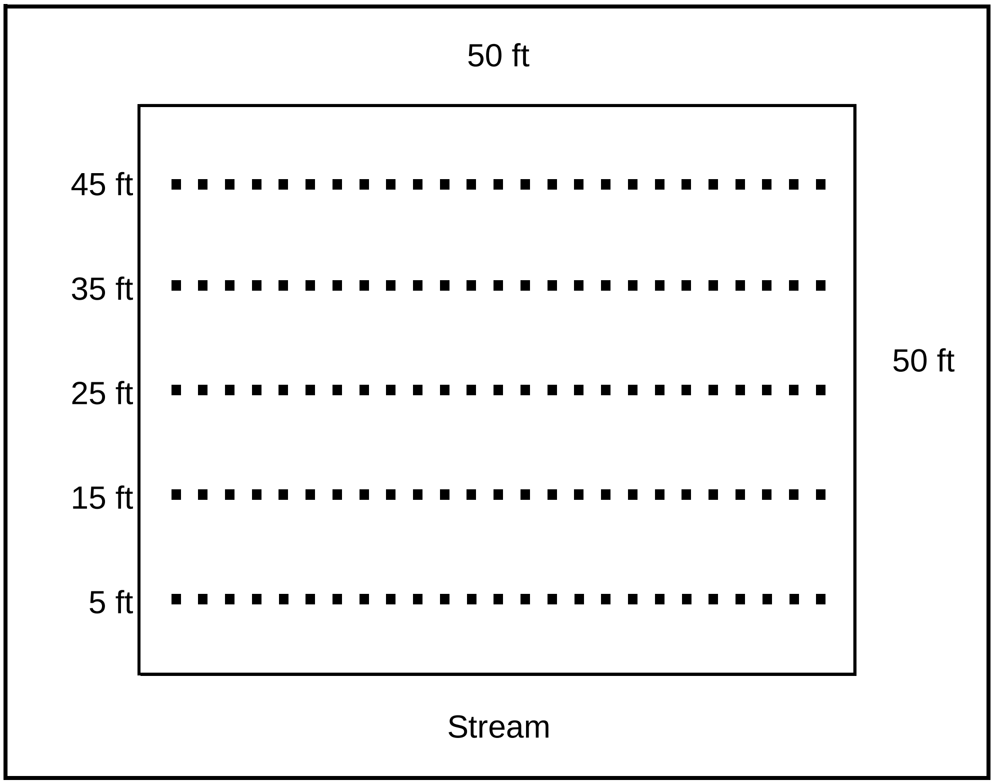

Figure 6. Schematic diagram of sample plot layout. Five transects were spaced 10 ft apart and positioned parallel to the stream. Soil disturbance measurements were taken every 2 ft along the transect and canopy cover measurements were taken every 4 ft.

4.5 Parameters Measured

4.5.1 Canopy Cover

Canopy cover is defined as the percentage of ground that is covered by vegetation. Canopy cover was measured using a Geographic Resource Solutions (GRS) vertical densitometer. The densitometer is a sighting tube with an internal crosshair and leveling bubble that is used to provide a simple, accurate and inexpensive alternative to measure canopy cover from a single point on the ground (Ganey and Block, 1994; Stumpf, 1993). Densitometers can be used in a wide range of conditions, given there is enough light for the operator to distinguish the amount of canopy cover present (Comeau et al., 1998). Ganey and Block (1994) recommend using the vertical densitometer over a spherical densitometer because of its ease in determining the mount of canopy cover, quickness in implementing, and the cost is also less. Sampling transects were located parallel to the stream and data collected along the line-point transect layout on a 50'x50' plot. Points were taken to yield a 95% confidence interval width between ±6.0% and ±10.1% cover. This allows the vegetation to be sampled both at the horizontal (landscape) and vertical level (canopy) (Stumpf, 1993). At each point, I held the densitometer level and looked directly overhead through the sighting tube and recorded whether or not there was canopy intersecting the crosshairs. To limit the amount of subjectivity in estimating the amount of canopy cover on a site, the same person was used for measuring all points and this dichotomous key of either "yes" or "no" was used to acquire accurate percentages. All data was collected during the non-dormant season.

4.5.2 Stand Volume

Data were collected to determine the amount of basal area and volume per plot for the initial and residual stands. In each 50'x 50' (15.24m x 15.24m) plot, the diameter at breast height (dbh in inches) for the remaining standing trees was measured for those trees greater than five inches. Stump diameters (inside bark) were also measured (> 3") to estimate the volume of timber and basal area removed. The following simple linear regression equations (Bylin, 1982a) were used to convert the recorded stump diameter to dbh:

All Pines: dbh (in) = .668 + .902(SDIB)* $R^2 = .95$
All Hardwoods: dbh (in)= 1.203 + .777(SDIB)* $R^2 = .90$

* SDIB = stump diameter inside bark

From this information, volume and basal area predications were made for the initial and residual stands and also for the amount that was removed. Volume and basal area predictions are useful to both foresters and landowners because they help define the stand structure, estimate stand inventories, and can predict the financial value by the amount of timber removed (McClure, 1968). Volume estimates were based on the volume prediction from stump diameter equation for softwood and hardwood species of the south where stump height was excluded. These equations are able to accurately predict total, merchantable, and sawtimber volumes within ±2 standard errors 95% of the time (Bylin 1982b):

All Pines:	$Vol^1 = -4.458 + .181(SDIB^2)^2$	$R^2 = .89$
All Hardwoods:	$Vol^1 = -.841 + .103(SDIB^2)^2$	$R^2 = .89$

[1] Vol = merchantable volume (cubic feet)

[2] SDIB = stump diameter inside bark

4.5.3 Soil Disturbance

Forestry operations have the potential to cause disturbance to the forest floor and there are a number of different ways to assess soil and site disturbance. Soil disturbance is defined as any loosening, compaction, puddling, or physical dislocation of soil particles. Due to time and logistical restraints involved in this study, we estimated visual soil disturbance as an index of soil physical changes by using the visual assessment method known as the McMahon (1995a) classification scheme. This visual assessment method focuses on the physical dislocation of soil and it is one of the most detailed schemes, resulting in 11 disturbance types that are then grouped into 5 categories (Thompson et al., 1997). This technique is a fast, simple, and inexpensive classification method is used as an index of amount of soil disturbance caused by forest harvesting.

At each point, a soil disturbance class was determined along the transects within the plot. For this study, McMahon’s grouping was modified slightly to form six new categories grouped in the following manner:

- “Undisturbed class” (codes 1,11) were areas with no disturbance or no soil;
- “Slight disturbance class” (codes 2,3) were areas where litter had been partially or entirely removed and in some cases topsoil was either partially removed or mixed with the litter layer.

- “Deep disturbance class” (code 4) was assigned to points where the topsoil had been removed and therefore the subsoil was exposed.
- “Rutted disturbance class” (codes 5,6,7) included rutting from wheels, tracks, logs that were anywhere from 5-30cm deep.
- “Deposited class” (code 8) was given to points where deposited material was covering the original forest floor and
- “Slash cover” (codes 9,10) was any point where the ground could not be seen.

It is important to note that the disturbance classifications (slight, deep, rutted) should not be considered as a direct impact on soil productivity, site damage and hydrologic functions (Aust et al., 1998; Hood et al., 2002) and they only estimate the amount of visual soil disturbance at one moment in time. We have found that visual disturbance classes match well with some and do not match well with other soil properties. On steeper terrain it has been shown that exposed soil and a decrease in vegetation will increase the amount of overland flow and sediment entering a stream channel (Kochenderfer and Wendel, 1983). Therefore, the forest litter layer, slash, and brush are key factors in trapping sediment before it reaches the stream channel (Swift, 1986)

Measurements were taken at two feet (0.61 meter) intervals along the parallel transect lines that were positioned perpendicular to the direction of the extraction. When compared with the grid point intercept method, the point transect method yields more accurate and consistent estimates of disturbance (McMahon, 1995b). Visual soil disturbance levels using different disturbance classes have also been found to have some correlation with relative static soil physical properties such as bulk density, saturated hydraulic conductivity, and macropore space (Aust et al., 1998).

4.5.4 Erosion (USLE)

The average erosion rate for the streamside management area was estimated in each 50'x50' (15.24m x 15.24m) plot using the Universal Loss Soil Equation (USLE) as modified for forests (Dissemeyer and Foster, 1984). The USLE is a widely used system because of its sound basis in soil and hydrology basics, the low cost and ease of implementing, and its direct application in forest systems (Hood et al., 2002). Erosion is defined as that amount of soil predicted to reach the bottom of a slope by the USLE. This estimation is not directly related to the amount of sediment that will enter a stream because a portion if not all of the eroded soil will be deposited before it reaches the stream (Dissmeyer and Stump, 1978; Hood et al., 2002). The USLE is a procedure that is used to estimate the amount of sheet and rill erosion produced for various practices.. The USLE was developed originally to predict long term, average soil losses in runoff on agricultural land (Dissemeyer and Foster, 1984), but increasingly it has been used on forestry land to estimate sheet and rill erosion where forestry operations have exposed the soil. Due to the need to estimate erosion on forest land, a modified version of the USLE was created and validated specifically for forest land by testing the methodology on several different watersheds using various forestry practices. Based on these results, the USLE yielded reasonable estimates of soil erosion for forest land and the formula is as follows, where each factor is multiplied by one another to estimate the amount of soil loss per unit area in tons/acre/year:

$$\mathbf{A = R*K*L*S*C*P}$$

A, the computed soil loss per unit area, expressed in units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year, but other units can be selected.

R, the rainfall and runoff factor, is the number of rainfall erosion index units. The R factor is usually read from an average annual rainfall indices map. For specific years or locations, the R factor can be computed from recording rain gage records.

K, the soil erodibility factor, is the soil loss per unit of R for a specific soil as measured on a unit plot, which is defined as a 72.6 foot length of uniform 9 percent slope continuously in a clean-tilled fallow. Clean-tilled fallow is an agricultural condition where the soil is kept bare and disked up and down slope-the most erosive condition for agricultural land. The C cover management factor has subfactors that adjust K to reflect untilled forest management conditions.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6 foot length under identical conditions.
S, the slope-steepness factor, is the ratio of soil from the field slope gradient to that from a 9 percent slope under other wise identical conditions.
C, the vegetative cover of land management factor, is the ratio of soil loss from an area with specific cover and management to that from an identical area in tilled, continuous fallow.
P, the support practice factor, is the ratio of soil loss with a support practice like contour disking to that with straight-row farming up and down slope.

**Dissemeyer and Foster, 1984*

The rainfall and runoff factor R is determined by the geographical position of your location and in this study values ranged from 125 EI unit/year in eastern West Virginia to 250 EI unit/year in the coastal plains of Virginia. One EI unit equals 100 (foot tons/acre) (inches/hour).

The soil erodibility factor K is measured in tons/acre/EI unit and can either be found in the USDA NRCS Soil Survey for that particular county, the Soil Conservation Service, or by using the soil erodibility nomograph found in the Guide for Predicting Sheet and Rill Erosion on Forest Land, where percent silt, sand, and organic matter and the type of soil structure and permeability are estimated.

The slope-length factor L and the slope-steepness factor S are evaluated together using either a topographic factor table which results in a LS value or a graph that can predict LS values for slope percentages greater than 20%. Slope percentage was measured using a clinometer.

The cover and management factor C uses the effects of several subfactors such as bare soil and fine roots, canopy cover, steps, depression storage, and high organic content to determine a value. Bare soil and fine roots are estimated using the percent of bare soil with dense mat of fine roots in the top three centimeters of soil and percent bare soil. The canopy cover value is estimated by canopy height and the percent of bare soil with canopy cover.

Next, steps were estimated using the percent of total slope in steps against the percent slope of the plot and depression storage values were determined for the amount of detached soil that potentially may be stored on site in depressions created from machinery or soil disturbance.

Finally, high organic content was estimated at 1.0 for those sites occurring in the Piedmont and Coastal Plain regions (the recommended value used for forests on recently abandoned farms where organic content has not had enough time to accumulate) and all other sites were estimated at 0.7 (the recommended value used for permanent forest soils) for soils with at least a one-inch thick top soil. The support practice factor does not pertain to this study because none of the sites were in agricultural management were disking or tilling was used.

4.6 Statistical Analyses

Statistical analyses were performed to detect statistically significant differences and relationships between the type of harvesting system used and the level of harvesting intensity with the visual soil disturbance and USLE data. Using the JMP IN second edition software program by SAS Institute Inc., 2001 parameters were tested with the bivariate analyses of the least squares regression linear model and the one-way analysis of variance (ANOVA). Analyses using the least squares regression linear model was conducted on an individual basis for all 118 plots. Analyses using ANOVA was conducted to determine statistical significance between the 50 tracts by averaging the subsamples found in each tract. Differences were considered statistically significant at a significance level of $p\text{-value} < 0.10$.

5.0 RESULTS

5.1 Site Description

There were 118 sample plots (50'x50') within streamside management zones on 50 different tracts of varying size. Manual harvesting systems were observed on 26 tracts and mechanized harvesting systems were observed on 24 tracts. A summary of plot information is provided in Table 5. The average timber volume removed from the SMZs was 1942 ft^3/ac. Average basal area before harvest was 115 ft^2/ac and the average basal area removed was 72 ft^2/acre. The average dbh in the SMZ prior to harvest was 11 inches estimated from stumps and remaining standing trees and post harvest was 9 inches estimated from remaining standing trees. The average estimated erosion rate in the SMZ after harvest was 2.25 ton/acre/year (4.95 Mg/ha/year). Harvesting operations occurred during the months of February to September and the majority of harvest treatments were diameter limit cuts or selective harvests, which are commonly used on private lands. There were no extreme weather conditions during the study period (June – September, 2004) in Virginia and West Virginia. One to two researchers were used to collect and record all data related to soil disturbance and canopy cover measurements.

Table 5. Stand dynamics given for initial and residual stages of harvests that took place in Virginia and parts of West Virginia, 2004.

Stand Parameter	Minimum	Maximum	Average
# Plots per tract	1	4	2.4
Harvest size (ac)	20	600	152
Slope (%)	2	65	27
USLE (ton/ac/yr)	0.003	47.35	2.25
Canopy cover removed (%)	0	100	53
Trees/acre			
Initial	35	401	161
Residual	0	209	79
Removed	0	314	81
dbh			
Initial	6	27	11
Residual	6	25	9
Removed	6	27	12
Basal area/acre (ft2)			
Initial	30	295	115
Residual	0	173	45
Removed	0	255	72
Volume/acre (ft3 inside bark)			
Initial	490	7609	2784
Residual	0	2471	863
Removed	0	7457	1942

5.2 Canopy Cover vs. Basal Area

Mean canopy cover remaining was 47% and 45 ft^2/ac. Basal area values remaining in plot ranged between 0-173 ft^2/ac and canopy cover values ranged between 0%-100% after harvest. In some plots where basal area was estimated to be 0 ft^2/ac, canopy cover estimates ranged from 0%-62%. Based on the regression equation, when 50% of the canopy cover was removed there was an average of 71 ft^2/ac basal area remaining in the stand. When 100% canopy cover was estimated there was 135ft^2/ac basal area in the stand (Figure 7). When tested using the least squares regression linear model and ANOVA, these parameters were found to be statistically dependant to one another (p=0.0001, r^2=0.44). Even though these parameters are clearly related with a p-value of less than 0.01, basal area is not an accurate predictor of canopy cover or visa-versa because it only explains 44% of the variation found within the model.

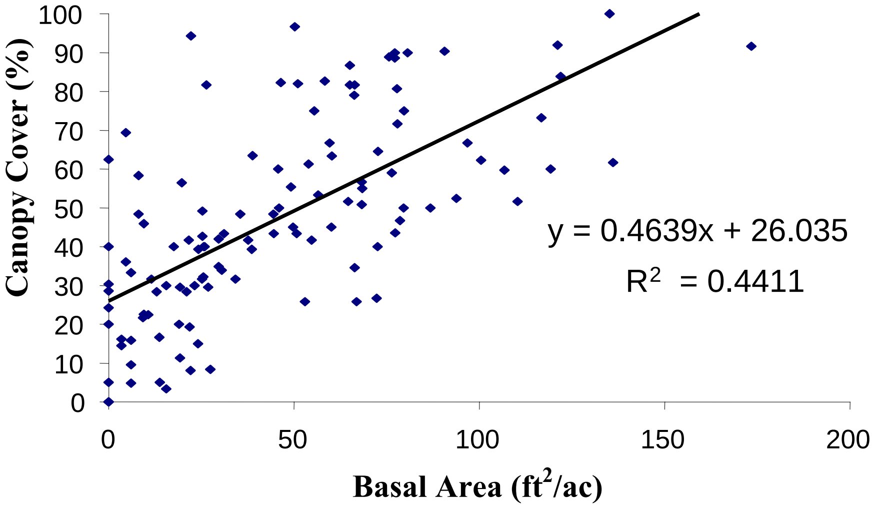

Figure 7. Relationship between basal area (ft^2/ac) and canopy cover (%) in a SMZ within 6 months after logging in Virginia and the eastern part of West Virginia, 2004..

5.3 Visual Soil Disturbance

Visual soil disturbance found in each plot was measured using a soil disturbance classification scheme and when compared with the USLE values found in each plot there was a statistical significant relationship, however only 26% can be explained by this model (p=0.0008, r^2 =

0.2623). Total soil disturbance values included slight, deep, and rutted categories and averaged 25% and ranged between 0–71%. USLE values for soil loss averaged 2.25 ton/acre/year and ranged from 0.003-47.35 ton/acre/year (Figure 8). A relationship exists between these parameters because vegetative cover which is one of the five factors that is used to predict annual soil erosion rates is directly related to visual soil disturbance. Both are estimates that include the amount of area on the forest floor that has been exposed. It is not a strong relationship because the USLE calculation not only measures the percentage of vegetative cover but also measures several other factors such as rainfall and runoff, soil erodibility, and slope.

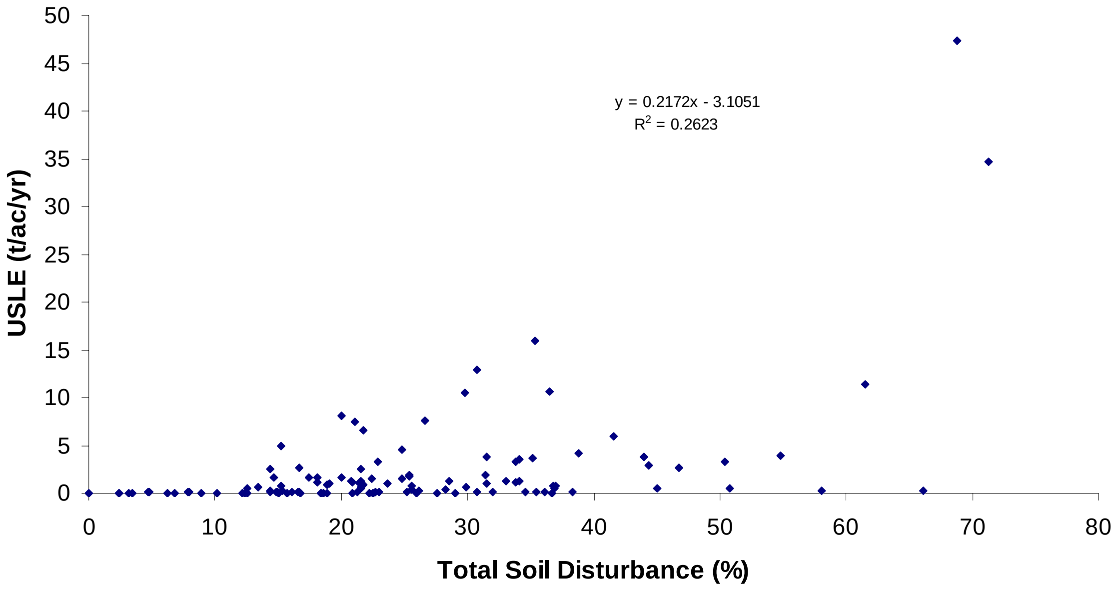

Figure 8. Relationship between USLE (ton/acre/year) and percent total soil disturbance inside SMZs withing 6 months after logging in Virginia and the eastern part of West Virginia, 2004.

5.3.1 Effects of Harvesting System

A visual assessment was performed on both soil disturbance and canopy cover after the harvest in each plot. All five soil disturbance classes that were used to describe the level of soil disturbance at each point were found in the study area. Over the entire study area, the manual harvest system yielded an average of 60% as undisturbed soil, 19% was rated as slight soil disturbance, 6% was shared evenly between deep disturbance and rutting, 14% had some level of slash covering the forest floor, and 1% was covered with deposited material. The mechanized harvest system had similar findings with 66% of undisturbed soil, 20% in the slight soil disturbance category, 3% deep disturbance and 2% rutting, 8% slash and 1% deposited material (Figure 9).

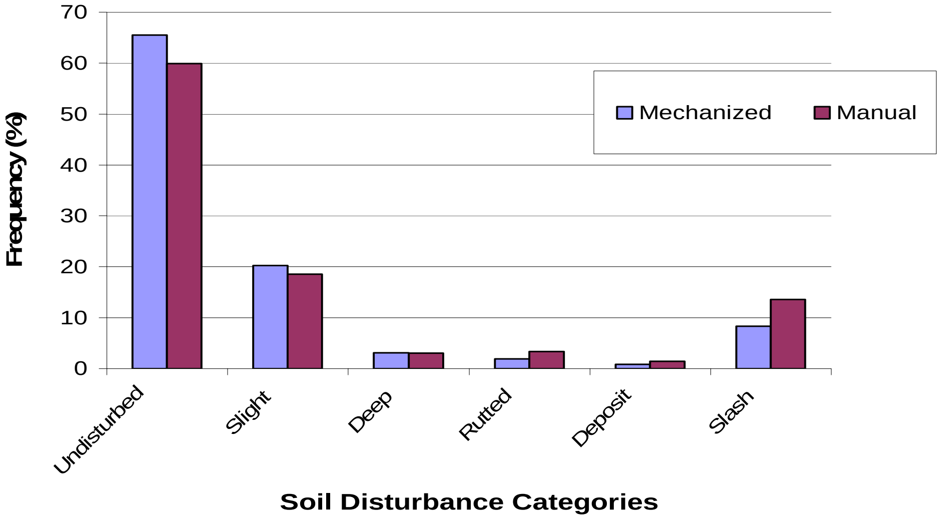

Figure 9. The frequency of total soil disturbance (%) for the two harvesting systems tested within 6 months after logging in Virginia and the eastern part of West Virginia.

After analyzing visual soil disturbance measurements based on the operating system, both systems yielded 26% soil disturbance. This includes slight, deep, and rutted classes that were distributed similarly between categories. The ANOVA analysis found no statistically significant difference between these two systems on soil disturbance ($p=0.91$, $r^2=0.0001$) and the alternative hypothesis (ha_1) which states cable winching systems will have higher disturbance levels than the feller-buncher system is false. However, the manual harvesting system showed significantly higher percentages than the mechanized systems in “rutted” disturbance classes ($p=0.03$, $r^2=0.038$) and “slash cover” classes ($p=0.04$, $r^2=0.036$). The manual system showed slightly higher percentages in “deposited” disturbance classes (1.4% vs. 0.8%). The mechanized system showed higher percentages than the manual system in the “undisturbed: class (65.5% vs. 59.9%) “slight disturbance class (20.1% vs. 18.6%), and “deep” disturbance classes (3.2% vs. 3.1 %). Manual systems had soil disturbance ranging from 2-71% and mechanized systems had disturbances ranging from 0-62% (Figure 9). Manual systems operated on slopes averaging 35%, while 17% was the average slope that mechanized systems operated on.

5.3.2 Effects of Harvesting Intensity

The intensity of harvest significantly affected soil disturbance percentages and therefore our second hypotheses (ha_2) that stated as harvesting intensities increase, the amount of soil disturbance will also increase was tested to be true ($p=0.0014$, $r^2=0.085$) by the least squares linear regression model. However, no direct relationship or prediction can be determined between the amount of canopy cover removed and total soil disturbance because there is very little that be can explained by the R-square value in this model (Figure 10). When an area becomes rutted and compacted, soil characteristics have the potential and tendency to change. Therefore, Figure 11 depicts a similar result when "rutted soil disturbance" values were compared with the amount of canopy cover removed ($p=0.0053$, $r^2=0.065$).

When 25% of the canopy cover was removed total soil disturbances averaged 17% (Figure 10) and rutted disturbances averaged 1% (Figure 11). At the suggested canopy cover removal level of 50% (as stated in the Virginia BMP manual) there were total soil disturbances averaging 28% and rutted disturbances averaging 0.6%. When 75% of the canopy cover was removed total soil disturbances averaged 44% and rutted disturbances averaged 1%. Overall, total soil disturbance percentages ranged from (0% to 71%) and rutted soil disturbance percentages ranged from (0% to 25%).

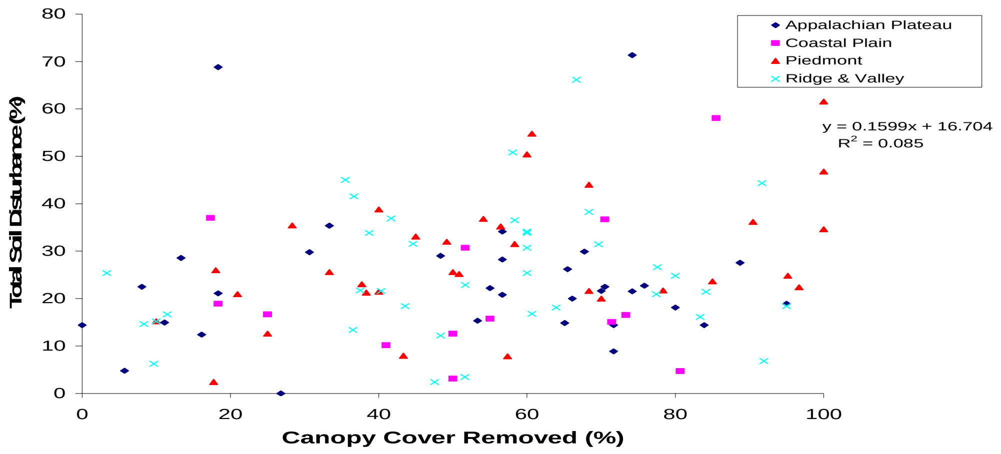

Figure 10. Data points plotted by physiographic regions between percent canopy cover remaining and percent total soil disturbance inside SMZs within 6 months after logging in Virginia and the eastern part of West Virginia, 2004.

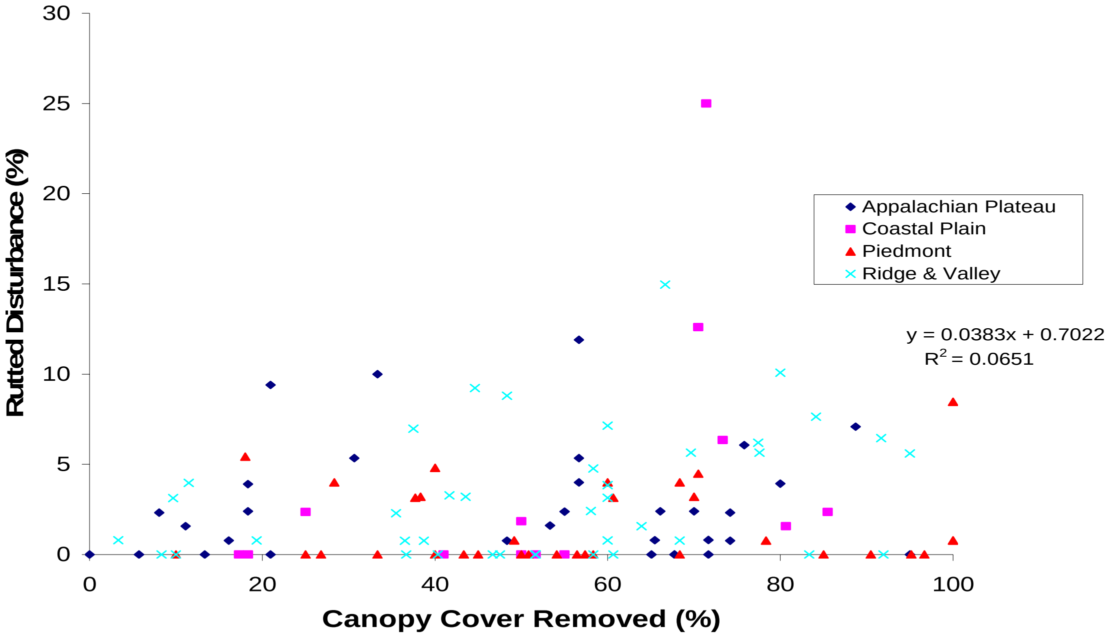

Figure 11. Data points plotted by physiographic regions between percent canopy cover removed and percent rutted disturbance inside SMZs within 6 months after logging in Virginia and the eastern part of West Virginia, 2004.

5.3.3 Effects of Slope Gradient

Slope gradient was found not to be a significant factor in the occurrence of soil disturbance when the "slight", "deep", and "rutted" disturbance classes were combined using the least squares regression linear model ($p=0.38$, $r^2=0.0066$) (Figure 12). When soil disturbance was compared with slope using only the "rutted class", again slope was found not to be a significant factor ($p=.70$, $r^2=0.0009$) (Figure 13). Overall, soil disturbance percentages ranged from 0% found on a 25% slope to 71% found on a 50% slope gradient. On lower slopes (0-10%), soil disturbance percentages ranged from 5-66%. On steeper slopes (50-65%) soil disturbance percentages ranged from 14-71%.

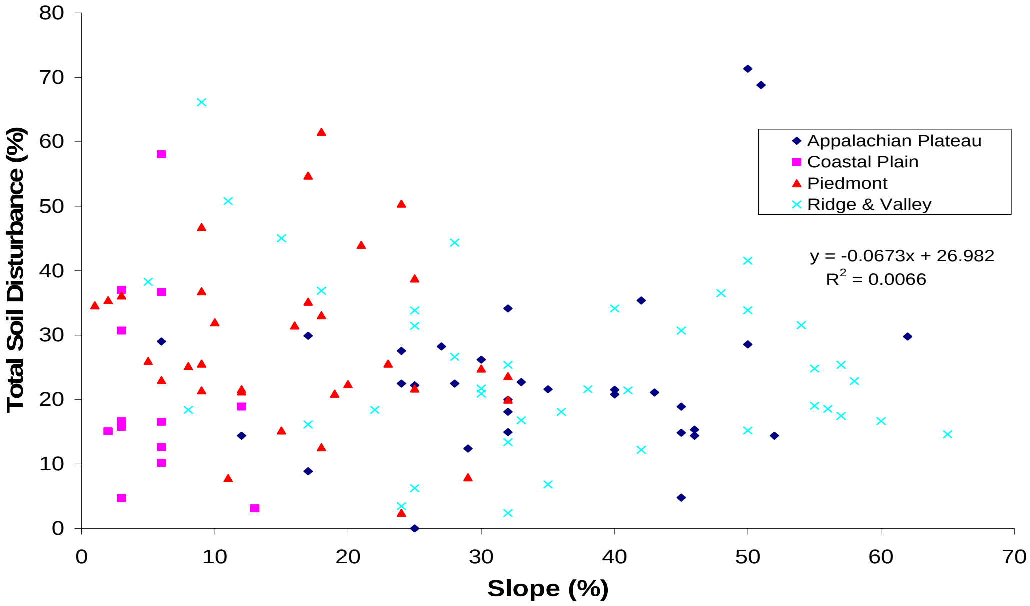

Figure 12. Data points plotted by physiographic regions between slope gradient (%) and the frequency of soil disturbance (slight, deep, and rutted classes) within 6 months after logging in Virginia and the eastern part of West Virginia, 2004.

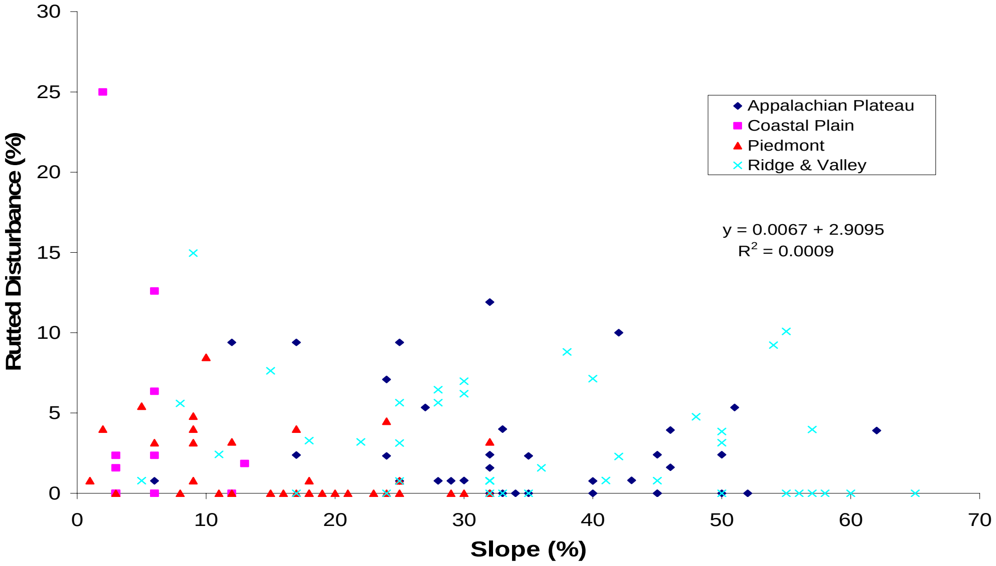

Figure 13. Data points plotted by physiographic regions between slope gradient (%) and the frequency of "rutted" soil disturbance within 6 months after logging in Virginia and the eastern part of West Virginia, 2004.

5.3.4 Effects of Distance from the Stream

Using the one-way analysis of variance, soil disturbance and type of harvesting system was analyzed to determine the frequency of soil disturbance at each 10-foot transect within the study plot. When grouped by harvest system for each transect along the stream, all values were statistically similar except at the 45-foot transect where the systems showed statistically different values when compared. The manual system had higher total soil disturbance area at 5 ft (24.7% vs. 20.8%) and at 15 ft (26.4% vs. 22.9). The mechanized system had higher total soil disturbance area at 25 ft (27.6% vs. 26.9%), at 35 ft (28.86% vs. 26.91%), and at 45 ft (30.0% vs. 25.1%) (Figure 14).

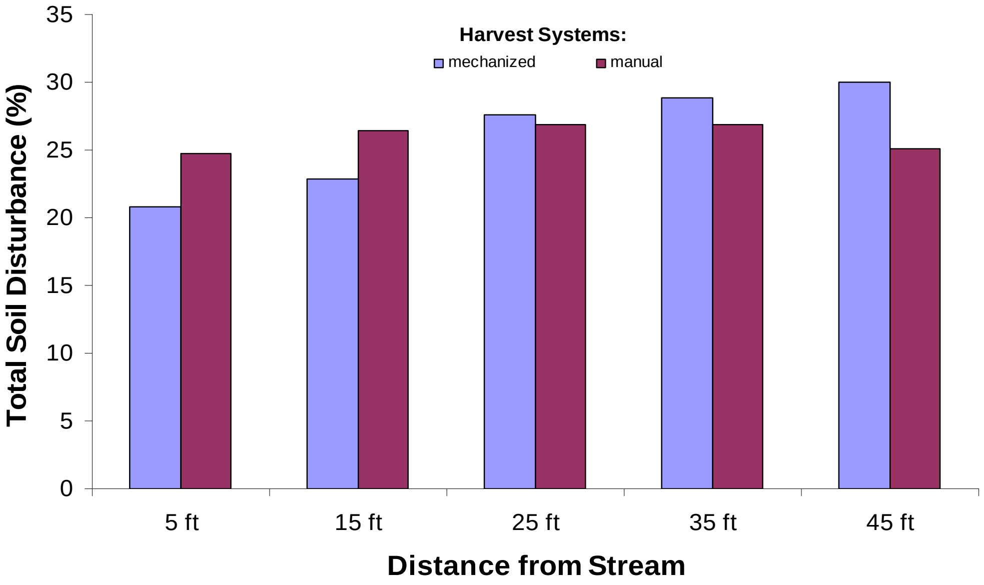

Figure 14. Comparison between two harvesting systems on their occurrence of soil disturbance at each 10-foot transect within 6 months after logging in Virginia and the eastern part of West Virginia. Soil disturbances are grouped by harvest system for each distance and letters indicate statistically similar values within each group at the α = 0.10 level, 2004.

6.0 DISCUSSION

Each state in the southeastern region of the USA has developed their own BMP manual with a section denoted to SMZs. In general the manuals discuss their requirements, definitions related to SMZs, and their purpose. The majority of the states have guidelines that seem feasible and practical to apply in the field. Most of these guidelines are based on past and current research studies while others are based on general knowledge. In this study certain parameters were measured and tested to see if there were any direct relationships between the type of harvesting system used and the amount of canopy cover removed on soil disturbance. Findings from this study suggest that there are some guidelines in place that may need to be revised or further research implemented.

6.1 Harvesting Systems in SMZs

Streamside management zone guidelines in the southeast vary by state, however there have been limited studies that actually quantify the impacts of harvesting on water quality (Liechty, 2002). Harvesting systems become an issue when dealing with sensitive areas such as SMZs. States have tried to minimize negative impacts by recommending where to perform the operation and what types of equipment should be used. The majority of states recommend that roads, landings, and skid trails remain outside of the SMZ. Several states allow equipment within the SMZ, but acknowledge that the proper measures should be taken to minimize impacts. Other states suggest that equipment should be located outside of the SMZ and timber should be skidded out with a cable-winching system.

The results of this study show that the two different harvesting systems did not have statistically significant different total visual soil disturbance levels. When compared, both systems individually had 26% total soil disturbance and the manual system had significantly larger percentages than the mechanized system in the “rutted” disturbance class ($p=0.03$, $r^2=0.038$) and “slash cover” class ($p=0.04$, $r^2=0.036$). The rutted soil disturbance category was analyzed to better assess the severity of site disturbance and included points where the soil had been exposed at depths from 5 to 30 cm. Generally harvested areas that show this level of disturbance can potentially affect the nature of soil porosity, soil structure, infiltration rates, vegetative growth, soil biota, and water and site quality (Reisinger et al., 1988). There were no significant differences in the “undisturbed”, “deep”, and “deposited” disturbance classes (Figure 9). The higher percentage of area in “rutted disturbance” for the manual system occurred when trees were felled and then skidded across the forest floor out of the SMZ. This dragging motion across the forest floor disrupts the organic cover, exposing and compacting the soil and creating long and continual channels for overland flow which can possibly contain excess nutrients, sediment, and debris to enter the stream. Compaction can result from rutting as logs are skidded across the ground or when equipment passes over a general area several times mixing, moving and hardening the soil (Patric 1978). The manual system had a higher percentage of slash cover, (13.6% vs. 8.3%) than the mechanized system. In manual operations trees are felled and topped within the SMZ and tops and limbs are then left in the SMZ as slash, unlike mechanized operations where trees are cut and entirely taken out of the SMZ for limbing and topping. This can be an advantage by adding protection and cover to the forest floor from erosion and adding nutrients to the soil as leaves and limbs decompose over time. Slash cover helps to absorb and decrease the impact of falling rain drops on the forest floor and the potential for soil detachment immediately following harvest when there are areas of exposed soil (Dissmeyer and Foster, 1984 and Patric, 1976).

Lanford and Stokes (1995) tested a skidder system with a forwarder system and found that the skidder system had significantly more “slightly” (13% vs. 9%), “deeply” (1% vs. 0%), and “rutted” (38% vs. 29%) disturbed area for the entire harvest area, not just the SMZ. Aust et al. (1993) tested wide-tired skidders on a wet pine flat in South Carolina and found undisturbed, slightly, and rutted disturbance percentages of 52%, 14%, and 34% for the entire site. The amount of rutted area for both of these studies had much higher percentages than what was found in our study (3.4% of rutted disturbance for the manual system and 1.9% rutted disturbance for the mechanized system) because soil disturbance was measured on areas including skid trails and decks in addition to the streamside management zone. This study shows somewhat similar results to Stuart and Carr, (1991) when they evaluated conventional ground-based harvesting systems on steep slopes in Virginia. They found that harvesting systems that left between 70 and 80 percent of the soil undisturbed resulted in no significant impact to water or site quality and these levels are comparable to our study where harvesting systems left 60 percent from the manual system and 66 percent from the mechanized system of the soils undisturbed. Again, the mechanized system where the machinery was allowed to enter the SMZ yielded lower overall soil disturbance percentages.

6.2 Harvesting Intensities on Visual Soil Disturbance

Percentage of visual soil disturbance was found to be dependent on the amount of canopy cover removed, but with a very low correlation. In studies where silvicultural treatments were analyzed, harvesting intensities were also known to affect the amount of soil disturbance. Visual soil disturbance levels were lower in single-tree selection cuts and higher in shelterwoods and clearcuts (Kleunder et. al, 1994).

Virginia allows either 50% of the canopy cover or basal area to be removed on perennial and intermittent streams. When compared with Canada's system of acceptable soil disturbance rates of 5% deep disturbance (definition of deep) Virginia had an average of 3% "rutted" soil disturbance within 6 months after harvest in the SMZ. Based on soil disturbance impacts with these low rates of disturbance found, it seems environmentally feasible and practical to harvest in these zones without seriously degrading water quality.

North Carolina is the only southeastern state that measures bare ground percentages instead of basal area or canopy cover for harvesting requirements in the SMZ. These figures were based on information from the State Sedimentation Pollution Control Act of North Carolina and research studies from Coweeta Experimental Forest. When North Carolina's recommendation of having <20% bare ground disturbance in the SMZ was compared with Virginia's 50% canopy cover remaining I found that these numbers on average equaled each other. As 50% of the canopy cover was retained there was an average of 19.3% bare ground disturbance. While North Carolina's method requires more time and knowledge from the operator, it attains the same desired results as Virginia who uses the fast and simple method of visually estimating canopy cover.

6.3 Basal Area vs. Canopy Cover

Most states suggest using either basal area or canopy cover to measure harvest intensities and some states use the parameters interchangeably. When these two variables were compared, they were found to be directly proportional to each other but with a low percentage explained by the model, r^2=44% (Figure 7). When dealing with canopy cover it is important to note that trees located outside and adjacent to the study plot may have had a slight affect on this analysis since their tree crowns may reach over into the study plot and be recorded as canopy cover. This was evident in those plots where no actual trees ≥ 5” were present, but canopy cover levels ranged from 0-62% and it may possibly explain the low R-square that was found. States that use basal area and canopy cover measurements interchangeably should remember that even though there is a correlation between the two, it is not a strong nor equal one.

6.4 *Impacts of Slope Gradient on Soil Disturbance*

In Virginia’s BMP manual it states that “steep slopes, cold water fisheries, and municipal water supplies all need wide SMZs to protect water quality” (VDOF 2002) yet the widths for warm water fisheries are not dependant on slope. It is proven that in most cases the steeper the slope the faster the runoff and therefore the more potential for soil erosion (Dissemeyer 1984). Most states have identified this relationship and developed their requirements according to slope gradients.

In this study, all soil disturbance classes were found not to be dependant on slope gradient (see also Figure 12). Others have also found this to be true, and as slope increases soil disturbance decreases (Stuart and Carr, 1991; Stokes et al., 1998). Generally sites that are more difficult to access have a greater amount of undisturbed area than sites that are easily accessed. This was evident for Coastal Plain harvesting systems were large areas were disturbed compared to the Appalachian Plateaus where there were few disturbed areas and generally when there is more disturbed area there a greater potential for erodibility.

6.5 Soil Disturbance Location

Position and harvest system was analyzed to determine their effect on the frequency of soil disturbance. At distances that were 5 ft and 15 ft away from the stream, the manual system resulted in higher soil disturbance percentages and from 25 ft – 35 ft the mechanized systems had the higher soil disturbance percentages. The manual system had a normal bell-shaped curve with very little variation is disturbance percentages along transects (19.5% vs. 21 %). The mechanized system was positively linear in shape with a wider range in soil disturbance area (16% vs. 23). Kiem and Schoenholtz (1999) found opposite results with their manual system in a study that tested harvesting treatments. There was a significantly higher percentage of soil disturbed area found at 30m (90ft) from the stream versus 5m (15ft) from the stream, although we should note that this SMZ is twice as wide. Rates of soil disturbance that were found in the SMZ were comparable between these two studies. Further research should be implemented to determine where the greater amount of soil disturbance exists within the SMZ. If disturbance occurs closer to the stream, similar to the manual system in this study, restrictions could potentially be made on how close systems should operate to the streambank and at what distance should trees be removed. There is at least one eastern state that already takes this component into consideration (Stringer and Thompson, 2000).

7.0 CONCLUSION

Streamside management zones are sensitive areas that have been vital in maintaining and protecting water quality on our forestlands. At the same time, these areas generally have high site productivity levels for growing timber and when harvested can produce income for the landowner or company. Timber harvesting, if improperly implemented can degrade water quality and site productivity, but if BMPs are followed by safe, experienced, and educated workers this degradation can be minimized. States have developed Best Management Practices to protect water quality when harvesting timber and recommendations are given specifically to harvesting in the SMZ.

In all southeastern states harvesting is allowed in SMZs and when focusing on Virginia, SMZs may have 50% of the canopy cover removed. At the removal of 50% canopy cover there was an average of 19% total soil disturbance and 0.6% rutted soil disturbance within 6 months after harvest. Canopy cover values were compared with basal area values and the study showed that there was a significant correlation between the two variables. In the field either this method tested to be successful, however the two parameters should not be used interchangeably. When tested, total visual soil disturbance was significantly dependant on the intensity of the harvest. When harvesting, there have been discrepancies among states and researchers as to which harvesting system actually causes the least amount of soil disturbance.

The two most common types of harvesting systems in Virginia (cable-skidder and feller-buncher/grapple-skidder) and their effects on soil disturbance were tested in SMZs. Once tested, there were no significant different visual soil disturbance levels reported between the two systems; both systems reported 26% of the area combined in slight, deep, and rutted soil disturbance. However, the manual system had significantly more rutted disturbance area and slash cover than the mechanized system. What is significant is that those states that put restrictions on allowing equipment to enter the SMZ does not seem to be beneficial based on the results from this study of visual soil disturbance levels. Based on the visual soil disturbance assessment and the USLE, both systems use practical and safe measures for removing timber without causing any severe degradation to water and site quality. Slope gradient also proved not to be a significant factor in soil disturbance. Data from this study shows that the frequency and occurrence of soil disturbance greatly depends on the specific site conditions present at each site. Currently, land managers and contractors have little quantitative basis for the selection of appropriate technology and equipment on some tracts. This information will become more important as more site-specific prescriptions evolve (Wear and Greis, 2002). Future studies should look at impacts that were not addressed here, such as stream water quality and direct measures of soil physical properties in SMZs and their potential effects on site hydrology.

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