Effects of Forestry Streamside Management Zones on Stream Water Quality, Channel Geometry, Soil Erosion, and Timber Management in the Virginia Piedmont

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Abstract

The major study objectives include determining if a 50-foot streamside management zone (SMZ) as described in the Virginia BMP Manual (VDOF 2002) is generally sufficient to protect stream water quality, riparian soils, and stream bank integrity in headwater streams where forest harvesting has taken place, as well as comparing other SMZ widths with regard to the same environmental protection performance. In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four SMZ treatments were installed across four experimental blocks during harvest. Each of the 16 watersheds was subsequently site-prepared with prescribed burning and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the established treatments were a 100- foot width with no thinning, a 50-foot width without thinning, a 50-foot width with thinning, and a 25-foot "stringer." Each of the four treatments was conducted within three of four blocks (Incomplete Block Design). After a two-year post-harvest monitoring period, it was determined that the SMZ treatments had no significant effect on water quality, channel geometry, or soil erosion in and around the streams. There was no apparent water quality degradation as a result of harvesting timber, and larger SMZs did not have an impact on any of the parameters studied. It was also apparent that leaving narrower SMZs or thinning within SMZs did not cause any apparent environmental degradation. It was also determined that landowners who leave SMZs on their property have very limited opportunities to manage timber within them for financial gain in the long term.

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I can't say enough about the willingness of my wife Holly to put up with this graduate school nonsense yet again. She moved out to the Shenandoah Valley, greatly extending her commute to Richmond, to keep mine below two hours one way. All that for another Forestry degree. What were we thinking?

And to my dear son William. Thank you very much for being who you are and for understanding that "Dad can't play right now." It's over.

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Thanks again to Sue Snow, Tracey Sherman, Kathie Hollandsworth, and Arlice Banks for their support in a variety of ways over the years.

I want to dedicate my accomplishments in life to four very important people:
My mother, who brought me into this world,
My father, who left it too early,
My son, who found us just in time,
And, My wife, who gave me my son.

Thank You All.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, excess nutrient inputs, thermal pollution, stream channel stabilizations, and enhancement of in-stream and riparian habitat (VDOF 2002). It is common for state BMP manuals to recommend some width of SMZ on each side of perennial and intermittent streams, and most southern states recommend between 25 and 50 feet in most cases (Castelle et.al. 1994). Most state BMP recommendations also include provisions for careful thinning of timber up to 50% of the original basal area or crown cover. These recommendations generally increase to some degree (as much as 200 feet) in cases involving more sensitive ecosystems such as cold water fisheries and municipal water supplies (VDOF 2002).

In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four treatments were installed across four blocks during 2003-2004. Each of the 16 watersheds of approximately 50 acres was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the streamside management zone treatments were established as 1) a 25-foot "stringer," 2) a 50-foot width with no thinning, 3) a 50-foot width with thinning, and 4) a 100-foot width with no thinning. Four major areas of study were monitored through the 2006 calendar year for a total of two years post-harvest. These study areas are 1) stream water quality, 2) soil erosion, 3) riparian timber management and associated costs to landowners, and 4) stream channel geomorphology. Hypothesis testing was completed to determine if the SMZ widths and thinning regimes had a significant impact on the above four areas of interest.

Chapter 2: Literature Review

Nonpoint Source Pollution

Even though forestry operations produce lesser amounts of nonpoint source pollutants than most other major land uses due to the ephemeral nature of associated soil disturbance, abundance of organic materials, and general lack of applied pollutants (Ward and Trimble 2004), it is important to consider that improvements are possible and necessary to comply with the federal Clean Water Act and associated amendments. It is also important to comply with stated goals defined for the cleanup of the Chesapeake Bay (Chesapeake Bay Local Assistance 2008) and other sensitive ecosystems.

The United States Environmental Protection Agency (USEPA) describes and characterizes nonpoint source (NPS) pollution as follows:

> *Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. These pollutants include:*

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septic systems;
- Atmospheric deposition and hydromodification are also sources of nonpoint source pollution (USEPA 2004).

Sediment, bacteria, nutrients, oils, fuels, and a variety of chemicals all contribute to environmental degradation and are the major targets of NPS and water quality programs in general (USEPA 2000, Duda 1985).

Environmental and Economic Impacts

NPS pollution often leads to serious degradation of streams, rivers, lakes, estuaries, and coastal waters (Figs. 1-1, 1-2, 1-3). The 2000 EPA water quality report indicates approximately 39% of streams in the U.S. are at least partially impaired due to poor water quality. The majority (50%) of the impaired river and stream mileage is a direct result of agriculture activity (Fig. 1-2).

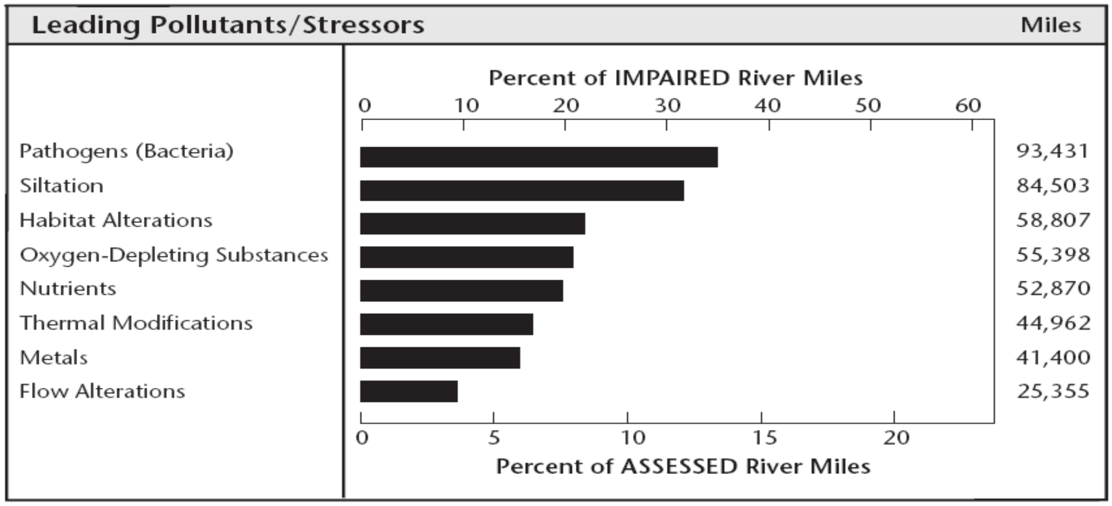

Figure 1-1: Leading water pollutants in streams surveyed in the U.S. for the 2000 National Water Quality Report (Adapted from USEPA 2000).

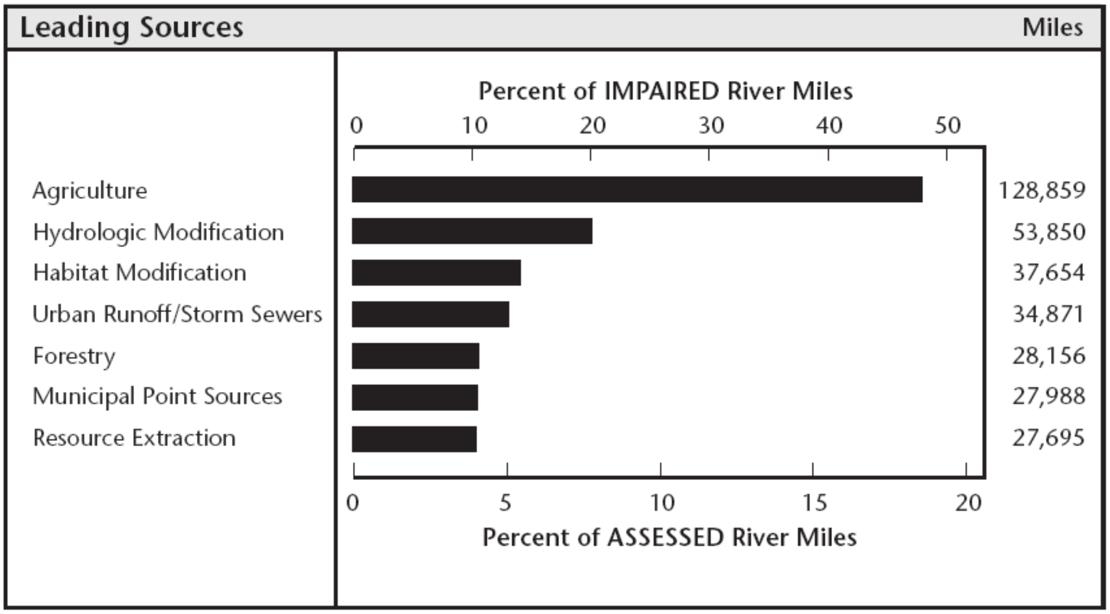

Figure 1-2: Leading sources of water pollutants in streams surveyed in the U.S. for the 2000 National Water Quality Report (Adapted from USEPA 2000).

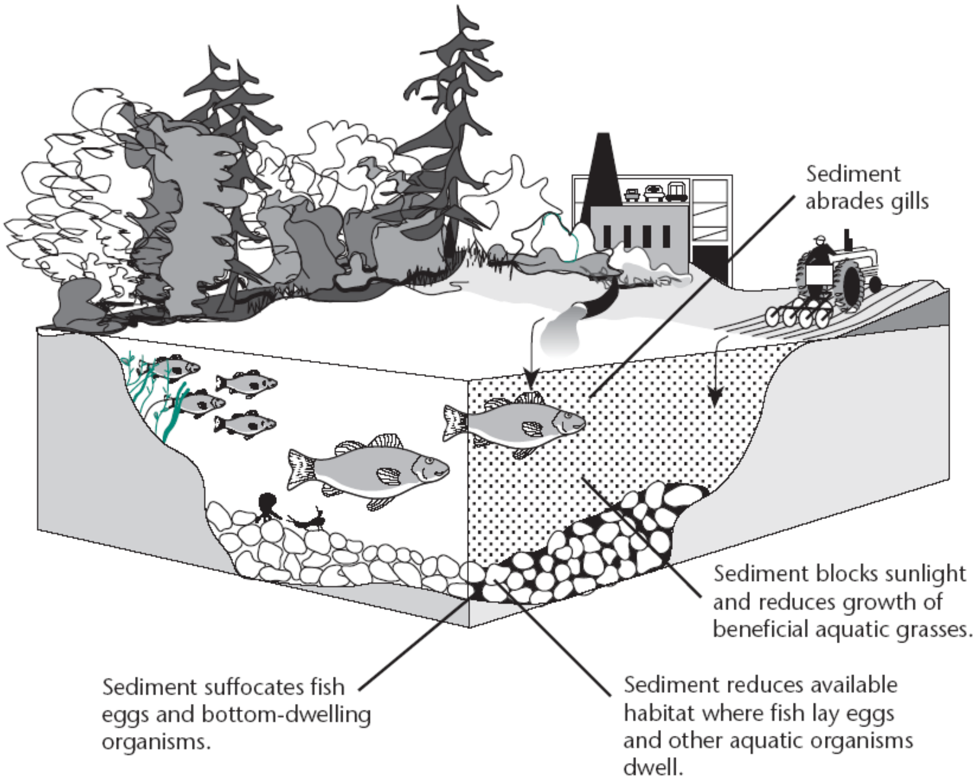

Figure 1-3: Basic impacts of sedimentation on aquatic ecosystems (Adapted from USEPA 2000).

Sedimentation can kill fish and other organisms directly and prevent successful reproduction by covering spawning habitat with silt. Resulting increases in turbidity can reduce photosynthesis by aquatic plants, further degrading habitat. Fish species requiring clear water will perish or migrate and fish species more tolerant of turbid water and muddy channels will dominate (Duda 1985). Fine sediment particles often damage gills of fish and organisms that fish feed on. The fine sediments often transport adsorbed pollutants such as pesticides, plant nutrients, and trace metals. Organic forms of mercury are often adsorbed to soil particles and can later be converted to an inorganic form by bacteria, which can then accumulate in living tissues (Oschwald 1972). Long-term sedimentation can drastically alter stream characteristics and alter entire ecosystems permanently (USEPA 2000, Duda 1985).

Economic impacts of increased nonpoint source pollutant inputs are not as obvious or visible but are equally large. Costs stem from a long list of problems such as increased flood damage, fish stocking, restoration of damaged waterways, cleaning of ditches, dam building, loss of recreational activities, commercial fishery degradation, regulatory program needs, and research and development of abatement and prevention methods (Colacicco et al. 1989, Duda 1985, Ribaudo and Young 1989, Stall 1972).

Excess Nutrients lead to a variety of problems for water quality. Excess nutrients in water lead to excess growth of algae and other plants that later die and decompose. The decomposition process depletes the oxygen levels in water, which can lead to significant fish kills. Although an unlikely result of silvicultural operations, “High concentrations of nitrate can cause methemoglobinemia, a potentially fatal disease in infants also known as blue baby syndrome" (Binkley et al. 1999, USEP 2004b). This condition occurs when excess nitrate is converted to fatal amounts of nitrite in the bloodstream, inhibiting the blood's ability to carry oxygen (USEPA 2004c). These issues can also lead to water quality that prevents swimming, fishing, and boating. Virginia has one of the leading nitrate water application rates in the country (Table 1-1).

Table 1-1. Total nitrate releases to water and land (pounds), 1991-1993, and responsible sources in general.

	Water	**Land**
Totals	**59,014,378**	**53,134,805**

Top 15 States	**Water**	**Land**
Georgia	12,114,253	12,028,585
California	0	21,840,999
Alabama	3,463,097	6,014,674
Louisiana	8,778,237	2,250
Missouri	6,985,890	206,181
Mississippi	6,952,387	0
Kansas	5,140,000	877,095
Virginia	**5,091,764**	**0**
Nevada	0	4,977,482
Florida	1,056,560	1,835,736
Arkansas	1,206,610	1,058,294
Maryland	1,802,219	138,819
Iowa	1,500,340	132,042
Oklahoma	1,436,348	14,199
Utah	0	1,045,400
Major Industries		
Nitrogenous fertilizer	41,584,611	8,607,376
Misc. ind. inorganics	4,113,312	29,676,919
Misc. metal ores	0	5,764,976
Misc. ind. organics	5,091,764	0
Fertilizer mixing	480,000	4,554,916
Explosives	850,921	1,297,590
Paper mills	1,727,061	0
Pulp mills	1,321,500	3,350
Canned foods	0	1,056,794
Phosphate fertilizers	1,000,000	0

*Adapted from (USEPA 2004c).

Bacteria and Viruses can be introduced into surface and groundwater by human and animal wastes and sewage effluent that is not properly treated. This can lead to water being unfit for drinking, swimming, fishing, wading, and boating. Shellfish can become infected and be dangerous as food (USEPA 2004b).

Pesticides (insecticides, herbicides, and fungicides) can enter both surface water and groundwater as a result of agriculture, forestry, and turf maintenance. These chemicals can kill fish and the organisms they depend on. Fish and shellfish may become contaminated and be unfit as food as a result. Aquatic vegetation can be killed, which leads to problems with ecosystem stability in general (USEPA 2004b).

Forestry Nonpoint Source Contribution

Logging in general delivers little NPS pollution to streams due to the relative lack of bare soil exposure when compared to more intensive land uses such as agriculture and development (Pritchett and Fisher 1987). The forest floor tends to remain intact across a cutover or thinned site in most situations (McClurkin et al. 1987). Hydrology recovery times in most cases are less than five years (Aubertin and Patric 1974, Aust and Blinn 2004, Patric 1980).

Streamflow and subsequent sediment transport can actually decrease in recent cutovers in as little as two years due to the new crop of aggressively growing woody and herbaceous plants (Lowrance et al. 1997). In general, water yields will increase moderately following clearcutting for one to five years at most (Hewlett and Doss 1984, Hornbeck et al. 1997, Kochenderfer et al. 1997, Oklahoma Cooperative Extension Service 1984, Swank and Crossley 1988). Regenerating the site with conifers generally reduces streamflow increases more rapidly, especially during the dormant season, due to increased rainfall interception and longer growth window of conifers (Hornbeck et al., 1993). One way to maintain increased water yields after harvesting is to apply herbicides to prevent regeneration of the site (Hornbeck et al. 1997). Lowland wetland sites are generally impacted less from a hydrology standpoint by harvesting than drier upland sites due to their minimal topography, deeper soils, and larger water storage capacities (Ge Sun et al. 2001). A recently cutover tupelo-cypress swamp in southwestern Alabama actually trapped more sediment than a nearby uncut control. This was likely due to the abundant plant regrowth following harvest (Aust et al. 1991).

Nutrient export from harvested sites to adjacent surface water is generally correlated well with streamflow increases and organic matter (slash and forest floor) decomposition. Increases in nitrogen (NH_4^+, NO_3^-) and phosphorous (PO_4^-) are generally minor when compared to most accepted standards and are short-lived (2-5 years) (McClurkin et al. 1985). Minor increases can continue for over 10 years in some cases. Clearcutting generally has little major impact on stream health due to nutrients in water and causes few detrimental effects to fisheries. Nutrient concentrations never exceeded USEPA guidelines for potable water (Aubertin and Patric 1974, Kochenderfer et al. 1997, Patric 1978, Swank and Crossley 1988). Significant nutrient, sediment, and thermal pollution are generally diluted below significant levels as water moves downstream and mixes with unaffected water (Patric 1978).

Uncontrolled logging practices that disturb stream channels, leave no SMZs, rut sites, or expose large amounts of forest floor to rainfall can elevate pollution from harvested sites. There has been little research, but thinning directly within an SMZ does not appear to significantly increase NPS pollutants in general (Patric 1978). Soil and site characteristics such as geology, soil types, slope, aspect, land use history, and weather can be important factors with most NPS pollution issues. It is thought that steeper slopes and highly erosive soils might induce a greater threat to water quality during and after silvicultural operations. In some cases, land use history might impact water quality threats from operations due to the possibly unstable conditions that still exist long after other land uses cease. (Beasley 1979, Beasley and Granillo 1988, Hubbard et.al. 1997, Kochenderfer and Edwards 1990, Oklahoma Cooperative Extension Service 1984, Patric 1978, Sheridan et. al. 1999, Yoho 1980).

Site Preparation activities, intended to prepare a harvested site for the planting of a new forest crop, have the potential to create significant amounts of NPS pollutants in nearby watercourses due to the relatively high intensity and site disturbance levels of such operations when compared to harvesting operations. Intensive site preparation is often critical to ensuring forest regeneration and quality of the new stand. Intensive prescriptions generally include combinations of heavy mechanical work (windrowing, bedding, shearing, chopping, combination plowing, and disking) with chemical pest controls, fire, and fertilizer additions (USDA 1997).

Intensive site disturbance can lead to elevated erosion and sedimentation due to the large amount of disturbance to the forest floor and subsequent exposed mineral soil. Plowing and bedding operations can lead to high erosion rates and even create rills and gullies or re-expose old gullies to fresh erosion (Beasley 1979, Beasley et al. 1986, Beasley and Granillo 1988, Oklahoma Cooperative Extension Service 1984). Sedimentation and nutrient loss due to site preparation disturbance is a function of soil type, slope, landform, landuse history, and slope position (Beasley and Granillo, 1988, Jackson 2004, Kochenderfer and Edwards 1990, VDOF 2002, Yoho 1980). Chemical site preparation methods create almost no sediment issues due to the lack of soil and forest floor disturbance (Beasley et al. 1986).

Prescribed fire is sometimes used to allow planter access and control competing vegetation or pests (USDA, 1997). Firelines constructed to contain prescribed burns are not always revegetated and can be a significant source of sediment. In some cases fire is allowed to burn through an SMZ, which can expose mineral soil and cause significant sedimentation in receiving waters. Fire impacts on water quality and nutrient volatilization depend highly on fire intensity. Higher-intensity fires burn more organic matter from the forest floor, volatilizing larger amounts of nutrients while exposing mineral soil to rainfall and encouraging more erosion (Swank et al. 1989). Firelines that directly intersect stream channels at the bottom of a watershed can cause sedimentation (VDOF 2002). Prescribed and wild fire generally do not lead to long-term degradation of water quality to streams even when SMZs are burned. Increases in sediment and nutrients from fire in the eastern United States are generally small and short-lived (Douglas and Van Lear 1983, Neary and Currier 1982, Swank et al. 1989, VanLear et al. 1985).

Fertilizer and pesticide use in forestry is very common and can be a source of plant nutrients and other chemicals such as herbicides, insecticides or fungicides. These chemicals are often applied by helicopter or fixed-wing planes, and materials can be accidentally applied in or near watercourses (USDA 1997). Overall effects of the uses of such chemicals are generally low (well below drinking standards) and obvious impacts are usually short-term due to the generally low concentrations, toxicity, and residence time in the environment. (Binkley et al. 1999, Edwards et al. 1991, Lowrance et al. 1997, Rierkirk 1983, Sopper 1975, Swank et al. 1989). Overall, recovery times from site-prep disturbances are generally a few years at most (Beasley 1979, Beasley and Granillo 1988, Riekerk 1983, Sheridan et.al. 1999, Shepard 1994, Yoho 1980).

> "A variety of studies has examined the effects of fertilizer application directly into streams (summarized by Bisson et al., 1992). Nutrient additions typically increase primary production (algal growth), and may increase the growth rates of fish (Perrin et al. 1987; Peterson et al. 1985). In some cases, fertilizer application has been used to intentionally improve fishery production. None of the studies reported by Bisson et al. (1992) found evidence of any detrimental effect of direct application of fertilizer to streams. Studies on the effects of forest application of fertilizers on stream ecosystems have shown no effects; background variation along stream reaches are typically too large relative to any minor and transient effects of elevated stream water nutrient concentrations to allow detection of any impacts on the biota (cf. Meehan et al. 1975; Stay et al. 1979; Gothe et al. 1993)." (Binkley et al. 1999).

Forest Roads are the greatest contributor of forestry-related NPS pollution, contributing approximately 90% of sediment detachment and movement (AAES 1984, Patric 1978) . Logging roads can contribute significant sediment to nearby streams if they are not properly planned and constructed and if BMPs are not installed and maintained. The most significant long-term problems stem from roads that are either not properly closed out after logging and regeneration activities with proper BMPs, and/or are left open to private or public traffic after forestry operations are over. Incorrect or overzealous maintenance can also lead to long-term water quality problems. Continued grading to smooth or level roads can be a long-term problem due to periodic exposure of soil on the road surface. Watercourse and forest road intersections can lead to direct input of large sediment loads, especially at stream crossings and along approaches (VanLear et al. 1995, VDOF 2002).

Skid trails can become rutted and expose mineral soil, which can lead to sediment in streams if the eroded soil can reach a watercourse. These trails are not likely to create water pollution unless located near to or crossing a stream. Skid trail density can be an indicator of pollution likelihood during and after harvesting operations, especially in areas with steep topography (Kochenderfer and Aubertin 1975, Oklahoma Cooperative Extension Service 1984, Van Lear et.al. 1995, VDOF 2002). Most state BMP guidelines recommend minimizing density and slope of skid trails in order to minimize pollution risk from skidding. It is also recommended that logging slash and debris be utilized during and after skidding to stabilize trails and allow natural vegetation recovery. Other long-term solutions to skid trail pollution potential include establishment of grasses and forbs, restriction of vehicle access, physical trail reclamation, and construction of water bars to divert surface flow away from trails (VDOF 2002).

Vegetation and gravel on and along roads can prevent surface water from eroding road and ditch materials and depositing large amounts of sediments into streams or rivers. The best strategy is to divert water away from roads and ditches into the surrounding land area by building turnouts, dips, and waterbars. These structures direct water into surrounding land areas where it can be absorbed into the ground and prevented from reaching any nearby watercourses (Kochenderfer and Helvey 1987, Swift 1986, VDOF 2002). Gravel surfaces should consist primarily of larger stone greater in size than crusher run. Size #1 to #3 (1½ inch to 3½ inch) and greater should be used when possible to prevent movement of gravel along and off of the road surface with water flow (Kochenderfer and Helvey 1987). Luck Stone Company in central Virginia recommends these larger stone sizes for industrial applications, erosion control, and sediment filtering applications. Road BMP recommendations for forestry roads can be found in the VDOF BMP manual (VDOF 2002).

Road location is critical to the prevention of erosion and water quality problems. Roads that have improper design, layout, or construction will generally have erosion problems to a greater degree. Problems usually stem from steep grades, sharp curves, steep side-slopes, soft or erosive surface material, slumping cut banks and fills, improper stream crossings, close proximity to streams, and poor drainage. It is much more difficult and expensive to repair and maintain a poorly planned road than a properly planned road. (AAES 1984, Kochenderfer and Helvey 1987, Oklahoma Cooperative Extension Service 1984, Reinhart et al. 1963, Swift Jr. 1986, Trimble and Sartz 1957, Van Lear et al. 1995, VDOF 2002, Yoho 1980).

Water Pollution Control Attempts

Federal Clean Water Act

The US Fish and Wildlife Service compiled a detailed history of the Clean Water Act and its numerous amendments as they relate to natural resource concerns. Portions of the USFWS review are included verbatim:

> The original 1948 statute (Ch. 758; P.L. 845), the Water Pollution Control Act, authorized the Surgeon General of the Public Health Service, in cooperation with other Federal, state and local entities, to prepare comprehensive programs for eliminating or reducing the pollution of interstate waters and tributaries and improving the sanitary condition of surface and underground waters. During the development of such plans, due regard was to be given to improvements necessary to conserve waters for public water supplies, propagation of fish and aquatic life, recreational purposes, and agricultural and industrial uses. The original statute also authorized the Federal Works Administrator to assist states, municipalities, and interstate agencies in constructing treatment plants to prevent discharges of inadequately treated sewage and other wastes into interstate waters or tributaries" (USFWS 2004).
>
> Major amendments were enacted in 1961, 1966, 1970, 1972, 1977, and 1987.
>
> The Reorganization Plan No. 3 of 1970 (December 2, 1970) created the Environmental Protection Agency, abolished the Federal Water Quality Administration in the Department of Interior, and transferred to EPA all functions formerly assigned to the Secretary of Interior and the Department of Interior which had been administered through.
>
> The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) stipulated broad national objectives to restore and maintain the chemical, physical, and biological integrity of the Nation's waters (33 U.S.C. 1251).
>
> In addition, the amendments significantly expanded provisions related to pollutant discharges. These included requirements that limitations be determined for point sources which are consistent with State water quality standards, procedures for State issuance of water quality standards, development of guidelines to identify and evaluate the extent of nonpoint source pollution, water quality inventory requirements, as well as development of toxic and pretreatment effluent standards (33 U.S.C. 1311-1313 and 33 U.S.C. 1315-1317).
>
> Section 303d of the 1972 amendments created the TMDL procedure to evaluate impaired watersheds and determine watershed wide strategies to control overall water pollution in any given watershed.
>
> Section 402 of the 1972 amendments established the National Pollutant Discharge Elimination System (NPDES) to authorize EPA issuance of discharge permits (33 U.S.C. 1342). Section 403 stipulated guidelines for EPA to issue permits for discharges into the territorial sea, the contiguous zone, and ocean waters further offshore (33 U.S.C. 1393).

> Important provisions were contained in Section 404 of the amendments. This section authorized the Corps of Engineers to issue permits for the discharge of dredged or fill material into navigable waters at specified disposal sites (33 U.S.C. 1344). EPA was authorized to prohibit the use of a site as a disposal site based on a determination that discharges would have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational uses.
>
> The 1977 amendments, the Clean Water Act of 1977 (P.L. 95-217), again extensively amended the Act. Of particular significance were the following provisions:
>
> - Development of a "Best Management Practices" Program as part of the state area wide planning program (33 U.S.C. 1329)
> - Authorization of $6 million for the Secretary of Interior to complete the National Wetlands Inventory by December 31, 1981 (33 U.S.C. 1288(i)(2))
> - Authority for the Corps of Engineers to issue general permits on a state, regional, or national basis for any category of activities which are similar in nature, will cause only minimal environmental effects when performed separately, and will have only minimal cumulative adverse impact on the environment (33 U.S.C. 1344(e))
> - Exemption of various activities from the dredge and fill prohibition including normal farming, silviculture, and ranching activities (33 U.S.C. 1344(f))
>
> The Water Quality Act of 1987 (P.L. 100-4) provided the most recent series of amendments to the original statute. Provisions included:
>
> - Authority to continue the Chesapeake Bay Program and to establish a Chesapeake Bay Program Office (33 U.S.C. 1267). The original authorization for this program, the Chesapeake Bay Research Coordination Act of 1980 (P.L. 96-460), expired on September 30, 1984
> - Increase in the penalties for violations of Section 404 permits (33 U.S.C. 1344)
> - Establishments of $400 million program for States to develop and implement, on a watershed basis, nonpoint source management and control programs with EPA responsibility for grant administration, program approval, and periodic program evaluation (33 U.S.C. 1329)
> - Authorization for a State/Federal cooperative program to nominate estuaries of national significance and to develop and implement management plans to restore and maintain the biological and chemical integrity of estuarine waters (33 U.S.C. 1330). Authorization to NOAA to conduct water quality research and trends assessment in estuaries of national significance (USFWS, 2004).

The most important sections of this law pertaining to forestry activities are the 1972 amendments, which entrusted the US Army Corps of Engineers to issue permits for dredge and fill activities in the nation’s navigable waterways, which also include wetlands of all types (section 403, 404), and established the TMDL (total maximum daily load) procedure for evaluating and controlling water quality in streams on a watershed basis (section 303d). The amendments also granted exemptions from section 404 to normal ranching and silvicultural operations provided that proper BMPs are followed. This section 404 exemption is the cornerstone for operational agricultural and forestry policy with regard to wetland issues. The TMDL procedures have not largely been instituted due to legal and financial issues within the federal government. It is widely expected that the TMDL procedures may eventually have an impact on forestry operations (USEPA 1999).

The Chesapeake Bay Preservation Act

In 1983 and 1987, the states of Virginia, Maryland, and Pennsylvania, the District of Columbia, the Chesapeake Bay Commission, and the US Environmental Protection Agency signed agreements that established the Chesapeake Bay Program partnership to protect and restore the Chesapeake Bay's ecosystem. The Bay Act was adopted by the Virginia General Assembly in 1988 in response to that agreement. The law requires all counties in Tidewater Virginia (other counties have the option) to develop a plan to protect water quality by designating certain Chesapeake Bay preservation areas and enforcing certain regulations with regard to development, agriculture, and forestry activities. The law relies heavily on counties, localities, and the Chesapeake Bay Local Assistance Department (CBLAD) to assist developers, landowners, foresters, and farmers in reducing the impacts of their activities on water quality within the Chesapeake Bay watershed (VDCR 2004).

In Virginia, forestry activities are exempt from the provisions of the law as long as those activities adhere to Virginia BMPs for silvicultural activities as recommended by the Virginia Department of Forestry. If forestry operations violate BMPs within a designated preservation area, certain punitive measures could be taken by state or local government in accordance with CBLAD regulations (VDCR 2004).

Virginia Silvicultural Water Quality Law

The Virginia General Assembly gives the State Forester the power to determine if any silvicultural operation in the state of Virginia is polluting or is likely to pollute the waters of the Commonwealth. If the State Forester determines that pollution is occurring or is likely to occur from a specific activity, the State Forester can recommend (i) corrective measures and (ii) a reasonable time period to prevent, mitigate, or eliminate the pollution. The State Forester cannot hold any operator responsible for pollution resulting from failure of correctly installed BMPs that result from an extreme weather event that could not have been reasonably anticipated. The State Forester may assess civil financial penalties in the event of continued non-compliance (Code of Virginia 1993).

Forestry Voluntary Controls

Best Management Practices

Best Management Practices (BMPs) are a collection of practices used to reduce erosion and prevent or control water pollution from forestry or other industrial practices. BMPs have been utilized to some degree for years in the areas of forestry, agriculture, and urban development. BMPs are generally intended to prevent erosion on disturbed sites and reduce the risk of associated water pollution (VDOF 2002).

Streamside Management Zones

Streamside management zones (SMZs) in forestry are areas adjacent to streams that are left relatively undisturbed during forestry operations, such as, but not limited to, harvesting, site preparation, fertilization, and weed control. SMZs are often referred to as riparian management zones (RMZs), buffer strips and buffers. SMZ specifications relating to width, tree density, management options, and stream types requiring an SMZ vary from state to state and are largely activity-dependent. Forestry SMZ delineation recommendations and specifications in Virginia are suggested by the Virginia Department of Forestry (VDOF) in the BMP manual entitled Virginia Forestry Best Management Practices for Water Quality. The most recent version of the BMP manual is the 4th edition, published in 2002 (VDOF 2002, Virginia Cooperative Extension 2000).

The VDOF BMP guidelines suggest a 50-foot SMZ, measured from the stream bank, on all perennial and intermittent streams that show evidence of significant water presence at some time during the year. Harvesting is acceptable in this buffer but at least 50% of the crown cover or basal area should be left. The BMP manual also recommends increased buffer widths in special cases such as cold water fisheries (trout and salmon) and municipal water supplies. Roads and skid trails should be located outside of any SMZs whenever possible. Cutting within SMZs is acceptable in the event of salvage and pest control problems. SMZs are sometimes damaged by storms and pests which will in some cases require harvesting operations to capture potential economic value and/or prevent the spread of pest infestations (VDOF 2002).

Streamside Management Zone Function

Streamside management zones (SMZs) are defined by the Virginia Department of Forestry (2002) as “areas adjacent to streams that protect water quality.” These areas are often referred to as buffers, buffer strips, riparian management zones, and riparian areas.

Current research indicates that SMZs have the capability to filter pollutants from surrounding uplands, maintain cooler in-stream water temperatures, stabilize stream banks, and provide terrestrial and aquatic wildlife habitat (Blinn and Kilgore 2001, Castelle et al. 1994, Phillips 1989, Todd 2002, Virginia Cooperative Extension 2000, VDOF 2002).

Forests within riparian zones are called by different names depending on the manager's perspective. SMZs are areas that are generally managed forests and are often used for forest product production as well as water quality protection. Riparian forests in general may not be managed intensively or at all. Regardless of whether they are called riparian forests or SMZs, these areas have the potential to promote numerous ecological and socioeconomic functions such as sediment trapping, nutrient uptake, carbon and chemical storage, streambank stabilization, stream channel modification, and provision of habitat both in the riparian zone and within the stream (Verry et al. 2000).

Sediment and attached water contaminants in shallow sheet flow are intercepted by SMZs and filtered when surface flow infiltrates into the forest floor. Sediment and associated contaminants are then trapped in the forest floor and are unlikely to reach the stream (Alabama Agricultural Experiment Station 1984, Austin 1988, Virginia Cooperative Extension 2000). It is important to recognize that concentrated surface flows that usually originate in swales and gullies will often generate enough energy to compromise most SMZs and carry sediment directly to the streams. SMZ function is often impacted greatly by surrounding slope, soil type, hydrology, forest floor disturbance in the SMZ, and surrounding land disturbance. Steep slopes and erosive soils are considered to pose a threat to water quality due to an increased likelihood of sedimentation. Steep slopes often encourage erosion due to the increased energy and volume of surface flows while erosive soils tend to release sediment to surface flows due to a general lack of structure and cohesiveness. (Pritchett and Fisher 1987, Ward and Trimble 2004). It is apparent that preventing soil disturbance and exposure in the SMZ prevents direct sediment movement into streams by preventing soil detachment and transport from the SMZ soil itself and stream bank surfaces (Alabama Agricultural Experiment Station 1984).

Nutrient interception, storage, and conversion are also primary functions of forestry SMZs. Dissolved nitrogen and phosphorous in surface flow and shallow base flow can be absorbed by tree roots and stored as biomass and adsorbed by soil particles. Nitrogen can be denitrified and converted to gas (N_2O and N_2) in frequently moist riparian soils (Mitsch and Gosselink 1993).

The tree canopy within SMZs is very important for water quality due to the shading effect during the summer months. The shade provided by a canopy moderates water temperature swings and prevents average temperatures from rising excessively. Maintaining natural water temperature regimes is critical to many species of aquatic invertebrates and vertebrates. This is especially important for cold water streams that support trout or salmon fisheries that are very sensitive to rising water temperatures (VDOF 2002).

Benchmark SMZ Research

It has been established that SMZs are an important best management practice for timber harvesting operations in the South (as evidenced by BMP recommendations southwide), but SMZ width recommendations vary due to a lack of completed operational research showing how wide SMZs should be to adequately protect water quality. It is likely that width recommendations will eventually vary by region, so this study will evaluate and concentrate on studies in the southern piedmont or upper coastal plain. There are three completed studies which will act as comparisons for the results of this study.

Wynn et al. (2000) evaluated three watersheds in the upper coastal plain of Virginia and determined that BMP implementation in general reduced sediment and nutrient pollution to streams after forest clearcutting. Keim and Schoenholtz (1999) found that unrestricted riparian harvesting (no SMZ) increased suspended sediment (TSS) in stream water and accelerated stream channel erosion, while streams with undisturbed SMZs and thinned SMZs adequately protected stream channels and water quality after harvesting. The authors also found that soil eroded from SMZs that were not logged and that sediment accumulated in SMZs that had experienced some level of harvesting. They also suspected that SMZs served to protect water quality mainly by reducing soil disturbance near the streams. Carroll et al. (2004) evaluated water quality in streams with SMZs of varying widths designated by forest managers with varying widths compared to clearcut tracts with no SMZ maintained. The authors reported that SMZs were very important for maintaining stream water temperatures and macroinvertebrate density but were not important with respect to stream water chemistry and nutrient concentrations. It was determined that streams with no maintained SMZ showed no significant evidence of changes in most water quality parameters. A more recent study in the piedmont of Virginia found that a 15-meter SMZ was effective at preventing stream water pollution from plant nutrients due to biosolid applications in watersheds with managed loblolly pine plantations. The SMZ appeared to be an effective buffer for the protection of water quality from nutrient enrichment following biosolid applications to adjacent stands of timber (Pratt 2008).

Justification and Objectives

There is an extensive body of research which investigates the function and value of forested and non-forested riparian buffers as filters of potential water pollutants. The research in general has determined that any significant amount of riparian buffer is beneficial to surface and subsurface water quality, including sediment and nutrient loading to streams, water temperatures and dissolved oxygen, and water yield. This statement also holds true for a variety of land uses such as development, forestry, and agriculture (Alabama Agricultural Experiment Station 1984, Austin 1998, Virginia Cooperative Extension 2000). The vast majority of this research is centered around traditional agricultural practices and pollutants from those activities. There is a significant gap in current research that adequately quantifies the effects of various SMZ widths and harvest levels on water quality in streams impacted by forest harvesting operations. It is clear that further replicated studies are needed to clarify SMZ function and compare SMZ benefits and costs to landowners.

This study analyzed four replicated treatments which are considered both operationally feasible for harvesting contractors and economically acceptable for landowners. The null hypotheses (H_o) were as follows:

1. SMZ width and harvest level will have no impact on water quality parameters.

2. SMZ width and harvest level will have no impact on SMZ erosion, sediment movement, or sediment trapping ability.
3. SMZ width and harvest level will have no impact on stream geomorphology.
4. SMZ width and harvest level will have no impact on landowner costs, or insect and storm damage to residual SMZ stands.

The major study goals include determining if a 50-foot SMZ as described in the Virginia BMP Manual (VDOF 2002) is generally sufficient to protect stream water quality, riparian soils, and stream bank integrity in headwater streams where forest harvesting has taken place, as well as comparing other SMZ widths with regard to the same water quality protection performance. It is also recommended in the BMP manual that timber be thinned within the SMZ in many cases and it is important to explore the possible water quality impacts of that practice. In Virginia, county ordinances attempting to regulate forestry practices are increasingly common and in most cases do not consider the available science or the impact on landowners. This study might give important insight to local governments as they attempt to regulate forestry practices.

It is also important to note that it is not the intent of the authors to expand the results of this study to shed light on necessary BMPs required to protect riparian resources from the detrimental effects of other land uses such as urban development and agriculture. The nature of pollutant loadings in highly disturbed watersheds is quite different in many ways, and the results of this study must not be used to make decisions for other land uses for that reason.

Chapter 3: Methods and Materials

Site Descriptions

The study watersheds are located in Buckingham and Nelson Counties in central Virginia (37°32’ N latitude, 78°43’ W longitude). This area is the western part of the piedmont plateau directly east of the Blue Ridge Mountains and approximately 110 miles west of the Chesapeake Bay (Figure 2-1) (Appendix A). The James River flows west to east through the central piedmont approximately 10 miles to the north of the study area. The typical elevation of the surrounding area ranges from 500 to 1000 ft above mean sea level (USGS 2000). Average January maximum and minimum temperatures are 8.3°C (46.9°F) and -2.8°C (27.0°F), respectively. Average July maximum and minimum temperatures are 30.3°C (86.5°F) and 18.0°C (64.4°F), respectively (USDA 2004).

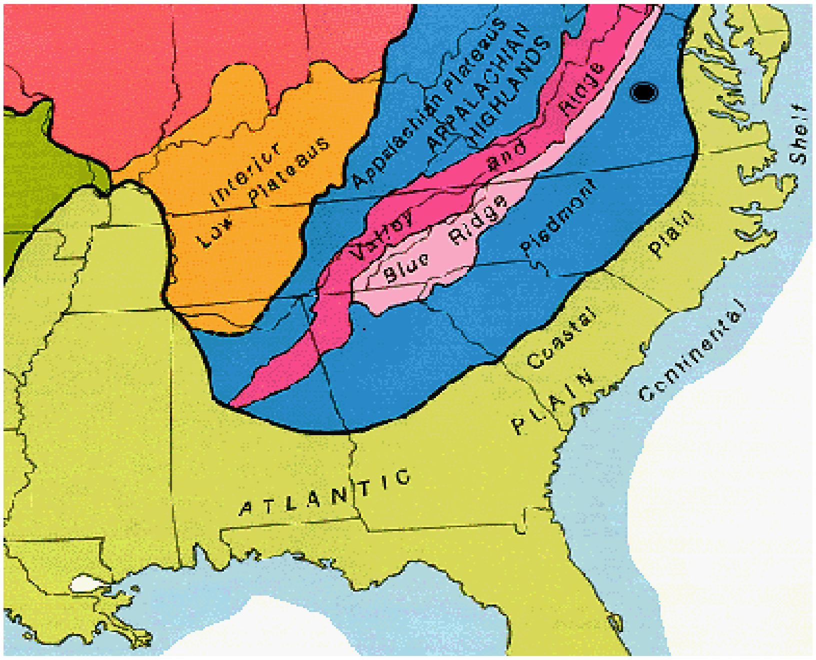

Figure 2-1: Map of the southeastern United States physiographic regions with general study area marked with a black sphere (Miwa 1999).

Soils are typically highly eroded, often-shallow ultisols with significant argillic horizons overlain by shallow Ap horizons. Due to past agricultural abuse and related soil erosion, very little organic matter is in the Ap horizon and eluvial E horizons are generally slight or absent. Soil textures are generally clay to clay loam with significant coarse fragments (USDA 2004).

Past land use in this area was dominated by intensive agricultural practices from the mid-1700s to the late 1800s. Most of central Virginia's farmland was highly degraded due to agricultural erosion and consequently abandoned (Van Lear et al. 2004). The subsequent upland natural pine and hardwood forests were dominated by various oak species (*Quercus spp*.), red maple (*Acer rubum*), sweet gum (*Liquidamber styraciflua*), hickory (*Carya spp*.), Virginia pine (*Pinus virginiana*), and shortleaf pine (*P. echinata*). Bottomlands were dominated by red maple, river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), elm (*Ulmus spp*.), alder (*Alnus rugosus*), black willow (*Salix nigra*) and yellow poplar (*Liriodendron tulipifera*) (Gemborys 1974). Many of these second-growth forests were subsequently harvested at least once during the 1900s, and many areas were replanted with loblolly pine (*P. taeda*), which is not native to the upper and middle Virginia piedmont. This coastal plain native has performed well overall in plantations east of the Blue Ridge and has become a major part of forested ecosystems in the piedmont.

All study sites are on MeadWestvaco property. The stands were harvested between summer 2003 and spring 2004. Most watersheds in blocks 1 through 4 have firelines installed.

Block 1 watersheds are the generally smaller and steeper watersheds with intermittent streams, while block 2 watersheds feed very minor ephemeral streams. Block 3 consists of the largest watersheds with intermittent and perennial streams. Block 4 is a group of watersheds at the northern part of Buckingham County closer to the James River with intermittent and perennial streams (Walker 2004).

Each of 16 watersheds (Table 2-1) of approximately 100 acres was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine. Within the watersheds, the streamside management zone treatments were established as a 25-foot "stringer," a 50-foot width with no thinning, a 50-foot width with thinning, and a 100-foot width with no thinning. Harvesting operations consisted of ground-based rubber-tired feller bunchers with rubber-tired skidders and knuckle boom loading at a log deck on site. These operations are very typical for pine plantation harvesting in the southeastern U.S. in general. Previous stands were typically loblolly pine plantations 25 to 30 years of age with scattered mixed hardwood components. Site prep was prescribed burning to reduce slash followed by hand planting by dibble bar crews. Herbicides were selectively used to reduce hardwood and herbaceous competition.

Table 2-1: Description of the block and watershed inventory for the SMZ study in central Virginia.

MWV Tract Name	County	Block	Watershed	SMZ Width	Treatment	Harvest Completion
Gunstock	Buckingham	1	1	50 ft.	thin	6/03
Gunstock	Buckingham	1	2	50 ft.	no thin	6/03
Gunstock	Buckingham	1	3	100 ft.	no thin	5/03
Gunstock	Buckingham	1	4	50 ft.	no thin	5/03
Irons	Buckingham	2	1	50 ft.	no thin	3/03
Irons	Buckingham	2	2	25 ft.	no thin	3/03
Irons	Buckingham	2	3	50 ft.	thin	4/03
Fisher / North	Buckingham	2	4	100 ft.	no thin	6/03
Doe	Buckingham	3	1	50 ft.	thin	1/04
Doe	Buckingham	3	2	25 ft.	no thin	7/03
G-Union Camp	Buckingham	3	3	50 ft.	no thin	2/04
Breezy Bee	Nelson	3	4	50 ft.	no thin	6/03
Baird-Payne	Buckingham	4	1	25 ft.	no thin	4/04
Baird-Payne	Buckingham	4	2	50 ft.	no thin	4/04
Miller	Buckingham	4	3	100 ft.	no thin	2/03
Miller	Buckingham	4	4	50 ft.	no thin	5/04

Treatment Descriptions

The streamside management zone widths chosen for this project were a 25-ft (7.57 m) stringer, a 50-ft (15.24 m) SMZ with no harvest, a 50-ft (15.24 m) SMZ with approximately 50% crown cover harvest, and a 100-ft (30.48m) SMZ no harvest (Walker, 2004). The 50-ft (15.24 m) width and 50% harvest level reflect current BMP recommendations for timber harvesting in Virginia (VDOF 2002).

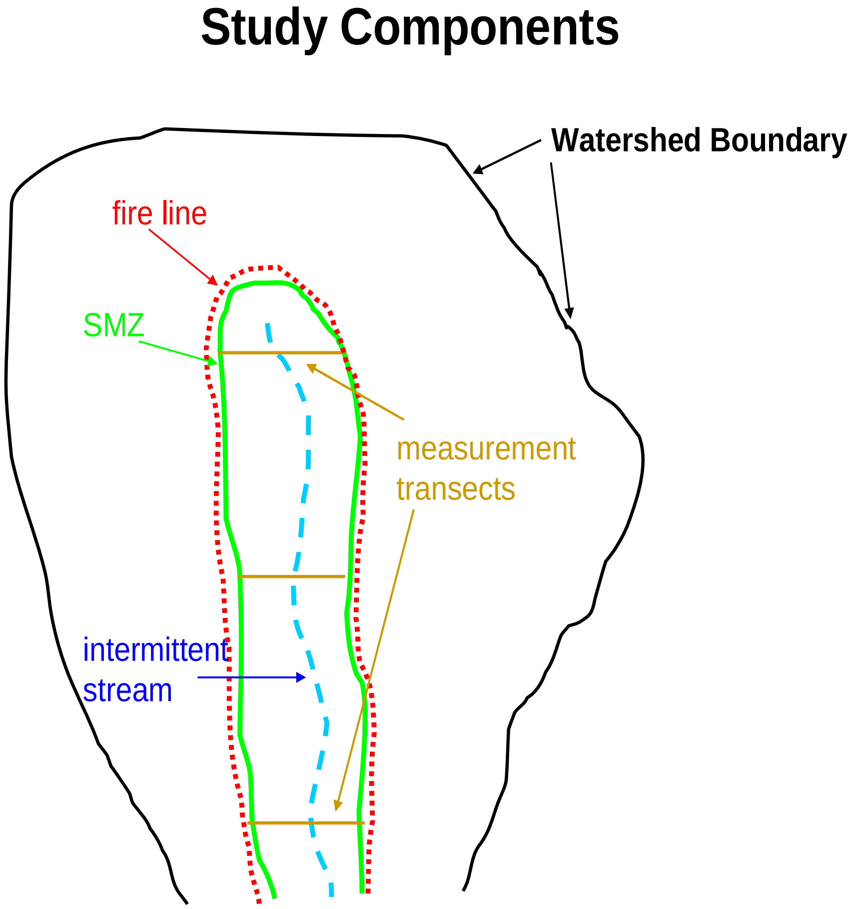

Figure 2-2: Representation of a typical study watershed with approximate location of SMZ boundaries, firelines, stream, and measurement transects for the SMZ study in central Virginia.

Data Collection and Watershed Monitoring

Site Characteristics

Rainfall

Overall county weather station data from the NOAA Coop station in Buckingham, Virginia, was used where needed.

Global Positioning System Mapping

GPS was used to map the boundaries of each watershed as well as locations of firelines, skid trails, SMZ boundaries, roads, and other areas of major soil disturbance that might have an impact on stream characteristics and SMZ function. This data was integrated into ArcMap® and used to produce maps of the study sites.

Vegetation Inventory

The overstory and midstory trees were inventoried systematically with 1/10- and 1/20-acre plots on a 3-chain by 3-chain grid. This plot spacing allowed for one sample plot per SMZ acre. Species, product class, diameter at breast height (dbh), cull percentage, and merchantable height were recorded. Trees below 5 inches dbh and/or 16 feet merchantable height were classified as pre-merchantable or midstory. TwoDog™ timber cruising software was used for inventory calculations. All volumes were calculated using the International ¼ rule. Post-harvest timber cruising took place approximately two years after harvest (Table 2-2). All storm and pest damage encountered in the cruise was recorded for further analysis.

Table 2-2: Timber inventory cruising specifications for the post-harvest vegetation characterization on the SMZ study watersheds in central Virginia.

Product Class	DBH Range	Top Diameter
Hardwood Sawtimber	12"+	10"
Hardwood Pulpwood	5"+	4"
Pine Pulpwood	5"+	4"
Pine Chip-n-Saw	9"-11.5"	6"
Pine Sawtimber	11.6"+	6"
Hardwood Premerch	<5"	n/a
Premerchantable Pine	<5"	n/a

The herbaceous and shrub layers were measured using ten 10.7 ft^2 fixed area plots per SMZ stand. The vegetation was identified to the family level except for the grasses. Grasses were recorded as “grass,” *Panicum* spp., and not identified further; the sedges were separated from this group.

For all plant identification, several sources were used to ensure the proper taxonomic classification: *Newcomb’s Wildflower Guide*, *Flora of West Virginia*, and *Manual of the Vascular Flora of the Carolinas*. The PLANTS Database, from the USDA’s National Plant Data Center, was used to assign scientific names, invasive/noxious/introduced status, and wetland indicator status (USDA NRCS 2000). The initial herbaceous and shrub survey took place in the second growing season following harvest (summer 2006).

Commercial Timber Values

Current market prices were determined during the winter of 2005-2006 and were applied to the cruise volumes to determine the value of the timber left in each SMZ. The data were averaged across all points for each watershed and applied to the watershed data analysis of variance (ANOVA) procedure (Table 2-3) for the incomplete block design (ICBD) with no split. The findings were used to determine which SMZ treatment scenarios are most costly to landowners and what long-term timber management regimes might be realistic for SMZs in the piedmont of Virginia.

Canopy Cover

Canopy cover was estimated using a spherical densitometer for each transect (Figure 2-2). This was done four times at each transect and stream intersection, once facing in each cardinal direction. The repetitions were then averaged to find the average canopy cover for each transect and averaged again for a watershed canopy cover value. The data were averaged across all transects for each watershed and applied to the watershed data ANOVA procedure in Table 2-3 for the ICBD design with no split.

Organic Horizon Depth

Organic horizon depth was measured in conjunction with soil erosion measurements at a point approximately 3 feet to the upstream side of each erosion rod. A slice was made through the organic layer to the mineral soil and the depth of the organic layer was measured to the nearest centimeter with a clear ruler and recorded. The organic horizon was measured once during the winter of 2005-2006. The data were averaged across all transects for each watershed and applied to the watershed data ANOVA procedure in Table 2-3 for the ICBD design with a split.

Universal Soil Loss Equation (USLE)

USLE soil erosion estimates were calculated for the cutover portions of the watersheds as well as for firelines, roads, and skid trails in order to identify high risk areas which might impact SMZ function and stream water quality. (Dissmeyer and Foster 1981, Dissmeyer and Foster 1984, Hood et al. 2002).

Erosion Rods

Along the downstream side of each transect a row of erosion rods was installed at 2.28 m (7 ft), 4.57 m (15 ft), 7.62 m (25 ft), 15.24 m (50 ft), 30.48 m (100 ft), and 38.1 m (125 ft) from the center of the stream. This was done on each side of the stream in all of the blocks except block 3. The erosion rods were 0.6 m (2 ft) lengths of rebar pounded 0.3 m into the ground. The remaining portion of the rod above ground was measured to the nearest millimeter at the mineral soil surface. The erosion rods were measured once per year to measure erosion or deposition at the site. The data were averaged across all rods for each transect and applied to the transect data ANOVA procedure in Table 2-3 for the split-plot design.

Sediment Traps

Three minor sub-drainages were randomly chosen in each watershed (two blocks only) for installation of an erosion trap made from commercially available silt fence and wooden stakes. The trap installation was limited to two blocks due to time constraints and the large amount of labor involved. The first drainage had a trap installed at the stream bank only to evaluate the amount of soil and debris that reached the stream. The second drainage had a trap installed just below the fireline to determine the total amount of eroded material that entered the SMZ at that point by that drainage. The third drainage had a trap installed just above the fireline at the edge of the cutover to determine the amount of eroded material entering the SMZ from the cutover area only. This allowed a detailed analysis of relative stream sediment contributions from the cutover and the fireline as well as an estimate of overall SMZ function (Robichaud and Brown 2002, Jackson 2004).

Hydrology Characteristics

Stream Cross-Sections

Iron rods were used to mark and measure a stream cross-section at each transect of each stream in order to monitor stream channel changes over time. Twelve watersheds were chosen in order to guarantee three replicates of each treatment for this analysis. All replicates were not maintained due to the extreme amount of time required to measure and re-measure these transects. A transit and Philadelphia rod was used to measure stream bed elevations at various points in each cross-section. Appropriate software (MS Excel® and WinXsPro) was used to create stream cross-sections and calculate sediment aggradations and degradation as well as changes in the stream bank. This procedure will replaced the sediment stone procedure described by Walker (2004) for the pre-harvest phase of the study.

Water Quality Parameters (surface water)

Water quality measurements were taken in the lower transect of each watershed when water was present using a Horiba® portable water meter and grab samples. The portable water meter was used to measure the pH, conductivity, turbidity, dissolved oxygen (DO), temperature, depth, salinity, total dissolved solids (TDS), and oxidation reduction potential (ORP) (Bolstad and Swank 1997, Lynch and Corbett 1990, Vowell 2000, Walker 2004).

Three grab samples (at lower transect only) were also taken (Bolstad and Swank 1997). The samples were processed at the soil nutrition, environmental engineering, and biological systems engineering labs at Virginia Tech. The colorimetric procedure was used for nitrate and ammonium (industrial method numbers 270-73W). Total nitrogen (SM 4500-N C / EPA 353.2) and total phosphorous (SM 4500-P F / EPA 365.4) were tested by the water quality laboratory in the Biological Systems Engineering Department at Virginia Tech.

Nalgene® stormwater samplers were also installed in the stream channels near the lower transects to capture water samples during higher flow events. The samplers were installed to capture flow when the water level in the stream approached 6 inches above normal baseflow levels.

A HOBO® temperature logger was previously installed by Walker in the middle transect of each watershed. The logger was launched to take a reading every 10 minutes and put in a submersible case. The case was then secured to a tree with plastic coated wire. These loggers, however, are unable to discern when the stream is actually flowing, and as a result, often take air temperature readings and incorrectly consider them water temperature readings. These HOBO water temperature readings were continued but were replaced by quarterly water temperature readings taken by manual meter. The data were applied to the transect data ANOVA procedure in Table 2-3 for the ICBD.

Data Analysis

Experimental Design (Watershed Transect Measurements)

Table 2-3: The general model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments (watersheds) and a split-plot by the three watershed sampling transects.

Source	Degrees of Freedom	
Treatment	(t-1)	3
Block	(b-1)	3
Error a	(t-1)(b-1)	9
Transect	(z-1)	2
Transect*Treament	(z-1)(t-1)	6
Error b		24
Total (Corrected)	(zbt)-1	47

Experimental Design (Total Watershed Measurements)

Table 2-4: The general model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments (watersheds) with no split.

Source	Degrees of Freedom	
Treatment	(t-1)	3
Block	(b-1)	3
Error a	(t-1)(b-1)	9
Total (Corrected)		15

All raw data were analyzed using a combination of Excel™ spreadsheets and The SAS™ System. Tukey's studentized range mean separation test was used to determine the alpha values between treatment means.

Chapter 4: Streamside Management Zone Characteristics and Water Quality in Headwater Streams in the Virginia Piedmont

Abstract

The major study objectives include determining if a 50-foot streamside management zone (SMZ) as described in the Virginia BMP Manual (VDOF 2002) is generally sufficient to protect stream water quality, riparian soils, and stream bank integrity in headwater streams where forest harvesting has taken place, as well as comparing other SMZ widths with regard to the same environmental protection performance. Forested SMZs are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations, and enhancement of in-stream and riparian habitat. In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four SMZ treatments were installed across four experimental blocks during harvest. Each of the 16 watersheds was subsequently site-prepared with prescribed burning and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the established treatments were a 100-foot width with no thinning, a 50-foot width without thinning, a 50-foot width with thinning, and a 25-foot "stringer." Each of the four treatments was conducted within at least three of four blocks (Incomplete Block Design). After a two-year post-harvest monitoring period, it was determined that the SMZ treatments had no significant effect on water quality in the streams regardless of time of year or time since harvest. There was no apparent water quality degradation as a result of harvesting timber, and larger SMZs did not have an impact on water quality. It was also apparent that leaving narrower SMZs or thinning within SMZs did not degrade water quality.

Introduction

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations, and enhancement of in-stream and riparian habitat (VDOF 2002, NCDFR 2006, GFC 2005, USEPA 2007, Blinn and Kilgore 2001, Castelle et al. 1994). It is widely accepted that SMZs positively affect water quality in headwaters streams where forestland management activities often occur, but little research has been done to determine how wide SMZs should be in most cases and if thinning is acceptable within SMZs from a water quality standpoint. Forestry Best Management Practices (BMP) guidelines vary across the South with regard to riparian management and SMZ specifications. However, most research on forestry riparian areas has not been on true headwater streams but has commonly focused on larger streams, and a widespread interest in headwater streams is quite recent (MacDonald and Coe 2007).

It is important to refine SMZ guidelines based on new data because the cost of leaving timber along streams can be substantial for landowners and timber buyers (Cubbage 2004, Lakel et al. 2006, Shaffer et al. 1998, Kluender et al. 2000). It is also likely that Total maximum daily loads (TMDLs) for sediment will be established in the Chesapeake Bay watershed in the near future, and forestry operations and BMPs in this region could be affected. It is imperative that the contribution of intensive forestry operations to pollutant concentrations in surface water in the Chesapeake Bay watershed and the southern piedmont in general be quantified in order to allow informed decisions with regard to future regulatory and management policy changes.

The literature generally notes that surface water quality from forested watersheds is superior to that in agricultural and urban watersheds even with active forest management practices (Randolph 2004, Novotny 2003, Ward and Trimble 2004, USDA 2000). However, more study is needed to determine how BMPs in general, and more specifically SMZs, contribute to acceptable water quality. Numerous studies have shown the positive impacts of SMZs (Castelle et al. 1994, Aust and Blinn 2004), but few have investigated the efficacy of various widths and thinning within them. The overall goal of our study is to evaluate the influence of SMZ width and harvest level on stream water quality.

Study Area and Site Descriptions

The study watersheds are located in and around Buckingham County in central Virginia (37^{o}32’57” N latitude, 78^{o}43’28” W longitude). This area is the western part of the piedmont plateau directly east of the Blue Ridge Mountains and approximately 110 miles west of the Chesapeake Bay (Figure 3-1). The James River flows west to east through the central piedmont approximately 10 miles to the north of the study area. The typical elevation of the surrounding area ranges from 500 to 1200 feet above mean sea level. Average January maximum and minimum temperatures are 8.3^{o}C (46.9^{o} F) and -2.8^{o}C (27.0^{o} F), respectively. Average July maximum and minimum temperatures are 30.3^{o}C (86.5^{o}F) and 18.0^{o}C (64.4^{o}F), respectively (USDA 2004).

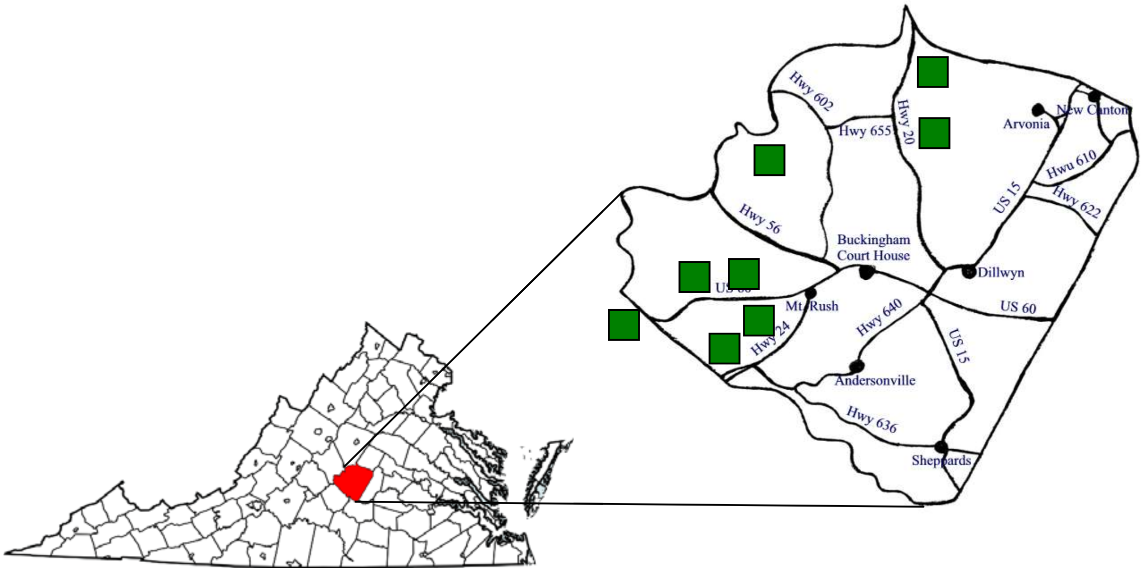

Figure 3-1: Approximate locations of study areas in and around Buckingham County, Virginia.

Soils are typically highly eroded, often-shallow ultisols with argillic horizons overlain by shallow Ap horizons. Due to past agricultural abuse and related soil erosion, very little organic matter remains in the Ap horizon and eluvial E horizons are generally minor or absent. Soil textures are generally clay to clay loam with significant coarse fragments (USDA, 2004).

Past land use in this area was dominated by intensive agricultural practices from the mid-1700s to the late 1800s. Most of the southern piedmont's farmland was highly degraded due to agricultural erosion and consequently abandoned (Van Lear et al., 2004). The subsequent upland natural pine and hardwood forests were dominated by various oak species (*Quercus spp*.), red maple (*Acer rubrum*), sweet gum (*Liquidamber styraciflua*), hickory (*Carya spp*.), Virginia pine (*Pinus virginiana*), and shortleaf pine (*P. echinata*). Bottomlands were dominated by red maple, river birch (*Betula nigra*), sycamore

(*Platanus occidentalis*), elm (*Ulmus spp*.), alder (*Alnus rugosus*), black willow (*Salix nigra*) and yellow poplar (*Liriodendron tulipifera*) (Gemborys 1974). Many of these second-growth forests were subsequently harvested at least once during the 1900s, and many areas were replanted with loblolly pine (*P. taeda*), which is not native to the Virginia piedmont in general (Schultz 1997). Loblolly pine, a coastal plain native, has performed well overall in plantations east of the Blue Ridge and has become a major part of forested ecosystems in the piedmont.

Watershed Treatments and Study Layout

Beginning in 2001, 16 first-order streams/riparian areas and associated forested watersheds on MeadWestvaco timberlands were monitored for baseline data prior to treatment installation, but little stream water data were obtained due to three years of severe drought in the region (Easterbrook et al. 2003). Four treatments were installed across four blocks during 2003-2004. Each of 16 watersheds was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine. Within the watersheds, the streamside management zone treatments were established on each side of the stream channel as a 25-foot "stringer" (treatment 1), a 50-foot width with no thinning (treatment 2), a 50-foot width with 30% to 50% basal area thinning (treatment 3), and a 100-foot width with no thinning (treatment 4) . Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). The study watersheds were blocked according to local geology and watershed size (Table 3-1). An additional analysis of covariance procedure was employed as described by Grabow et al. (1988) and Wynn et al. (2000). The 100-foot SMZ treatment data for total nitrogen and total phosphorous was used as a control treatment, and all other data for each pairwise comparison in each block was regressed against the control values in discreet XY pairs for each sampling period. All regression results where evaluated using SAS™ system software with the regression procedure (proc reg). A significant treatment effect was identified by a slope value significantly different from 1 along with an overall significant regression model. A series of regressions indicating a treatment effect for the same pairwise comparison for nitrogen or phosphorous across several blocks might indicate a treatment effect overall.

Table 3-1: Organization of watersheds, blocks, and treatments and associated information relating to the study layout and data analysis for the SMZ study in Central Virginia.

Watershed Name	County	Block #	Trt #	SMZ Treatment	Acres	Acre Average per Block
Gunstock 1	Buckingham	1	3	50 ft-thinned	20	20
Gunstock 2	Buckingham	1	2	50 ft-not thinned	14	
Gunstock 3	Buckingham	1	4	100 ft-not thinned	29	
Gunstock 4	Buckingham	1	2	50 ft-not thinned	16	
Irons-North	Buckingham	2	2	50 ft-not thinned	36	24
Irons 1	Buckingham	2	1	25 ft-not thinned	19	
Irons 2	Buckingham	2	3	50 ft-thinned	31	
Fisher-North	Buckingham	2	4	100 ft-not thinned	10	
Doe 1	Buckingham	3	3	50 ft-thinned	103	142
Doe 2	Buckingham	3	1	25 ft-not thinned	178	
G-Union Camp	Buckingham	3	2	50 ft-not thinned	112	
Breezy Bee	Nelson	3	2	50 ft-not thinned	174	
Baird-Payne	Buckingham	4	1	25 ft-not thinned	130	79
Baird-Payne	Buckingham	4	2	50 ft-not thinned	51	
Miller	Buckingham	4	4	100 ft-not thinned	77	
Miller	Buckingham	4	2	50 ft-not thinned	59	

Between June 2004 and July 2006, water quality in the streams was monitored in order to determine the influence of the SMZ treatments on post-harvest stream water quality with respect to total nitrogen (TN), ammonium, nitrate, total phosphorous (TP), orthophosphate, dissolved oxygen (DO), turbidity, total suspended solids (TSS), total organic carbon (TOC), temperature (temp), pH, conductivity (cond), and oxidation-reduction potential (ORP).

Each watershed represents an experimental unit with one treatment applied in each. Each stream segment was bisected by three equally spaced reference transects for measurement purposes. The lowest transect in each watershed was the sampling point for water quality analysis in order to guarantee that collected samples would reflect a cumulative watershed effect. Water grab samples were collected approximately quarterly for two years and an attempt was made to time sampling around periods of higher flows in order to increase the likelihood of adequate sample collection. It was also expected that pollution would be higher during these higher flow events. Nalgene® Stormwater Samplers were installed in stream channels to collect samples during two flood events: one in 2004 and one in 2006. These samples were analyzed at the Virginia Tech Water Quality Laboratory in the Biological Systems Engineering Department for total suspended solids (TSS) (EPA 2540 D), total nitrogen (TN) (SM 4500-N C / EPA 353.2), and total phosphorous (TP) (SM 4500-P F / EPA 365.4). During these quarterly sampling events a Horiba® portable water meter was used to measure dissolved oxygen (DO), turbidity, total suspended solids (TSS), total organic carbon (TOC), temperature (temp), pH, conductivity (cond), and oxidation-reduction potential (ORP). This method required that a technician be on site during periods of adequate stream flow in order to collect data.

All data were analyzed using a combination of Excel™ spreadsheets and The SAS™ System. The Tukey-Kramer adjusted mean separation test was used to determine significance between treatment means. The watersheds and treatments were organized in an incomplete block design (Table 3-2) and each treatment had at least three replicates.

Table 3-2: The model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments split by sampling event.

Source	**Degrees of Freedom**	
Treatment	(t-1)	3
Block	(b-1)	3
Error A	(t-1)(b-1)	9
Sampling Event	(z-1)	7
Sampling Event*Treatment	(z-1)(t-1)	21
Error B		84
Total (Corrected)	(zbt)-1	127

Results and Discussion

Nutrients in Water

SMZ treatment had no effect on overall water nutrient concentrations for the two-year post-harvest monitoring period (Table 3-3). The 100-foot buffer had no significant advantage over any other SMZ treatment, and thinning within 50-foot buffers had no impact on the water quality parameters. These conclusions were consistent for both measurement years. Adjusted P-values ranged from 0.50 to 0.98 for multiple treatment comparisons for total nitrogen and 0.63 to 0.99 for multiple comparisons for total phosphorous. All other p-values were similarly large.

Table 3-3: The final water nitrogen and phosphorous data (lsmeans) for the SMZ project in central Virginia for each year and both years combined as well as data for each sampling event (quarter). Mean separation significance at the α = 0.10 (Tukey-Kramer) is in lower case to the right of each value.

Year	**Treatment**	**Sample Size n (reps)**	**Total Nitrogen (ppm)**	**Standard Error**	**Ammonium (ppm)**	**Standard Error**	**Nitrate (ppm)**	**Standard Error**	**Total Phosphorous (ppm)**	**Standard Error**
1 2004-2005	1 – 25 feet stringer	3	0.1217 a	.0061	0.1012 a	.0061	0.0385 a	.0149	0.0078 a	.0023
	2 – 50 feet no thin	7	0.1041 a	.0052	0.0938 a	.0051	0.0415 a	.0102	0.0042 a	.0020
	3 – 50 feet thinned	3	0.1097 a	.0061	0.1024 a	.0061	0.0517 a	.0149	0.0046 a	.0023
	4 – 100 feet no thin	3	0.1131 a	.0061	0.0973 a	.0061	0.0445 a	.0149	0.0031 a	.0023
2 2005-2006	1 – 25 feet stringer	3	0.1100 a	.0115	0.0083 a	.0023	0.0040 a	.0030	0.0102 a	.0125
	2 – 50 feet no thin	7	0.1160 a	.0095	0.0077 a	.0020	0.0051 a	.0024	0.0271 a	.0082
	3 – 50 feet thinned	3	0.1000 a	.0115	0.0068 a	.0024	0.0076 a	.0032	0.0083 a	.0125
	4 – 100 feet no thin	3	0.1173 a	.0115	0.0073 a	.0025	0.0073 a	.0033	0.0095 a	.0125
Both Years Average	1 – 25 feet stringer	3	0.1154 a	.0064	0.0612 a	.0036	0.0240 a	.0086	0.0090 a	.0064
	2 – 50 feet no thin	7	0.1105 a	.0046	0.0570 a	.0028	0.0260 a	.0058	0.0157 a	.0046
	3 – 50 feet thinned	3	0.1052 a	.0066	0.0616 a	.0036	0.0319 a	.0089	0.0060 a	.0066
	4 – 100 feet no thin	3	0.1188 a	.0067	0.0585 a	.0037	0.0282 a	.0092	0.0071 a	.0067
Split Plot	**Date**	**Condition**								
Sampling Event	1 – Aug 04	Stormflow	0.1129 a	.0075	0.0997 ab	.0040	0.0242 a	.0104	0.0044 a	.0085
	2 – Feb 05	Baseflow	0.1105 a	.0075	0.0950 a	.0040	0.0265 a	.0104	0.0041 a	.0085
	3 – June 05	Baseflow	0.1052 a	.0075	0.0900 a	.0040	0.0340 a	.0104	0.0104 a	.0085
	4 – Oct 05	Baseflow	0.1182 a	.0075	0.1100 b	.0040	0.0908 b	.0104	0.0009 a	.0085
	5 – Feb 06	Baseflow	0.1104 a	.0075	--------	--------	-------	-------	0.0019 a	.0085
	6 – April 06	Baseflow	0.1116 a	.0085	0.0061 c	.0045	0.0000 a	.0118	0.0072 a	.0096
	7 – June 06	Stormflow	0.1098 a	.0085	0.0060 c	.0043	0.0006 a	.0111	0.0120 a	.0091
	8 – July 06	Baseflow	0.1182 a	.0075	0.0100 c	.0040	0.0167 a	.0104	0.0346 a	.0085

None of the additional study nutrients showed any significant differences among treatment means for either monitoring year independently or for the entire two-year period averages. Orthophosphate was tested but concentrations were generally below detectable levels and means could not be consistently calculated for the treatments. It is therefore likely that most of the total phosphorous in the streams during the monitoring period was not immediately plant-available (labile) and unlikely to cause eutrophication in the streams in the near future.

The regression based analysis of covariance (100-foot control vs. other treatments) was also used to further investigate the relationship between individual watershed nitrogen and phosphorous data for each block (Grabow et al. 1998, Wynn et al. 2000). The results of the paired regression analysis did not indicate an overall treatment effect when pooled across all blocks for either the total phosphorous or total nitrogen data. Regression results generally indicated insignificant regression models, and slope values did not indicate a likely departure from a 1:1 relationship in most cases. This analysis reinforces the results of the analysis of variance procedure.

The study region in Virginia is part of the Chesapeake Bay watershed, and as a result, nutrients in surface water are very important to this study. Nitrogen and phosphorous are the two primary nutrients that often cause severe water quality problems in the Chesapeake Bay region. Excess nutrients in water lead to excess growth of algae and other aquatic plants that later die and decompose. Subsequent decomposition processes cause accelerated eutrophication, which depletes the oxygen level in water and often leads to significant fish kills in the bay (CBF 2007). The United States Environmental

Protection Agency (USEPA) has determined that Virginia has one of the highest water nitrate application rates in the country (USEPA 2004).

The data (Table 3-3, Figs. 3-2, 3-3) show no significant water quality differences by treatment in either year or in total for both years together (Fig. 3-3). Adjusted P-values for ammonium ranged from 0.60 for the treatment 1 versus 2 comparison to 0.99 for the treatment 1 versus 3 comparison. Adjusted P-values for nitrate ranged from 0.91 for the treatment 1 versus 3 comparison to 0.99 for the treatment 2 versus 4 comparison. All other P-values were similarly large. Increasing SMZ widths had no impact on nutrient concentrations, and thinning up to 50% of the canopy had no significant impact either. These results suggest that forest operations that minimize SMZ width and total acreage reserves as a riparian buffer will not necessarily increase nitrogen or phosphorous levels on similar sites in the southern piedmont region. It is also apparent that increasing buffer widths to 100 feet, which is currently not common in the South for normal forest operations, may not reduce nutrient concentrations in stream water overall. This is true for baseflow as well as stormflow events (Table 3-3).

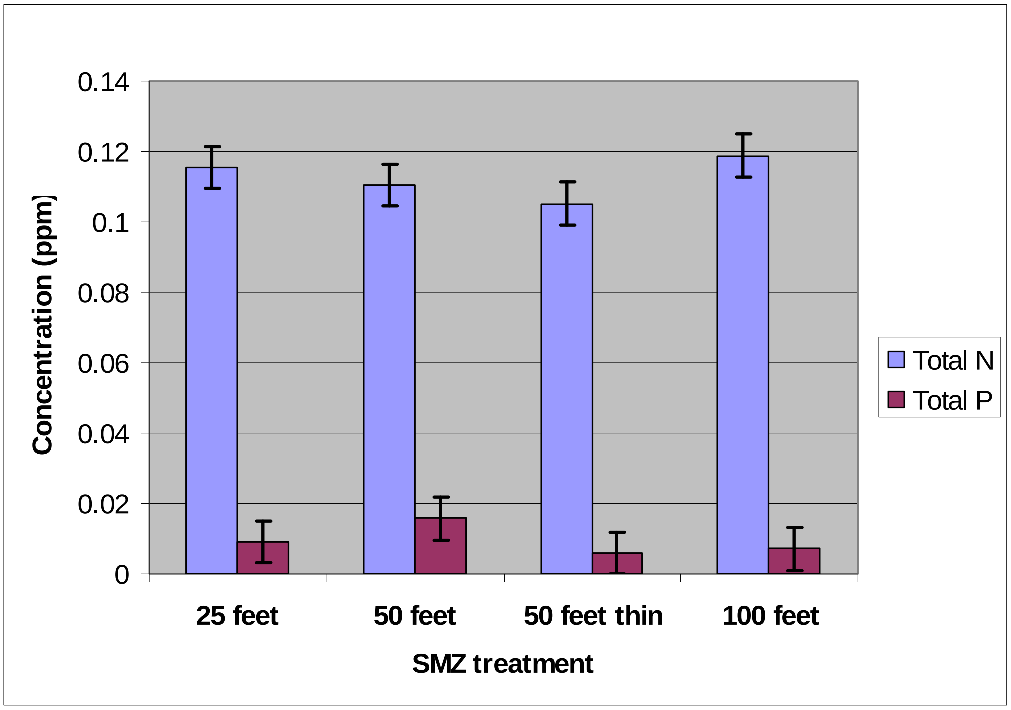

Figure 3-2: Total nitrogen and total phosphorous for stream water by SMZ treatment averaged over the two-year post-harvest study period for the SMZ study in central Virginia.

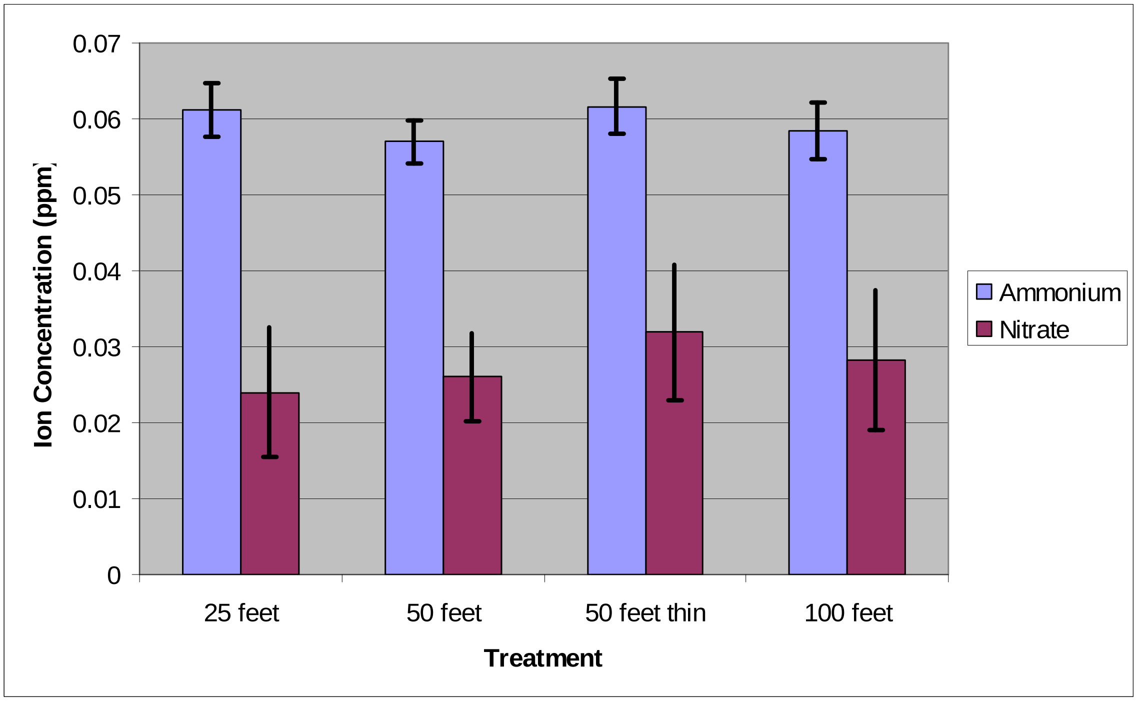

Figure 3-3: Ammonium and nitrate concentration in stream water by SMZ treatment for the SMZ study in central Virginia.

With these findings in mind, it is important to note that extending a 25-foot SMZ to 50 feet will increase SMZ acreage by three acres per mile of SMZ (per side of stream) and six acres per mile of SMZ by extending a 50-foot SMZ to 100 feet. This could easily account for as much as 12 acres per mile of SMZ lost to harvest and future production. This also could account for a monetary loss to the landowner or timber buyer in excess of $12,000 at the time of harvest ($1,000 per acre) and that estimate does not consider lost future production due to the loss of manageable acreage (Cubbage 2004, Lakel et al. 2006, Shaffer et al. 1998, Kluender et al. 2000, Shaffer and Aust 1993, LeDoux 2006). This estimate will vary greatly depending upon miles of SMZ in any given harvest block. SMZ width recommendations vary across the South, and it is often expected that more SMZ is better for water quality, but the nutrient data presented in Table 3-3 may dispute that contention in many cases. The cost of increasing SMZ width is generally carried by landowners and timber buyers and does not necessarily improve water quality from a nutrient standpoint in the piedmont region of Virginia (Fig. 3-1).

Table 3-3 and Figure 3-4 display the overall means by sampling period over the two-year post-harvest monitoring period for total nitrogen and total phosphorous. There are no significant differences by sampling period (Fig. 3-5), and the data show that the concentrations of these two primary nutrients are very low when compared to water in streams impacted by other land uses and typical of managed forested watersheds. Adjusted P-values for the sampling period mean comparisons (Tukey-Kramer) ranged from 0.86 to 1.00.

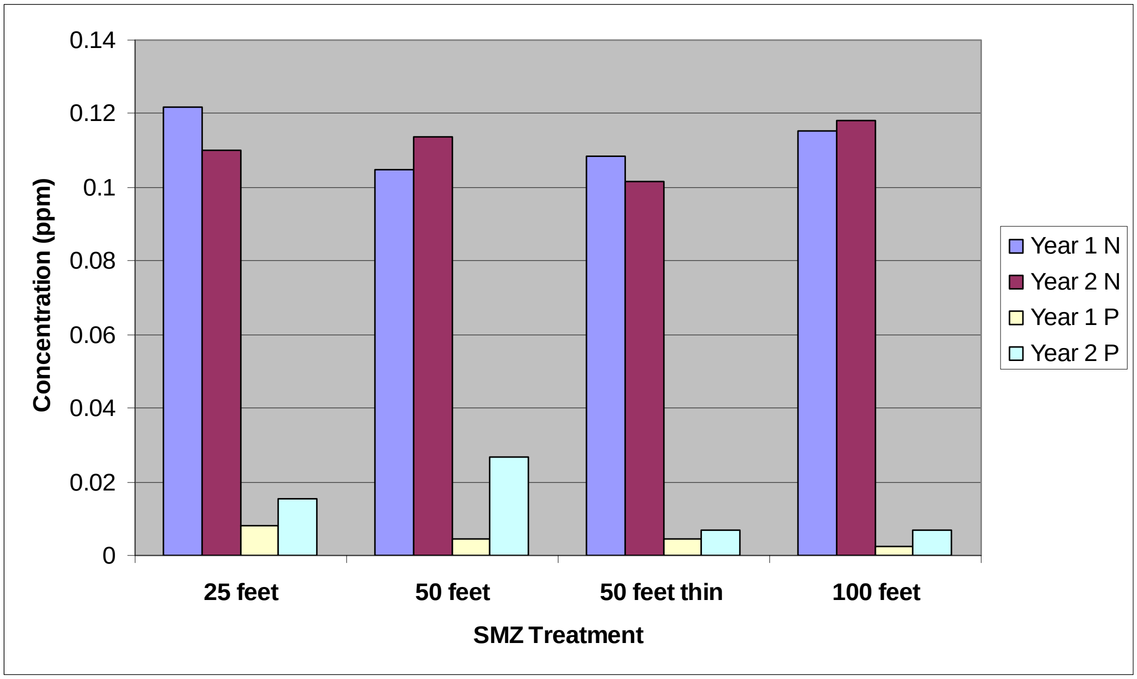

Figure 3-4: Total nitrogen and total phosphorous for stream water by SMZ treatment for both years of post-harvest monitoring for the SMZ study in central Virginia.

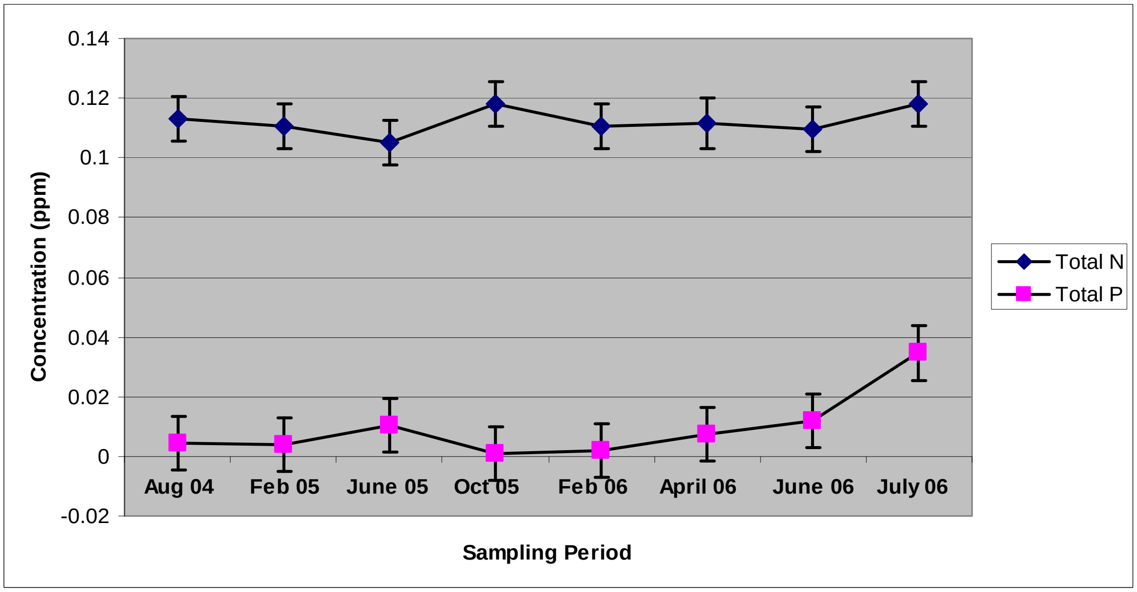

Figure 3-5: Total nitrogen and total phosphorous means for stream water by sampling period for the two-year post-harvest monitoring period for the SMZ study in central Virginia.

Aust and Blinn (2004) reviewed BMP literature relating to water quality impacts in the southern piedmont and coastal plain and found very similar concentrations for a variety of forestry studies. The authors highlighted a study by McClurkin et al. (1985), which evaluated forest harvesting effects on water quality in Tennessee and found that harvesting had no significant effects on nutrients in stream water and overall nitrogen and phosphorous concentrations were very similar to the values reported here in Table 3-3. Wynn et al. (2000) evaluated forest harvesting impacts on stream water quality in Westmoreland County, Virginia, in 2000 with and without proper BMPs and found that BMPs generally had a positive impact on most water quality parameters post-harvest. That study reported average post-harvest stream water concentrations for total nitrogen (TN) of 22.11 and 3.04 mg/l with and without BMPs respectively and also for total phosphorous (TP) of 3.70 and 0.24 mg/l with and without BMPs. The nutrient concentrations for all four SMZ treatments in the Buckingham County study compare favorably to the values reported in Westmoreland County (Table 3-3, Fig. 3-1). Carroll et al. (2004) reported nitrate in streamwater values of 0.07 mg/l for harvested areas with well maintained SMZs and 0.38 mg/l for harvested areas in north central Mississippi with no maintained SMZ. These values were not found to be significantly different, however, and the authors came to the conclusion that SMZ maintenance had no impact on nitrate concentrations. A recent SMZ study in Dinwiddie County, Virginia, determined that a 15-meter (49.2-ft) SMZ was adequate to protect water quality from ammonium, nitrtae, and phosphorous pollution in streams following direct application of biosolids to adjacent pine stands (Pratt 2008). Van Lear et al. (1985) found that forest harvesting in the piedmont of South Carolina produced small increases in streamwater nutrient concentrations ranging from 0.02 to 0.10 mg/l for nitrogen and 0.005 to 0.016 mg/l for phosphorous. The authors determined that these small increases were insignificant when compared to stream conditions for other land uses. This is the same conclusion reached in this study in central Virginia and overall nitrate concentrations were generally comparable (Table 3-3).

It is apparent that season, month, or time since harvest had no impact on nitrogen or phosphorous in water, and the very low values overall indicate that forest harvesting had minimal impact on nutrient concentrations even when narrower buffers and thinned buffers were utilized. There was no fertilization on the tracts except very low rates that were applied to firelines to promote the establishment of grasses to prevent soil erosion. Even with the light additions of fertilizer to the firelines, nitrogen and phosphorous levels in stream water were very low for every SMZ type (Fig. 3-2).

It is likely that the inherent nutrient deficiencies in these watersheds limited the amount of nutrients available to near-surface groundwater and surface water in the streams. Limited fertilizer applications on firelines were not large enough to be detected in stream water. The agricultural history in these watersheds likely depleted the natural pools of nutrients in the soil, and the new crop of trees and shrubs quickly utilized available plant nutrients. Unlike other mixed-use watersheds, these small forested drainages have very little excess nutrient inputs that would likely become water pollutants, and as a result, very small SMZs are likely sufficient to control nutrient inputs to streams for forestry operations in general. It is important to remember that these results are for watersheds managed for forest operations, which tend to produce less nonpoint source pollutants than either agricultural, urban, or construction activities; therefore, these results should not be used as rationale for using minimal-width SMZs for these activities. It is also important to note that very few SMZ failures (blowouts) were observed that might cause pollution problems under different circumstances.

Other Water Quality Indicators

There are a host of additional water quality indicators often used in some combination to monitor and evaluate water quality in forested watersheds. Table 3-4 provides the results for the two-year post-harvest monitoring period in central Virginia for a set of indicators often evaluated. Forestry studies typically concentrate on pH, dissolved oxygen (DO), temperature, turbidity, total dissolved solids, and total suspended solids because of their importance to aquatic life and drinking water quality. It is often considered that these indicators relate well to common forestry pollutants such as nutrients, organics, sediment, and increased thermal inputs.

These data were examined and evaluated utilizing the same statistical design and methods described previously for the water nutrients discussion. The apparent result of this part of the water quality analysis is very similar to the previous results in that there are no significant differences between SMZ treatments for any of the water quality indicators (Table 3-4). Again, it is apparent that overall, increasing SMZ widths and exclusion of harvesting within the buffer did not have a positive effect on water quality according to our measured parameters, and reducing SMZ widths and allowing harvesting within them did not degrade water quality to any measurable degree (Table 3-4, Fig. 3-6). Again, the overall treatment means indicate a generally high level of water quality in all study streams well beyond what would be expected in urban, agricultural, or mixed-use watersheds.

Table 3-4: The final water quality data (lsmeans) for the SMZ project in central Virginia for both years combined as well as data for each sampling event (quarter). Mean separation significance at the α = 0.10 (Tukey-Kramer) is in lower case to the right of each value.

Treatment	**Stream pH**	**Conductivity (uS/cm)**	**Turbidity (NTU)**	**Dissolved Oxygen (mg/l)**	**Temperature (^{o}C)**	**Total Dissolved Solids (ppm)**	**Oxidation Reduction Potential (mv-m)**
1 – 25 feet stringer	5.65 a	6.72 a	33.70 a	9.14 a	15.78 a	0.044 a	237.04 a
2 – 50 feet no thin	5.68 a	10.95 a	43.34 a	9.04 a	15.41 a	0.078 a	216.58 a
3 – 50 feet thinned	5.52 a	7.02 a	22.62 a	9.30 a	15.41 a	0.042 a	255.54 a
4 – 100 feet no thin	5.42 a	12.22 a	33.84 a	8.34 a	15.41 a	0.081 a	211.22 a
Sampling Event							
1 – February 2005	5.64 ab	3.25 a	95.4 a	12.2 d	10.17 a	0.0209 a	192.04 a
2 – July 2005	4.99 a	11.4 a	14.54 a	9.19 b	19.78 c	0.0737 a	190.22 a
3 – October 2005	5.27 ab	11.35 a	20.16 a	6.28 a	14.97 b	0.0731 a	182.46 a
4 – January 2006	----	----	----	10.63 c	10.24 a	----	----
5 – April 2006	6.31 b	11.91 a	17.83 a	8.06 b	13.19 b	0.0701 a	215.25 a
6 – June 2006	5.64 ab	9.24 a	17.7 a	9.04 b	19.40 c	0.0680 a	370.50 b

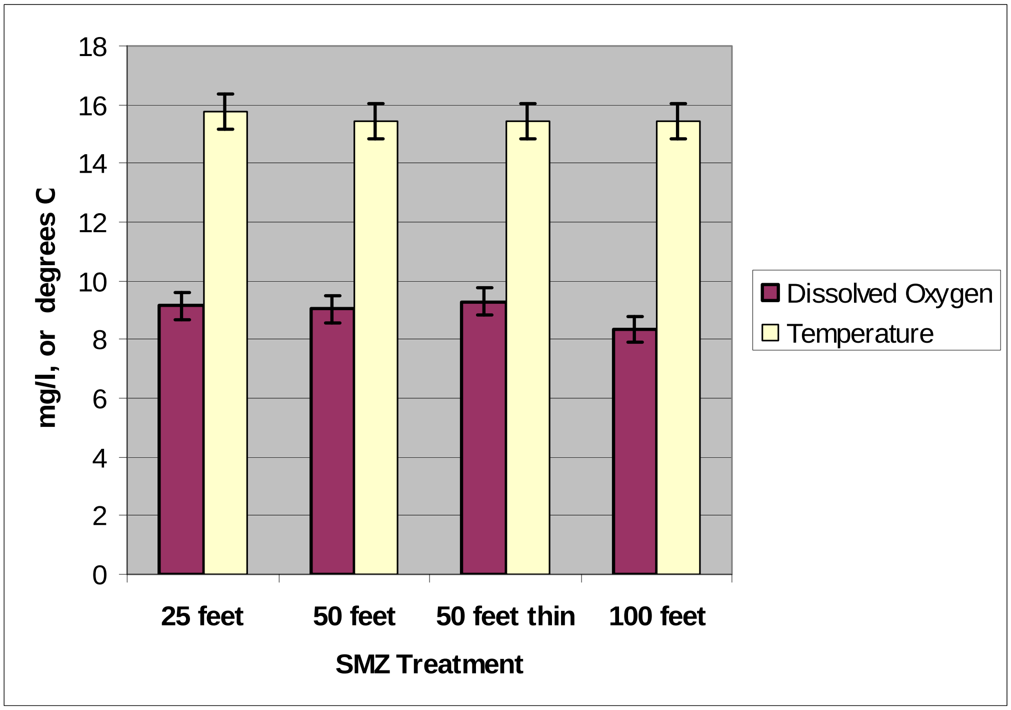

Figure 3-6: Dissolved oxygen and temperature data for the streams by SMZ treatment averaged over all sampling periods for the SMZ study in central Virginia.

Sampling month and time since harvest also had little effect on most parameters studied with the exceptions of dissolved oxygen and temperature, which was expected due to the seasonal nature of both (Fig. 3-7). Stream pH values varied by month, but no discernible patterns were discovered and there were no significant interactions among the treatments and sampling periods (Table 3-4).

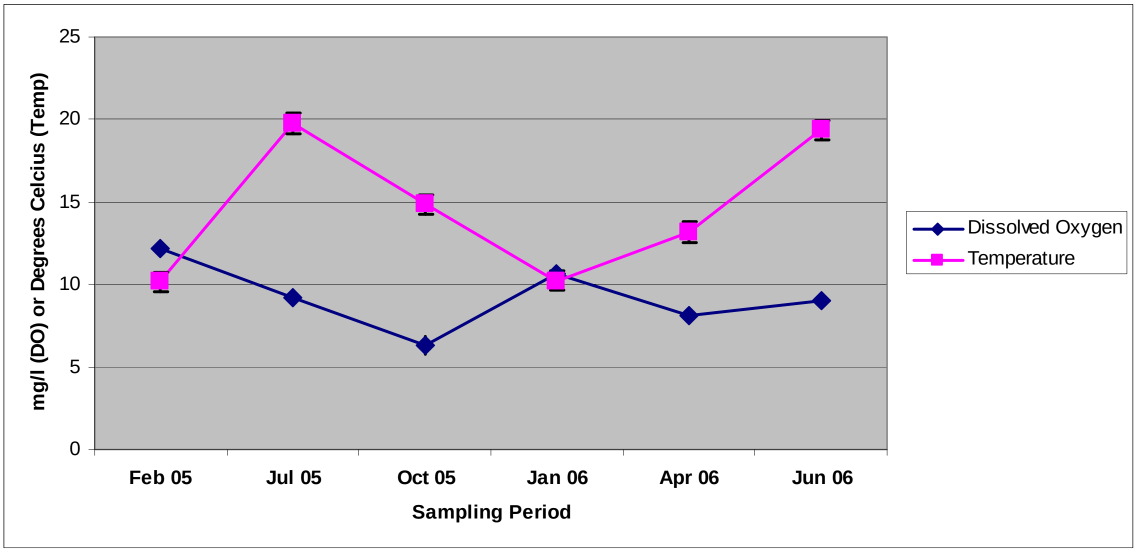

Figure 3-7: Dissolved oxygen and temperature for stream water by sampling period for the two year post-harvest monitoring period for the SMZ study in Central Virginia.

Values reported for dissolved oxygen and temperature in Figures 3-6 and 3-7 compare favorably to EPA descriptive statistics for Ecoregion IX, sub-region 45. The EPA reports median values for DO of 8.75 mg/l across the ecoregion, which compares well to study data regardless of season or SMZ treatment. Turbidity values also compare well to EPA median values, which ranged from 9 to 80 NTU (USEPA 2000). Total dissolved solids are well below the Virginia DEQ regulations for public water supplies, which require 500 mg/l or less (Virginia Department of Environmental Quality 2007). The study values for any treatment never exceeded 0.09 mg/l (Table 3-4).

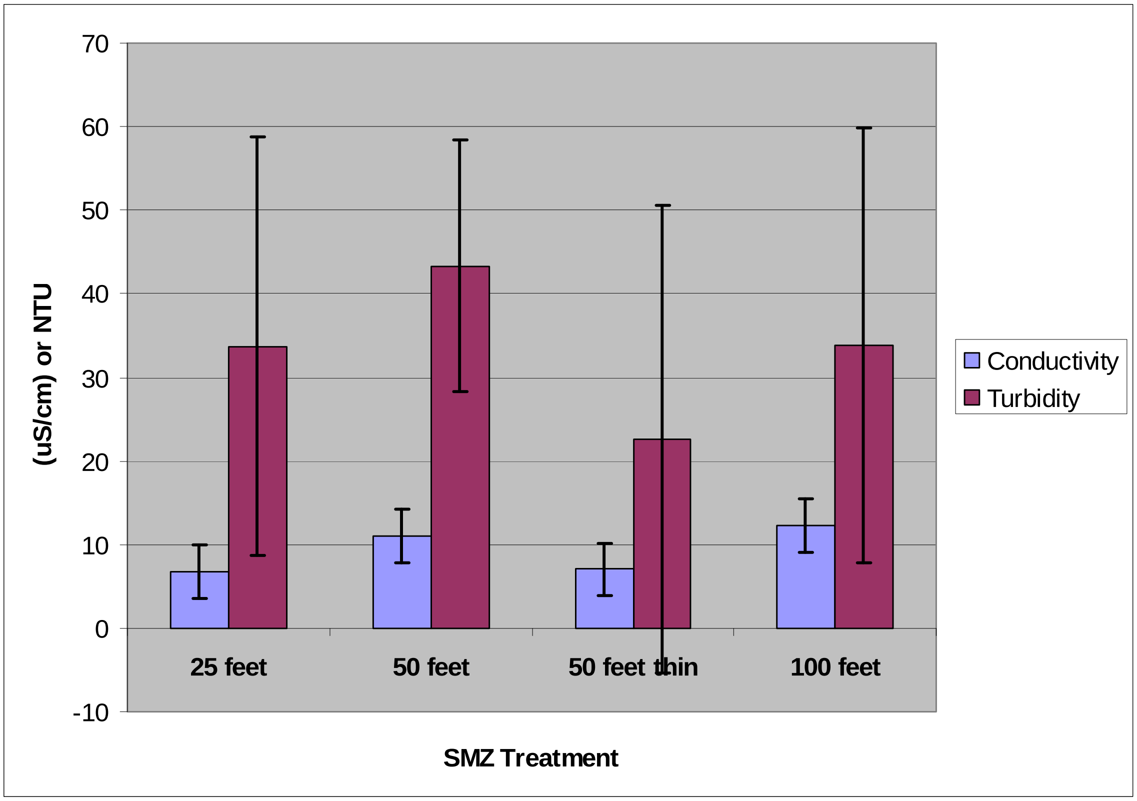

Figure 3-8: Conductivity and turbidity for streams averaged over the two post-harvest monitoring years for the SMZ study in central Virginia.

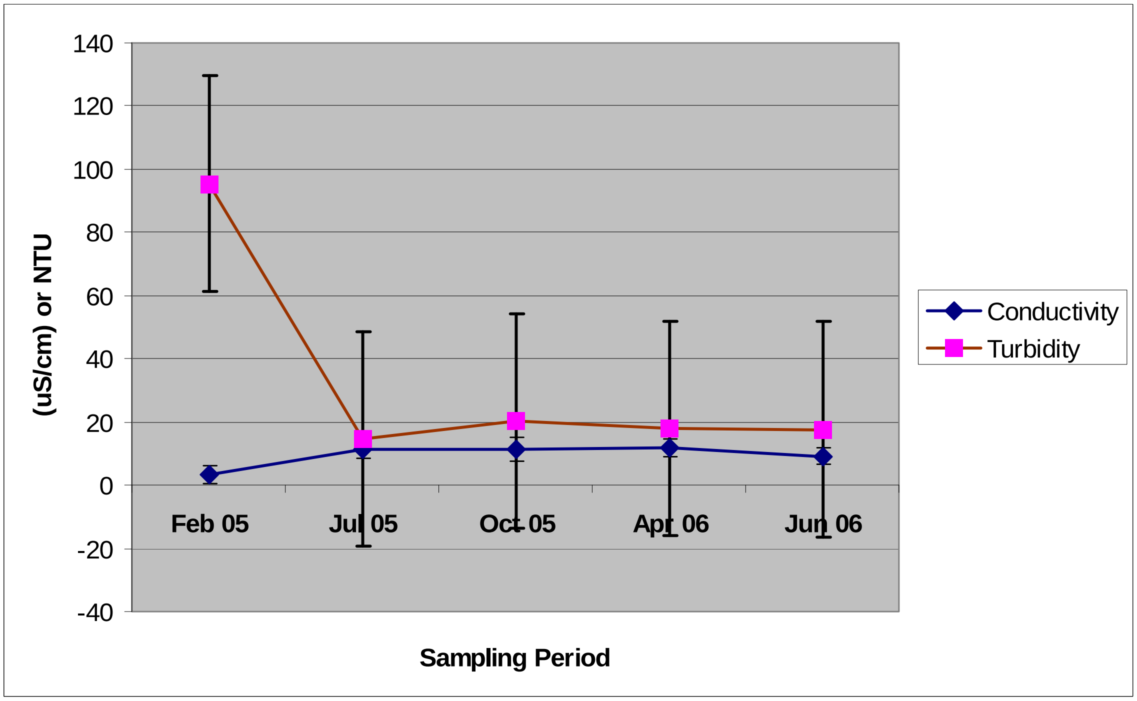

Figure 3-9: Conductivity and turbidity for streams by sampling period for the two-year post-harvest monitoring period for the SMZ study in Central Virginia.

Perhaps the most comparable studies to this are the Carroll et al. (2004) study in northeastern Mississippi and the Kiem and Schoenholtz (1999) study in western Mississippi. This study investigated similar SMZ issues and measured similar water quality parameters and the authors found very similar results for most parameters. There were apparently lower turbidity and TSS measurements recorded in both of the Mississippi studies when compared to the Virginia study, but dissolved oxygen was much higher and temperature was much lower in Virginia. Both Mississippi studies also concluded that harvesting in general did not create serious water quality degradation regardless of harvesting practices and BMP utilization with respect to the parameters in Table 3-4. It is important to recognize that the values in Table 3-4 for temperature and DO are generally consistent with healthy cold- and warm-water fisheries water quality conditions (Novotny 2003).

Wynn et al. (2000) recorded total suspended solids concentrations of 99 mg/l pre-harvest and 3,299 mg/l post-harvest for the harvesting and water quality study in eastern Virginia. These post-harvest values are somewhat higher than the values in Table 3-5 but are within reason for studies involving harvesting operations in the south where past agricultural landuse still has an impact on sediment loads in streams. Both sets of data are well below TSS data recorded for developing watersheds in the South Carolina piedmont, which had peak TSS concentrations exceeding 8,000 mg/l during some storm events (Hur et al. 2008).

Table 3-5: Post-treatment total suspended solids (TSS) values for all treatments on the SMZ project in central Virginia for one major storm event in 2006.

Treatment	TSS (mg/l)	Standard Error
1 – 25 ft stringer	1078.67 a	306.4
2 – 50 ft no thin	432.65 a	287.4
3 – 50 ft thinned	473.90 a	287.4
4 – 100 ft no thin	1018.54 a	306.4

Conclusions

In general, the data indicate that forest harvesting did not degrade water quality to any measurable degree in these streams with regard to any of the monitored parameters during the two-year post-harvest period. This was true for all sampling periods and sampling season and time, since harvest did not change this conclusion. It is also apparent that SMZ width did not impact water quality in these streams. It was apparent that wider SMZs were not superior with respect to water quality and narrower SMZs were just as effective. The data also supports moderate thinning within SMZs as an appropriate timber management tool since the practice did not degrade water quality.

The statement "more is better" is not likely true with regard to forestry SMZs in the southern piedmont, and SMZ width and thinning recommendations should be examined across the South. It is important that current and future SMZ recommendations involve a more in-depth cost-benefit analysis, as the expense to landowners and timber buyers can be significant and water quality gains are not assured.

It is also important to repeat that this study is specific to managed forestry watersheds and is not applicable to other watersheds dominated by more intensive land uses such as agriculture and urban development. The results of this study might not be portable to other physiographic regions.

Chapter 5: Streamside Management Zone Characteristics and Soil Erosion in Headwater Drainages in the Virginia Piedmont

Abstract

The major study objectives include determining if a 50-foot streamside management zone (SMZ) as described in the Virginia BMP Manual (VDOF 2002) is generally sufficient to protect stream water quality, riparian soils, and stream bank integrity in headwater streams where forest harvesting has taken place, as well as comparing other SMZ widths with regard to the same environmental protection performance. Forested SMZs are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations, and enhancement of in-stream and riparian habitat. In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four SMZ treatments were installed across four experimental blocks during harvest. Each of the 16 watersheds was subsequently site-prepared with prescribed burning, and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the established treatments were a 100-foot width with no thinning, a 50-foot width without thinning, a 50-foot width with thinning, and a 25-foot "stringer." Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). After a two-year post-harvest monitoring period, it was determined that the SMZ treatments had no significant effect on soil erosion or sediment deposition in the SMZs regardless of SMZ treatment. There was no increase in soil erosion or sediment deposition as a result of harvesting timber, and larger SMZs did not protect soil any more than narrower SMZs. It was also apparent that thinning within SMZs did not encourage soil erosion or sediment movement.

Introduction

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations and enhancement of in-stream and riparian habitat (Castelle et al. 1994, Blinn and Kilgore 2001, Virginia Department of Forestry 2002, Georgia Forestry Commission 2005, North Carolina Department of Forest Resources 2006, United States Environmental Protection Agency 2007). It is widely accepted that SMZs positively affect soil erosion, sediment deposition, and water quality in and around headwaters streams where forestland management activities often occur, but little research has been done to determine how wide SMZs should be and if thinning is acceptable within SMZs from a soil erosion standpoint. Forestry Best Management Practices (BMP) guidelines vary across the South with regard to riparian management and SMZ specifications. However, most research on forestry riparian areas has not been on true headwater streams but has commonly focused on larger streams, and widespread interest in headwater streams is quite recent (MacDonald and Coe 2007).

It is important to collect data in order to refine SMZ guidelines because the cost of leaving timber along streams can be substantial for landowners and timber buyers (Shaffer et al. 1998, Kluender et al. 2000, Cubbage 2004, Lakel et al. 2006). It is also probable that total maximum daily loads (TMDLs) for sediment will be established in the Chesapeake Bay watershed in the near future, and forestry operations and BMPs in this region could be affected. It is imperative that the contribution of intensive forestry operations to erosion rates near surface waters in the Chesapeake Bay watershed and the southern piedmont in general be quantified in order to allow informed decisions with regard to future regulatory and management policy changes.

Erosion and associated sedimentation from forestry operations are important because sediment can kill fish and other organisms directly and prevent successful reproduction by covering spawning habitat with silt. Resulting increases in turbidity can reduce photosynthesis by aquatic plants, further degrading habitat. Fish species requiring clear water will perish or migrate, and fish species more tolerant of turbid water and muddy channels will dominate (Duda 1985). Fine sediment particles often damage gills of fish and organisms that fish feed on (Duda 1985, USEPA 2000). The fine sediments often transport adsorbed pollutants such as pesticides, plant nutrients, and trace metals. Organic forms of mercury are often adsorbed to soil particles and can later be converted to an inorganic form by bacteria which can then accumulate in living tissues (Oschwald 1972). Long-term sedimentation can drastically alter stream characteristics and alter entire ecosystems permanently (Duda 1985, USEPA 2000).

Economic impacts of increased nonpoint source pollutant inputs are not as obvious or visible as point source but are equally large. Costs originate from multiple problems including increased flood damage, fish stocking, restoration of damaged waterways, cleaning of ditches, dam building, and loss of recreational activities, commercial fishery degradation, regulatory program needs, and research and development of abatement and prevention methods (Stall 1972, Duda 1985, Colacicco et al. 1989, Ribaudo and Young 1989). The USEPA has identified sediment as the second largest impairment of river miles in the U.S. (Fig. 4-1) (USEPA 2000).

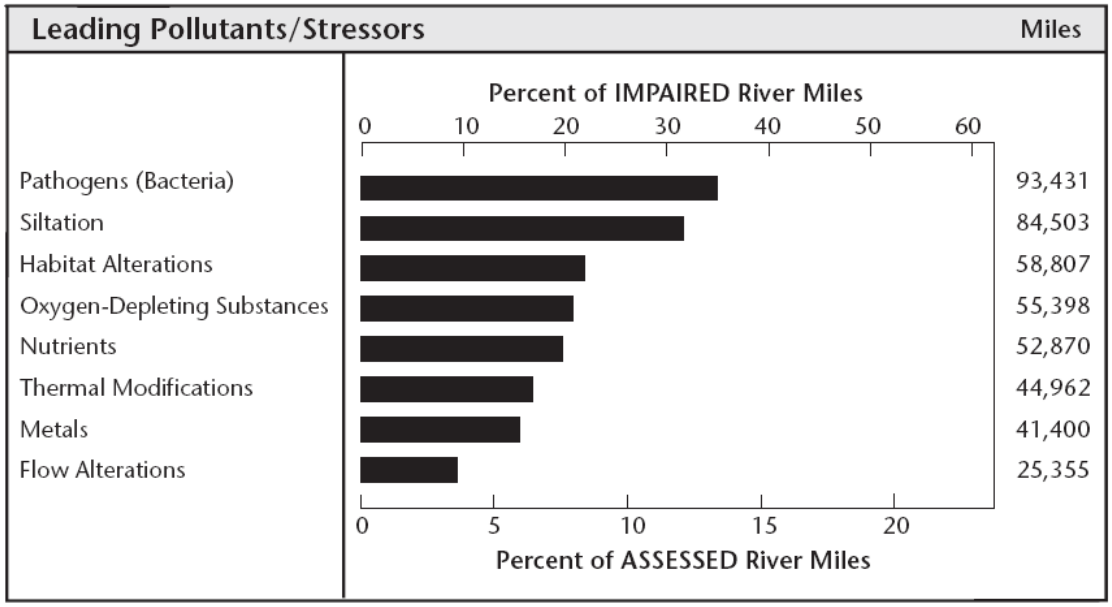

Figure 4-1: Leading water pollutants in streams surveyed in the U.S. for the 2000 National Water Quality Report. (Adapted from USEPA 2000).

Study Area and Site Descriptions

The study watersheds are located in and around Buckingham County in central Virginia (37^{o}32'57" N latitude, 78^{o}43'28" W longitude). This area is the western part of the piedmont plateau directly east of the Blue Ridge Mountains and approximately 110 miles west of the Chesapeake Bay (Fig. 4-2). The James River flows west to east through the central piedmont approximately 10 miles to the north of the study area. The typical elevation of the surrounding area ranges from 500 ft to 1200 ft above mean sea level. Average January maximum and minimum temperatures are 8.3^{o}C (46.9^{o}F) and -2.8^{o}C (27.0^{o}F), respectively. Average July maximum and minimum temperatures are 30.3^{o}C (86.5^{o}F) and 18.0^{o}C (64.4^{o}F), respectively (USDA, 2004).

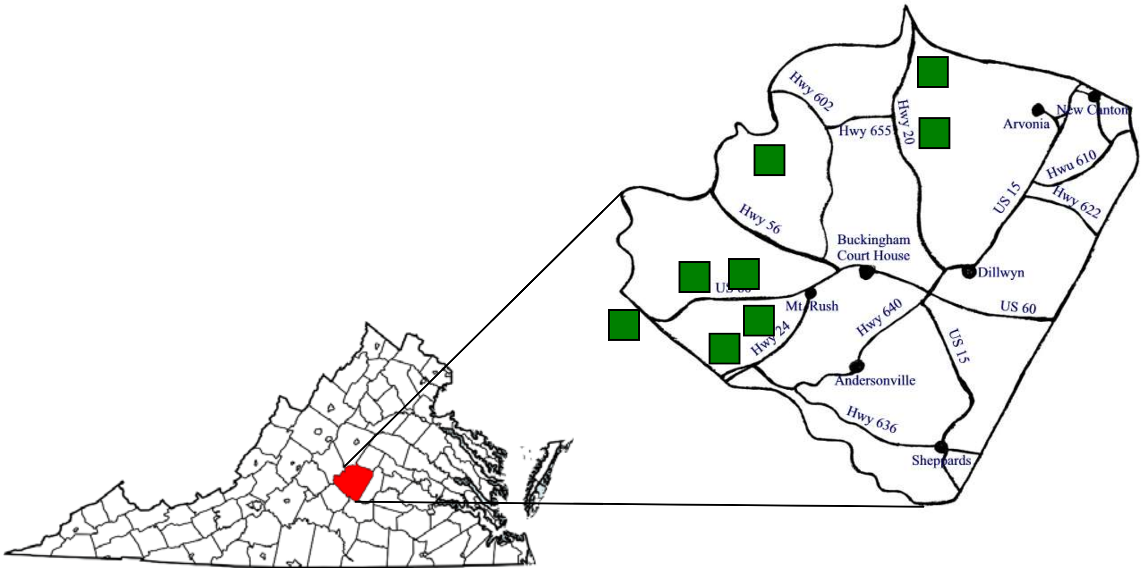

Figure 4-2: Approximate locations of study areas in green in and around Buckingham County, Virginia.

Soils are typically highly eroded, often-shallow ultisols with argillic horizons overlain by shallow Ap horizons. Due to past agricultural abuse and related soil erosion, very little organic matter remains in the Ap horizon and eluvial E horizons are generally minor or absent. Soil textures are generally clay to clay loam with significant coarse fragments (USDA, 2004). Common upland soil series include Spears Mountain silt loam (fine, mixed, semiactive, mesic, typic, hapludults), Fairystone channery loam (clayey-skeletal, parasesquic, mesic, typic, hapludults), and Bugley channery silt loam (loamy-skeletal, mixed, semiactive, mesic, lithic, dystrudepts). Common bottomland soils include Hatboro loam (fine-loamy, mixed, active, nonacid, mesic, fluvaquentic, endoaquepts), and Delanco gravelly loam (fine-skeletal, mixed, semiactive, mesic, aquic, hapludults).

Past land use in this area was dominated by intensive agricultural practices from the mid-1700s to the late 1800s. Most of the southern piedmont's farmland was highly degraded due to agricultural erosion and consequently abandoned (Van Lear et al. 2004). The subsequent upland natural pine and hardwood forests were dominated by various oak species (*Quercus spp*.), red maple (*Acer rubrum*), sweet gum (*Liquidamber styraciflua*), hickory (*Carya spp*.), Virginia pine (*Pinus virginiana*), and shortleaf pine (*P. echinata*). Bottomlands were dominated by red maple, river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), elm (*Ulmus spp*.), alder (*Alnus rugosus*), black willow (*Salix nigra*) and yellow poplar (*Liriodendron tulipifera*) (Gemborys 1974). Many of these second-growth forests were subsequently harvested at least once during the 1900s, and many areas were replanted with loblolly pine (*P. taeda*), which is not native to the Virginia piedmont in general (Schultz 1997). Loblolly pine, a coastal plain native, has performed well overall in plantations east of the Blue Ridge and has become a major part of forested ecosystems in the piedmont.

Watershed Treatments and Study Layout

Beginning in 2001, 16 first-order streams/riparian areas and associated forested watersheds on MeadWestvaco timberlands were monitored for baseline data prior to treatment installation, but little stream water data were obtained due to three years of severe drought in the region (Easterbrook et al. 2003). Four treatments were installed across four blocks during 2003-2004. Each of 16 watersheds was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine. Within the watersheds, the streamside management zone treatments were established on each side of the stream channel as a 25-foot “stringer” (treatment 1), a 50-foot width with no thinning (treatment 2), a 50-foot width with 30% to 50% basal area thinning (treatment 3), and a 100-foot width with no thinning (treatment 4) . Each of the four treatments was conducted within at least three of four blocks (Incomplete Block Design). The study watersheds were blocked according to local geology and watershed size (Table 4-1).

Table 4-1: Organization of watersheds, blocks, and treatments and associated information relating to the study layout and data analysis for the SMZ project in central Virginia.

Watershed Name	County	Block #	Trt #	SMZ Treatment	Acres	Mean Acres per Block
Gunstock 1	Buckingham	1	3	50 ft-thinned	20	20
Gunstock 2	Buckingham	1	2	50 ft-not thinned	14	
Gunstock 3	Buckingham	1	4	100 ft-not thinned	29	
Gunstock 4	Buckingham	1	2	50 ft-not thinned	16	
Irons-North	Buckingham	2	2	50 ft-not thinned	36	24
Irons 1	Buckingham	2	1	25 ft-not thinned	19	
Irons 2	Buckingham	2	3	50 ft-thinned	31	
Fisher-North	Buckingham	2	4	100 ft-not thinned	10	
Doe 1	Buckingham	3	3	50 ft-thinned	103	142
Doe 2	Buckingham	3	1	25 ft-not thinned	178	
G-Union Camp	Buckingham	3	2	50 ft-not thinned	112	
Breezy Bee	Nelson	3	2	50 ft-not thinned	174	
Baird-Payne	Buckingham	4	1	25 ft-not thinned	130	79
Baird-Payne	Buckingham	4	2	50 ft-not thinned	51	
Miller	Buckingham	4	4	100 ft-not thinned	77	
Miller	Buckingham	4	2	50 ft-not thinned	59	

USLE soil erosion estimates were calculated for the harvested portions of the watersheds (pre- and post-harvest) as well as for firelines, roads, and skid trails in order to identify high-risk areas which might impact SMZ function and stream water quality (Dissmeyer and Foster 1981, Dissmeyer and Foster 1984, Hood et al. 2002).

Between June 2004 and July 2006, soil erosion in the SMZs was monitored using pre-installed erosion rods along three equally spaced transects (Fig. 4-3) in order to determine the influence of the SMZ treatments and timber harvesting in general on post harvest soil erosion. Along the downstream side of each transect a row of erosion rods was installed at 2.28 m (7 ft), 4.57 m (15 ft), 7.62 m (25 ft), 15.24 m (50 ft), 30.48 m (100 ft), and 38.1 m (125 ft) from the center of the stream. This was done on each side of the stream in all of the blocks except Block 3 due to one-sided harvests. The erosion rods were .6 m (2 ft) lengths of rebar pounded halfway into the ground. The remaining portion of the rod above ground was measured to the nearest millimeter at the mineral soil surface. The erosion rods were measured once after two years (post-harvest) to measure erosion or deposition. The data was split by transect and applied to the transect data ANOVA procedure in Table 4-2 for the split-plot design.

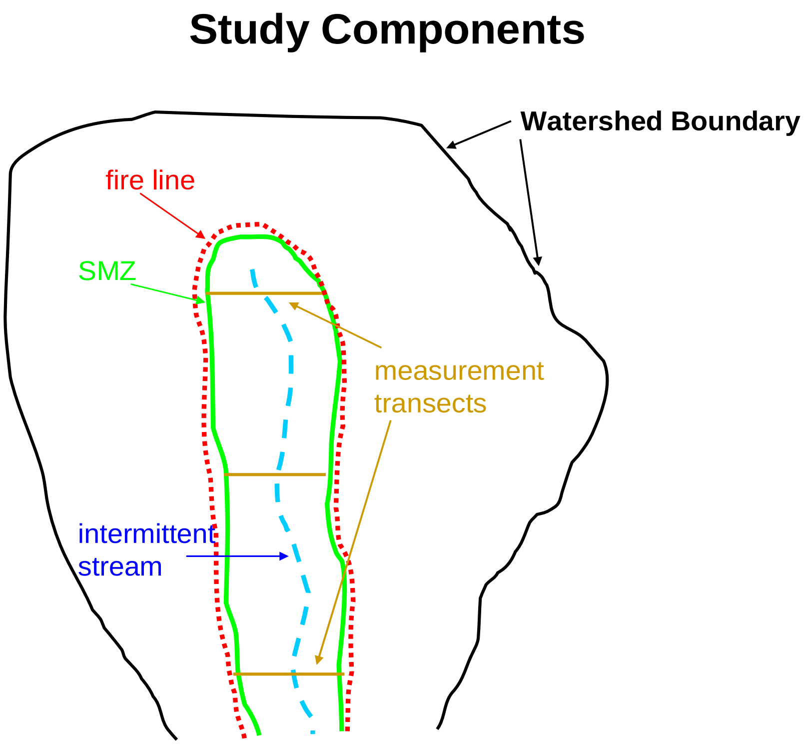

Figure 4-3. Representation of a typical study watershed with approximate location of SMZ boundaries, firelines, stream, and measurement transects for the SMZ study in central Virginia.

Table 4-2: The generalized model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments split by sampling transect.

Source	**Degrees of Freedom**	
Treatment	(t-1)	3
Block	(b-1)	3
Error A	(t-1)(b-1)	9
Sampling Transect	(z-1)	7
Sampling Transect*Trt	(z-1)(t-1)	21
Error B		84
Total (Corrected)	(zbt)-1	127

Three minor sub-drainages were randomly chosen in each watershed (two blocks only) for installation of an erosion trap made from commercially available silt fence and wooden stakes. Traps were not installed on all blocks due to the time and labor involved to transport materials to remote locations as well as install and maintain more traps. The first drainage had a trap installed at the stream bank only to evaluate the amount of soil and debris that reached the stream. The second drainage had a trap installed just below the fireline to determine the total amount of eroded material that entered the SMZ at that point by that drainage. The third drainage had a trap installed just above the fireline at the edge of the cutover to determine the amount of eroded material entering the SMZ from the cutover area only. This allowed a detailed analysis of relative stream sediment contributions from the cutover and the fireline as well as an estimate of overall SMZ function (Robichaud and Brown 2002, Jackson 2004). The data were applied to the split-plot model described in Table 4-2 and the measurements were split by trap position (below cutover, below fireline, at stream bank).

Canopy cover was estimated using a spherical densitometer for each transect (Fig. 4-3). This was done four times at each transect intersection with the stream channel, once facing in each cardinal direction. The repetitions were then averaged to find the average canopy cover for each transect and averaged again for a watershed canopy cover value. The herbaceous and shrub layer were measured using ten 1-m^2 (10.7-ft^2) fixed area plots per SMZ laid out on a systematic grid. These two layers were combined to obtain an estimate of understory density which may have an impact on soil erosion. Midstory vegetation was measured with ten 1/100-acre plots per SMZ spaced on a systematic grid averaged across each SMZ.

The organic layer of each soil profile was measured in close proximity to each erosion rod on each measurement transect. A slice was made through the organic layer to the mineral soil and the depth of the organic layer was measured to the nearest cm with a clear ruler and recorded. The organic horizon was measured once during the winter of 2006-2007. The data were averaged across all transects for each watershed and applied to the watershed data ANOVA procedure in Table 4-3 for the ICBD design with no split.

All data were analyzed using a combination of Excel™ spreadsheets and The SAS™ System. The Tukey-Kramer adjusted mean separation test was used to determine significance between treatment means and transect means. The watersheds and treatments were organized in an incomplete block design (Table 4-2) and each treatment had at least three replicates.

Results and Discussion

Timber harvesting can and usually does increase the risk of soil erosion for one to several years after harvest due largely to disturbed forest floor and associated bare soil. This study conformed to that general concept for those very same reasons. The data indicate that the average soil erosion risk is much lower in the upland areas before harvesting occurred, and there were no significant differences among SMZ treatments before or after harvesting (Table 4-3, Fig. 4-4). This implies that the experimental units (watersheds) were relatively uniform before treatment installation with regard to ground disturbance and erosion risk. It also allows us to determine that harvesting practices during treatment installation were relatively uniform with regard to ground disturbance and erosion risk. This gives us confidence that differences among logging contractors or harvesting systems did not likely impact treatment effects or overall study results with regard to soil erosion or sediment deposition in the SMZs. As expected, USLE estimates did predict an increase in soil movement after harvesting due primarily to increased litter disturbance and exposed soil.

Table 4-3: USLE soil erosion estimates for upland harvest areas by treatment for the SMZ study in central Virginia. Lower and upper case letters indicate statistical significance among treatments and time periods, respectively ($\alpha = 0.10$).

	Pre-Harvest Soil Loss (t/ac/yr)		**Post-Harvest Soil loss (t/ac/yr)**	
Treatments	**Mean**	**Std Error**	**Mean**	**Std Error**
1 – 25 ft stringer	0.19 a	0.12	1.28 a	1.29
2 – 50 ft no thin	0.20 a	0.08	3.73 a	0.85
3 – 50 ft thinned	0.22 a	0.12	2.00 a	1.29
4 – 100 ft no thin	0.22 a	0.12	5.49 a	1.29
Average	**0.21 A**	**0.40**	**3.17 B**	**0.40**

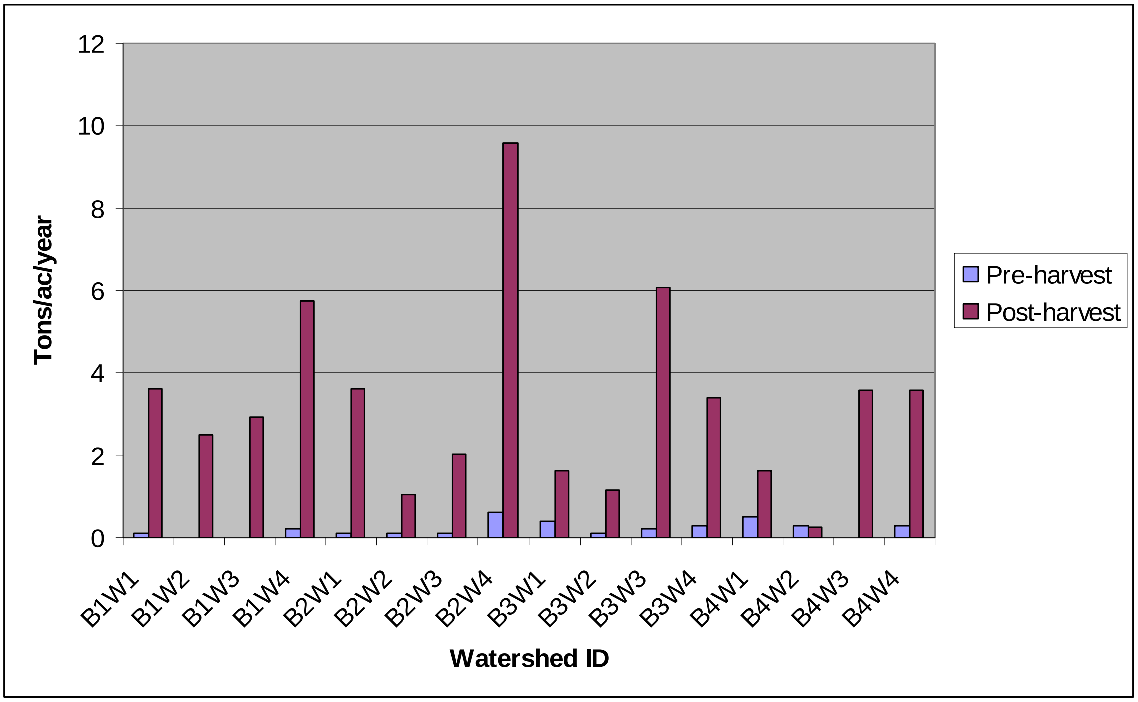

Figure 4-4: USLE erosion estimates by block and experimental unit (watershed) for the harvest areas before and after harvesting for the SMZ study in central Virginia.

The lack of significance among post-harvest means for the different SMZ treatments (Table 4-4, Fig. 4-5) indicates that harvesting timber closer to streams and farther down approaching slopes did not likely increase soil erosion adjacent to the SMZs, because sediment accumulation or degradation was not different within the SMZs regardless of SMZ width. P-values between treatments ranged from 0.37 to 0.99. Wider SMZs cover more of the slopes approaching the streams and provide a greater area and distance of somewhat lesser disturbed forest floor, but they were not shown to have an impact on sediment entering or leaving the SMZ (Table 4-4, Fig. 4-5). Depth of forest floor in a forest stand is important to protecting underlying mineral soil and preventing soil erosion (Pritchett and Fisher 1987). The data in Table 4-4 indicate that the organic horizon and leaf litter layer in the SMZs were of uniform depth across all treatments.

Table 4-4: Soil erosion rod measurements and leaf litter depth for the pre-harvest and two year post-harvest time periods for the SMZ study in central Virginia. The post-harvest data was split by measurement transect. Lower case letters indicate statistical significance (α = 0.10). Negative values indicate soil erosion and positive values indicate sediment accumulation.

	Pre-Harvest Soil Loss (t/ac/yr)		**Post-Harvest Soil Loss (t/ac/yr)**		**Leaf Litter Depth (cm)**	
Treatments	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**
1 – 25 feet	-28.72 a	8.14	+9.63 a	7.58	2.18 a	0.66
2 – 50 feet	-7.55 a	5.23	-6.65 a	5.28	3.72 a	0.43
3 – 50 feet thin	+0.18 a	8.14	+0.12 a	7.58	3.28 a	0.61
4 – 100 feet	-2.88 a	8.14	+0.88 a	7.01	3.61 a	0.61
Transects						
1 – Upper	-----	-----	3.51 a	5.76	-----	-----
2 – Middle	-----	-----	4.01 a	6.07	-----	-----
1 – Lower	-----	-----	2.14 a	6.15	-----	-----

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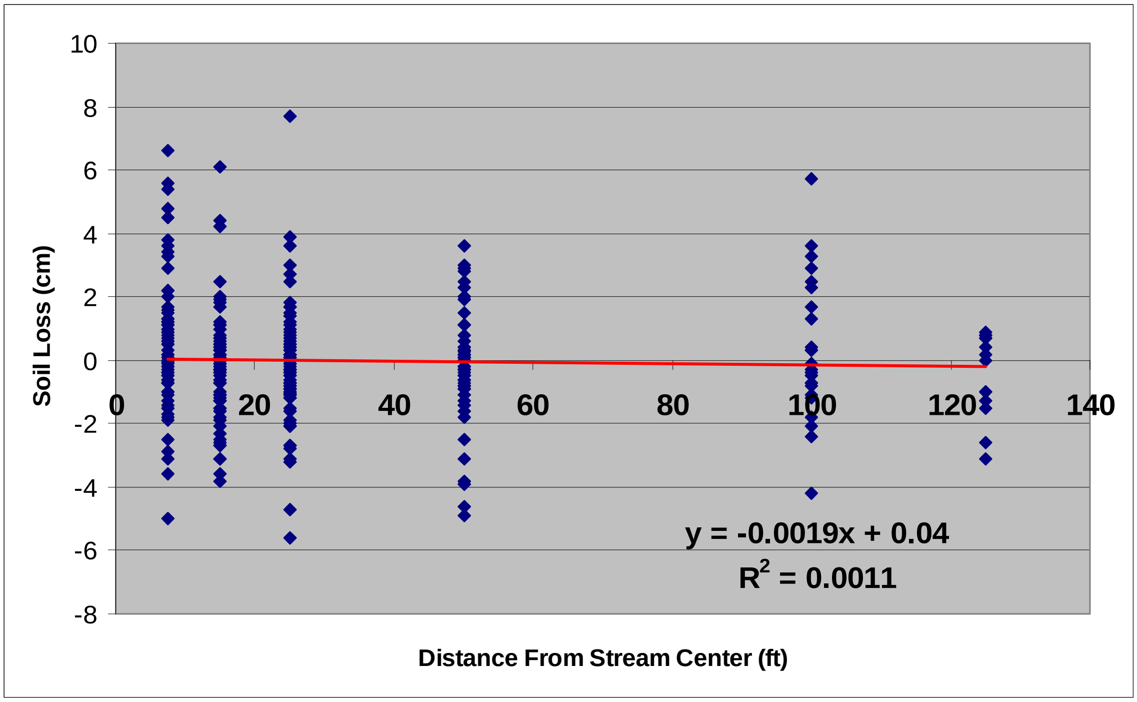

Figure 4-5. Soil loss (cm) at each erosion rod across all SMZs regardless of block and treatment versus the distance of each erosion rod from the stream bed center two years after harvest for the SMZ study in central Virginia.

Overall erosion values for each transect position within the watersheds (upper, middle, lower) did not differ when pooled across all treatments (Table 4-4). It was anticipated that erosion within SMZs might not be uniform across all areas within the watersheds; however, the data indicate that erosion and deposition of soil were relatively consistent regardless of measurement transect position. P-values between pooled positions for the post-harvest soil loss mean comparisons ranged from 0.37 to 0.99, and p-values for pre-harvest soil loss mean comparisons ranged from 0.12 to 0.99. P-values for the post-harvest soil loss transect comparisons (split plot) ranged from 0.65 to 0.99.

The pre- and post-harvest data in Figure 4-5 suggest that soil erosion and sediment deposition data were not likely different except for the 25-foot treatment. These narrow SMZ treatments appear to have created a sediment deposition effect after harvesting. This effect could be due to an increase in logging-related debris and vigorous regrowth of vegetation following harvesting.

It was expected that the position of each erosion rod on the landscape might have an impact on the likelihood of that rod experiencing soil erosion or sediment accumulation. The rods at the lower positions (7.5, 15, and 25 feet from the stream) were more likely to be on a toe slope or floodplain position; thus, smaller SMZs would have relatively more rods in such positions and, as a result, a bias toward sediment accumulation. In an attempt to evaluate this possibility, all sediment rod erosion measurements were plotted against the distance from the stream for each rod (Fig. 4-6). The plot does not show any differences in overall erosion or accumulation by distance from the stream but does demonstrate the relatively large variability in the overall data set. Therefore, it was determined that soil erosion was occurring uniformly across landscape positions and treatments in this study. It is important to note that data points closer to the stream (7.5 and 15 feet) are likely to be measured from a floodplain or toeslope position, while points farther from the stream (50, 100, and 125 feet) are likely to be measured on a steeper backslope position.

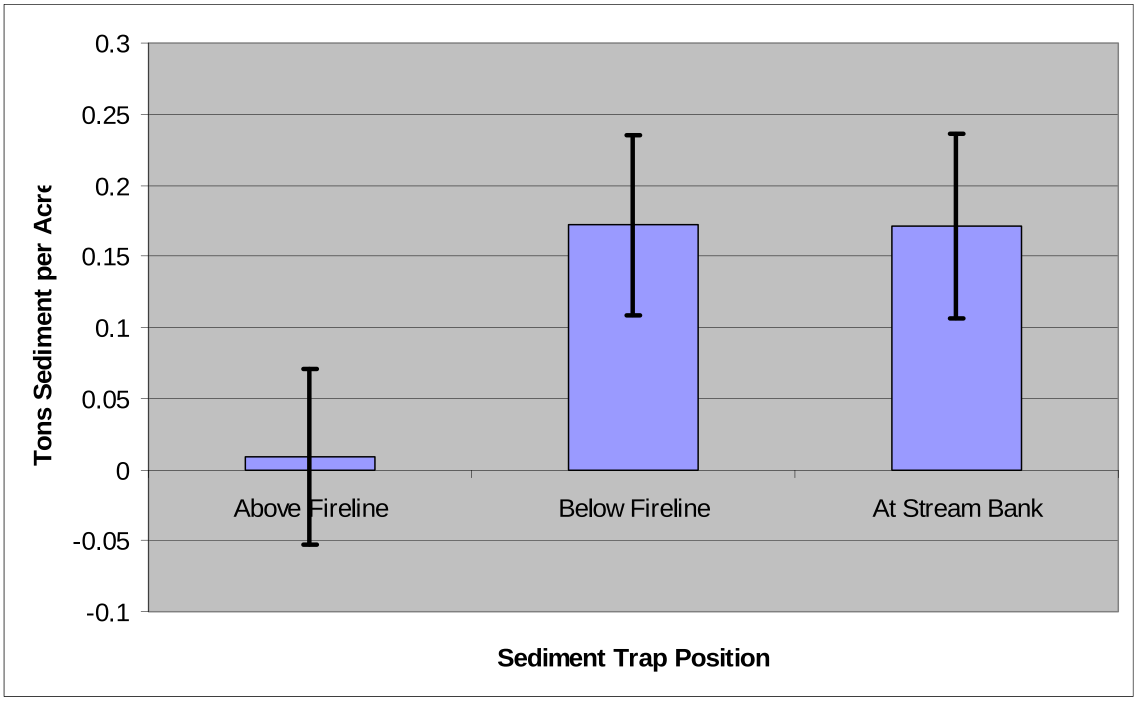

Figure 4-6: Sediment trap accumulations (two-year totals) by trap position during the two-year post-harvest monitoring period in Buckingham County, Virginia.

Sediment trap data on two blocks of this study (Table 4-5) indicate that all four SMZ types were equally effective at preventing eroded sediment from reaching the stream channel. P-values between treatments ranged from 0.26 to 0.77. Most traps showed no significant accumulation of sediment, but several locations did experience larger accumulations due directly to nearby road BMP failures (Fig. 4-8).

Table 4-5: Sediment trap accumulation data measured two years after harvest on two blocks only for the SMZ study in central Virginia. The post-harvest data was split by trap position. Lower case letters indicate statistical significance at the $\alpha = 0.10$ level.

	Post-Harvest Sediment Accumulation (t/ac/yr)	
Treatments	**Mean**	**Std Error**
1 – 25 feet stringer	0.14 a	0.06
2 – 50 feet no thin	0.22 a	0.05
3 – 50 feet thinned	0.00 a	0.09
4 – 100 feet no thin	0.00 a	0.06
Trap Position		
1 – Above Fireline	0.01 a	0.06
2 – Below Fireline	0.12 a	0.06
1 – At Stream Bank	0.15 a	0.06

There were no significant (treatment x position) interactions and it was found that wider SMZs were not more effective at preventing movement of concentrated sediment flows to the stream channel. It was, however, apparent that the cutover area contributed very little sediment to traps installed above firelines (Fig. 4-7). It is also evident that traps installed below firelines and at the stream bank did not accumulate larger amounts of sediment than traps above the firelines on a per-acre basis, and it appears unlikely that the SMZs were generally effective at stopping any concentrated flows of sediment in minor drains regardless of width (Table 4-5, Fig. 4-7). Visual evidence indicated that significant scouring and minor channel formation within these minor sub-drainages within the SMZs could actually be contributing sediment to streams directly as a result of surface water accumulation and runoff during rainfall events. It was also apparent in the field that traps with larger accumulations of sediment were receiving most of that sediment from improperly maintained roads and/or a specific BMP failure on steeper terrain and more fragile soils. These associated BMP failures were also noted in the second year after harvest and likely indicate that BMP success on slopes and stream approaches is often short-lived. It is also appropriate to mention that the common (VDOF 2002) practice of pushing firelines around SMZs rather than through them does not likely reduce the threat of stream sedimentation and may actually increase that threat based on these data (Fig. 4-7).

Figure 4-7. A sediment trap receiving large sediment loads directly from a failed water turnout on a forest road in central Virginia. Distance to the road is approximately 3 chains or 200 feet.

Figure 4-8. A sediment trap receiving surface flows from a cutover area and revegetated fireline but not receiving flows directly from any roads in Central Virginia.

It is important to note that the amount of accumulated sediment in the traps, even in the worst scenario, is still relatively minor and not likely indicative of a severe water quality problem as described by the Virginia Silvicultural Water Quality Law (Code of Virginia, § 10.1-1181.2) and is unlikely to pose a danger to aquatic life or public health. Lakel et al. (2008) found that these same treatments did not differ with regard to a host of water quality parameters, including suspended sediment concentrations, turbidity, and total dissolved solids. Water quality was considered to be exceptional in all watersheds studied, and water quality did not change with SMZ width.

Carroll et al. (2004) found that sediment deposition in riparian zones of the Mississippi piedmont was not affected by SMZ or harvest treatment and did not differ by distance from the stream or landscape position. Measured deposition ranged from 0.1 cm to 0.4 cm and no treatments showed a net loss of sediment. It was determined that sediment deposition in riparian areas is an ongoing natural process that is not noticeably impacted by harvesting in general regardless of SMZ treatments. Kiem and Schoenholtz (1999) also found that sediment deposition in the Mississippi Loess Hills region ranged from 0.2 to 2.0 cm over a three-year post-harvest study period. The presence of an SMZ (thinned or not) or the complete lack of an SMZ had no impact on sediment deposition in the riparian areas. It appeared that the maintenance of an SMZ to encourage deposition or decrease erosion was simply unnecessary. It was also determined that distance from the stream had no significant impact on sediment deposition or soil erosion. Both of these studies are very similar to the Virginia study in purpose, design, and result. The most important result is that larger SMZs did not encourage soil erosion or sediment deposition in riparian areas in the southern piedmont following forest harvesting, and SMZ function appeared to be uniform across the SMZ. All three studies together lead one to believe that simply maintaining forest floor integrity regardless of canopy removal encourages a generally adequate level of surface flow filtration and soil protection. Sheridan et al. (1999) also found that forested buffers could be managed for financial gain through commercial thinning and clear-cutting while still maintaining their sediment filtering functions.

Wynn et al. (2000) also monitored water quality in several watersheds in the coastal plain of Virginia and found that BMPs in general worked well to limit total suspended solids

(TSS) in stream water after harvesting and site preparation, but the study did not determine if elevated TSS values in the no-BMP watershed were due to any deficiencies in SMZ maintenance or proper road stabilization. Elevated TSS values in the no-BMP watersheds may have been due to the lack of water control structures on roads and decks.

It is important to note that extending a 25-foot SMZ to 50 feet will increase SMZ acreage by three acres per mile of SMZ (per side of stream), and six acres per mile of SMZ by extending a 50-foot SMZ to 100 feet. This could easily account for as much as 12 acres per mile of SMZ lost to harvest and future production. This also could account for a monetary loss to the landowner or timber buyer in excess of $12,000 at the time of harvest, and that estimate does not consider lost future production due to the loss of manageable acreage (Cubbage 2004, Lakel et al. 2006, Shaffer et al. 1998, Kluender et al. 2000, Shaffer and Aust 1993, LeDoux 2006). This estimate will vary greatly depending upon miles of SMZ in any given harvest block. SMZ width recommendations vary across the South, and it is often suggested that more SMZ is better for soil erosion prevention and water quality maintenance, but the soil erosion data and the accumulated sediment data presented (Tables 4-4 and 4-5, respectively) dispute that contention. The cost of increasing SMZ width is carried by landowners and timber buyers and does not likely improve soil stability or water quality from an erosion and sedimentation standpoint for forestry operations in the Piedmont region of Virginia. Figures 4-7 and 4-8 illustrate the importance of proper road BMPs and the negative influence that runoff from roads can have on soil erosion and sediment deposition. Concentrated surface flows from roads often carry sediment long distances to SMZs (Figure 4-8) where adequate filtration is not likely due to the concentrated nature of flows during storm events.

SMZ Vegetation Characteristics

It is generally accepted that vegetation in SMZs plays a primary role in protecting soil in the SMZ as well as filtering surface water flow and capturing sediment from upland areas that have been or are being harvested (Ward and Trimble 2004). Raindrop interception and the dispersal of associated kinetic energy is known to reduce the detachment of soil particles, thereby reducing the transport of soil particles into streams (Ward and Trimble, 2004). Roughness associated with healthy vegetation and associated detritus is also credited with slowing and storing surface flow, thereby initiating the sediment filtering process.

Crown cover percentage was lowest for the 25-foot stringers (Table 4-6) and may indicate that some selective harvesting took place in these stringers and that the thinned 50- foot SMZs (treatment 3) were not thinned as heavily as BMP guidelines would allow. Overall, overstory crown cover did not vary by treatment except for the stringers and, to a small degree, the thinned treatments. It is also evident that all treatments had a very vigorous understory (herbaceous and shrub layer) and midstory species (large saplings and suppressed pole timber) within them (Table 4-6). All stands seemed to benefit from the harvesting from a new growth standpoint, as very high densities of growth in both categories were observed across all SMZ types. It was predicted that thinned treatment would have significantly higher numbers of understory stems due to the increased sunlight that penetrates thinned stands. However, this was not the case (Fig. 4-9) due to the relatively few trees that were removed from the thinned stands as well as the proximity of a hard edge along all SMZs, which allowed for adequate light penetration and vigorous growth in all treatments.

Table 4-6: Stand vegetation data by treatment for the SMZs in the study in Buckingham County, Virginia. Lower case letters indicate statistical significance at the α = 0.10 level.

	Crown Cover (%)		Understory Density (Stems/ac)		Midstory Density (Stems/ac)	
Treatments	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**
1 – 25 feet stringer	59.1 a	3.64	30,381 a	27,206	6,614 b	678
2 – 50 feet no thin	84.1 b	2.34	21,912 a	22,411	2,465 a	515
3 – 50 feet thinned	70.5 ab	3.64	48,511 a	35,154	4,341 ab	674
4 – 100 feet no thin	80.8 b	3.64	72,881 a	27,568	4,445 ab	678

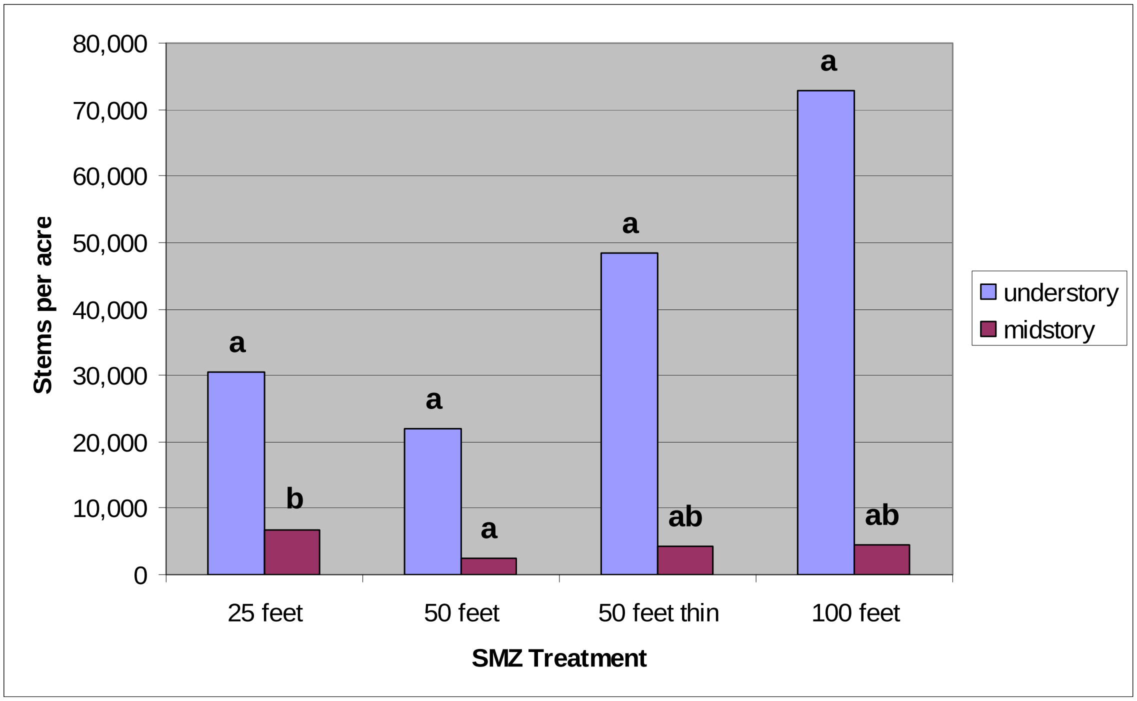

Figure 4-9: Density of both understory and midstory vegetation for all treatments two years after harvest in Buckingham County, Virginia.

This relative uniformity of vegetation density, crown cover percentage, and the aforementioned organic horizon depth is likely responsible for the lack of erosion and water quality differences between treatments. The vigorous nature of the regrowth experienced for all SMZ types was likely very protective and provided adequate filtering capacity for surface runoff, and was also likely responsible for the uptake of significant soil moisture and near-surface groundwater during the growing seasons.

Conclusions

Forest harvesting did not significantly increase soil erosion in these watersheds or in the SMZs with regard to overall surface erosion or concentrated surface flow during the two-year post-harvest period. It is also apparent that SMZ width did not impact soil loss or accumulation in these riparian areas. Wider SMZs were not superior with respect to soil erosion or sediment deposition, and narrower SMZs were just as effective at holding soil in place. The data also support thinning within SMZs as an appropriate timber management tool, since the practice did not create an erosion hazard or sediment source likely to pollute the streams.

With regard to sediment, the statement “more is better” is not likely true with regard to forestry SMZs in the southern piedmont, and SMZ width and thinning recommendations should be examined across the South. It is often mandated that larger SMZs be left when harvesting timber near sensitive waters such as cold water fisheries and public water supplies, but there is not generally a solid scientific basis for that requirement in many situations. It is important that current and future SMZ recommendations involve a more in-depth cost-benefit analysis, as the expense to landowners and timber buyers can be significant and water quality gains are not assured.

These findings are not intended to discourage the use of BMPs in general but to reconsider SMZ function as a sediment barrier or filter and consider that forest harvesting in general, even in riparian areas, is not a particularly large source of sediment reaching streams until forest road impacts are considered. It is also important to remember that swift recovery of harvested sites, especially in riparian areas, is likely to encourage control of sediment from silvicultural activities. Future research regarding SMZ function should concentrate on areas of surface water concentration and flow such as ephemeral drains, road turnouts or ditches, established gullies, and firelines, as these are the areas where SMZ failures are likely to occur and sediment is most likely to reach stream channels.

Chapter 6: Stream Channel Stability in Headwater Drainages in the Virginia Piedmont as Impacted by Commercial Timber Harvesting and Streamside Management Zones

Abstract

The major study objectives include determining if a 50-foot streamside management zone (SMZ) as described in the Virginia BMP Manual (VDOF 2002) is generally sufficient to protect stream water quality, riparian soils, and stream bank integrity in headwater streams where forest harvesting has taken place, as well as comparing other SMZ widths with regard to the same environmental protection performance. Forested SMZs are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations and enhancement of in-stream and riparian habitat. In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four SMZ treatments were installed across four experimental blocks during harvest. Each of the 16 watersheds were subsequently site-prepared with prescribed burning and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the established treatments were a 100-foot width with no thinning, a 50-foot width without thinning, a 50-foot width with thinning, and a 25-foot "stringer." Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). Each of the four treatments was replicated at least three times in an incomplete block design. During the first year after harvest, 12 stream channels were profiled using standard differential leveling techniques. After a two-year post-harvest monitoring period, the same cross-sections were re-evaluated and it was determined that SMZ treatments, and timber harvesting in general, had no significant effect on stream channel cross-sectional area, width/depth ratio, or stream channel geometry.

Introduction

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations and enhancement of in-stream and riparian habitat (Castelle et al. 1994, Blinn and Kilgore 2001, Virginia Department of Forestry 2002, Georgia Forestry Commission 2005 North Carolina Department of Forest Resources 2006, United States Environmental Protection Agency 2007). It is widely accepted that SMZs positively affect stream channel and bank stability in and around headwater streams where forestland management activities often occur, but little research has been done to determine how wide SMZs should be and if thinning is acceptable within SMZs from a stream channel stability standpoint. Forestry Best Management Practices (BMP) guidelines vary across the South with regard to riparian management and SMZ specifications. However, most research on forestry riparian areas has not been on true headwater streams but has commonly focused on larger streams, and widespread interest in headwater streams is quite recent (MacDonald and Coe 2007).

It is important to collect data in order to refine SMZ guidelines because the cost of leaving timber along streams can be substantial for landowners and timber buyers (Shaffer et al. 1998, Kluender et al. 2000, Cubbage 2004, Lakel et al. 2006). It is also probable that total maximum daily loads (TMDLs) for sediment will be established in the Chesapeake Bay watershed in the near future, and forestry operations and BMPs in this region could be affected. It is imperative that the contribution of intensive forestry operations to stream bank erosion and stream channel changes in headwater streams in the Chesapeake Bay watershed and the southern piedmont in general be quantified in order to allow informed decisions with regard to future regulatory and management policy changes.

Stream bank erosion and associated changes in channel processes from forestry operations are important because associated sediment can kill fish and other organisms directly and prevent successful reproduction by covering spawning habitat with silt. Resulting increases in turbidity can reduce photosynthesis by aquatic plants further degrading habitat. Fish species requiring clear water might perish or migrate, and fish species more tolerant of turbid water and muddy channels will dominate (Duda 1985). Fine sediment particles often damage gills of fish and organisms that fish feed on. The fine sediments often transport adsorbed pollutants such as pesticides, plant nutrients, and trace metals. Organic forms of mercury are often adsorbed to soil particles and can later be converted to an inorganic form by bacteria which can then accumulate in living tissues (Oschwald 1972). Long-term degradation and sedimentation can drastically alter stream characteristics and alter entire ecosystems permanently (Duda 1985, USEPA 2000).

Economic impacts of increased nonpoint source pollutant inputs are not as obvious or visible but are equally large. Costs originate from multiple problems, including increased flood damage, fish stocking, restoration of damaged waterways, cleaning of ditches, dam building, and loss of recreational activities, commercial fishery degradation, regulatory program needs, and research and development of abatement and prevention methods (Stall 1972, Duda 1985, Colacicco et al. 1989, Ribaudo and Young 1989). The USEPA has identified sediment as the second largest impairment of river miles in the U.S. (Fig. 5-1) (USEPA 2000).

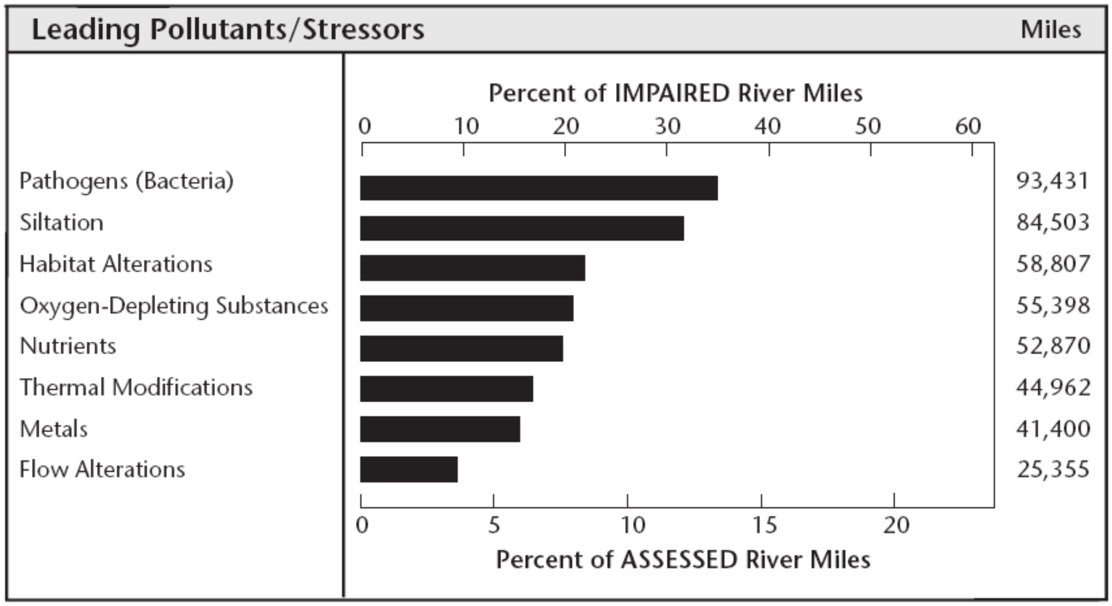

Figure 5-1: Leading water pollutants in streams surveyed in the U.S. for the 2000 National Water Quality Report. (Adapted from USEPA 2000).

Study Area and Site Descriptions

The study watersheds are located in and around Buckingham County in central Virginia ($37^o32'57''$ N latitude, $78^o43'28''$ W longitude). This area is the western part of the piedmont plateau directly east of the Blue Ridge Mountains and approximately 110 miles west of the Chesapeake Bay (Fig. 5-2). The James River flows west to east through the central piedmont approximately 10 miles to the north of the study area. The typical elevation of the surrounding area ranges from 500 ft to 1200 ft above mean sea level. Average January maximum and minimum temperatures are 8.3^oC (46.9^oF) and -2.8^oC (27.0^oF), respectively. Average July maximum and minimum temperatures are 30.3^oC (86.5^oF) and 18.0^oC (64.4^oF), respectively (USDA 2004).

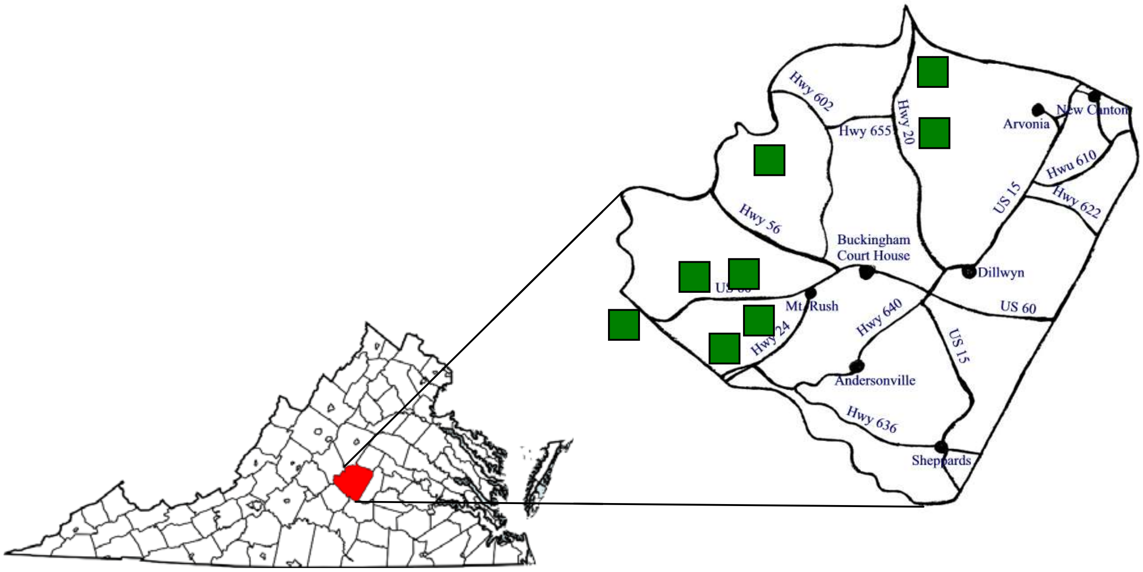

Figure 5-2: Approximate locations of study areas in green in and around Buckingham County, Virginia.

Soils are typically highly eroded, often-shallow ultisols with argillic horizons overlain by shallow Ap horizons. Due to past agricultural abuse and related soil erosion, very little organic matter remains in the Ap horizon and eluvial E horizons are generally minor or absent. Soil textures are generally clay to clay loam with significant coarse fragments (USDA 2004). Common upland soil series include Spears Mountain silt loam (fine, mixed, semiactive, mesic, typic, hapludults), Fairystone channery loam (clayey-skeletal, parasesquic, mesic, typic, hapludults), and Bugley channery silt loam (loamy-skeletal, mixed, semiactive, mesic, lithic, dystrudepts). Common bottomland soils include Hatboro loam (fine-loamy, mixed, active, nonacid, mesic, fluvaquentic, endoaquepts), and Delanco gravelly loam (fine-skeletal, mixed, semiactive, mesic, aquic, hapludults).

Past land use in this area was dominated by intensive agricultural practices from the mid-1700s to the late 1800s. Most of the southern piedmont's farmland was highly degraded due to agricultural erosion and consequently abandoned (Van Lear et al. 2004). The subsequent upland natural pine and hardwood forests were dominated by various oak species (*Quercus spp*.), red maple (*Acer rubrum*), sweet gum (*Liquidamber styraciflua*), hickory (*Carya spp*.), Virginia pine (*Pinus virginiana*), and shortleaf pine (*P. echinata*). Bottomlands were dominated by red maple, river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), elm (*Ulmus spp*.), alder (*Alnus rugosus*), black willow (*Salix nigra*), and yellow poplar (*Liriodendron tulipifera*) (Gemborys 1974). Many of these second-growth forests were subsequently harvested at least once during the 1900s, and many areas were replanted with loblolly pine (*P. taeda*), which is not native to the Virginia piedmont in general (Schultz 1997). Loblolly pine, a coastal plain native, has performed well overall in plantations east of the Blue Ridge and has become a major part of forested ecosystems in the piedmont.

Watershed Treatments and Study Layout

Beginning in 2001, 16 first-order streams/riparian areas and associated forested watersheds on MeadWestvaco timberlands were monitored for baseline data prior to treatment installation, but little stream water data were obtained due to three years of severe drought in the region. Four treatments were installed across four blocks during 2003-2004. Each of 16 watersheds was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine. Within the watersheds, the streamside management zone treatments were established on each side of the stream channel as a 25-foot "stringer" (treatment 1), a 50-foot width with no thinning (treatment 2), a 50-foot width with 30% to 50% basal area thinning (treatment 3), and a 100-foot width with no thinning (treatment 4) . Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). The study watersheds were blocked according to local geology and watershed size (Table 5-1).

Table 5-1: Organization of watersheds, blocks, and treatments and associated information relating to the study layout and data analysis for the SMZ study in central Virginia.

Watershed Name	County	Block #	Trt #	SMZ Treatment	Acres
Gunstock 1	Buckingham	1	3	50 ft-thinned	20
Gunstock 3	Buckingham	1	4	100 ft-not thinned	29
Irons-North	Buckingham	2	2	50 ft-not thinned	36
Irons 1	Buckingham	2	1	25 ft-not thinned	19
Irons 2	Buckingham	2	3	50 ft-thinned	31
Fisher-North	Buckingham	2	4	100 ft-not thinned	10
Doe 1	Buckingham	3	3	50 ft-thinned	103
Doe 2	Buckingham	3	1	25 ft-not thinned	178
G-Union Camp	Buckingham	3	2	50 ft-not thinned	112
Breezy Bee	Nelson	3	2	50 ft-not thinned	174
Baird-Payne	Buckingham	4	1	25 ft-not thinned	130
Miller	Buckingham	4	4	100 ft-not thinned	77

To evaluate stream channel cross-sections, 12 of the lowest stream channel cross-sections (Figure 5-3) were measured using standard differential leveling techniques immediately after harvesting and again two years later (Harrelson et. al. 1994). Measurement points were located at variable distances across the transect and were targeted to important morphological areas that defined the channel. All 16 watersheds were not included in the analysis due to the time and labor requirements involved in the field. It was guaranteed through the selection process that all treatments were replicated three times. A combination of Microsoft® Excel^{TM} and WinXSpro Version 3 as developed by the USDA Forest Service were used to plot stream channel cross-sections and calculate channel parameters.

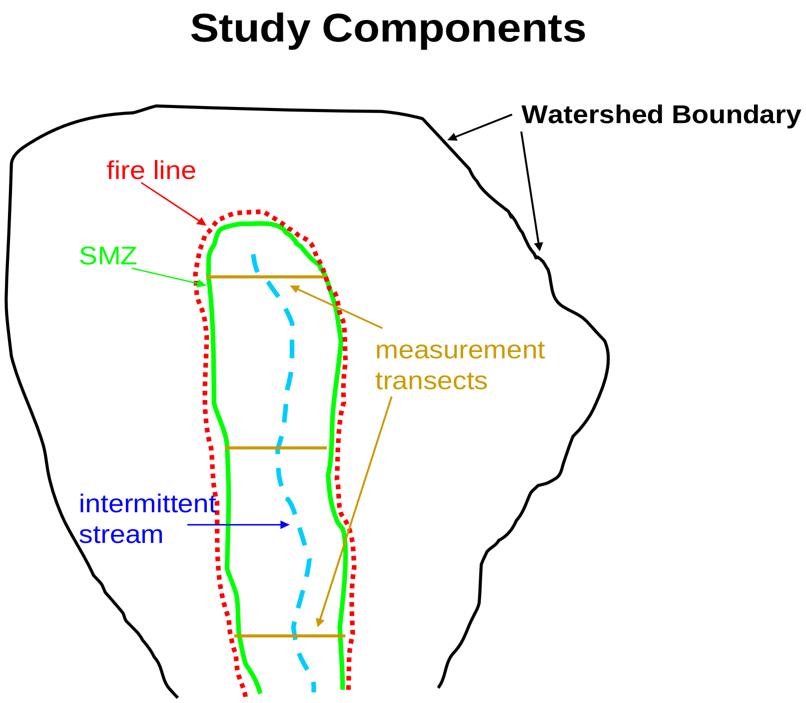

Figure 5-3: Representation of a typical study watershed with approximate location of SMZ boundaries, firelines, stream, and measurement transects for the SMZ study in Central Virginia. All stream cross section measurements were taken at the lowest of the three measurement transects.

All data were analyzed using a combination of Excel™ spreadsheets and The SAS™ System. The Tukey-Kramer adjusted mean separation test was used to determine significance between treatment means. The watersheds and treatments were organized in an incomplete block design (Table 5-2) as follows and each treatment had at least three replicates.

Table 5-2: The generalized model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments.

Source	Degrees of Freedom	
Treatment	(t-1)	3
Block	(b-1)	3
Error a	(t-1)(b-1)	9
Total (Corrected)		15

Results and Discussion

The 12 streams along with their measured reference conditions (2005) are listed in Table 5-3. The data show that these streams are typical of southern piedmont streams impacted by agriculture and forestry operations over time. The values reported below compare favorably to rural streams in the piedmont of North Carolina reported by Doll et al. (2002). These cross-sectional area and average depth values are also lower in general than those values reported by Doll et al. (2002) for urban streams with high percentages of watershed acreage in impervious surface. In general, average channel depths did not exceed 2 feet and the width/depth ratio ranged from 8.30 to 52.05. Cross-sectional area at the time of harvest (2005) was as low as 6.04 ft^2 and as high as 32.94 ft^2. The initial Gini coefficients are very small and indicate that all stream channels exhibit a wide and flat geometry. This basic channel shape indicates that peak flows are not likely high enough to initiate severe down-cutting of the channels on a regular basis.

Table 5-3: Reference conditions measured in 2005 immediately after timber harvest for the 12 streams that were monitored and re-measured in 2007 for the SMZ study in central Virginia.

Watershed Name	SMZ Treatment	Cross-Sectional Area (ft^2)	Average Depth (ft)	W/D Ratio	Gini Coefficient
Gunstock 1	50 ft-thinned	30.58	1.9	8.55	0.00140
Gunstock 3	100 ft-not thinned	18.6	1.1	15.21	0.00044
Irons-North	50 ft-not thinned	13.06	0.8	20.69	0.00030
Irons 1	25 ft-not thinned	6.04	0.3	52.05	0.00074
Irons 2	50 ft-thinned	13.28	1.2	9.08	0.00044
Fisher-North	100 ft-not thinned	10.77	0.8	15.55	0.00067
Doe 1	50 ft-thinned	32.94	1.8	10.39	0.00080
Doe 2	25 ft-not thinned	7.05	0.5	26.82	0.00075
G-Union Camp	50 ft-not thinned	17.12	1.4	8.30	0.00099
Breezy Bee	50 ft-not thinned	17.96	1.3	10.15	0.00120
Baird-Payne	25 ft-not thinned	8.75	0.8	12.94	0.00053
Miller	100 ft-not thinned	19.38	1.1	15.60	0.00098

It is generally accepted that forest harvesting often increases water yields to stream channels for one to five years following harvest, but yields will usually return to pre-harvest levels (or less) as the site is re-occupied by vegetation (Douglas et al. 1980, Hewlett and Doss 1984, Hornbeck et al. 1997, Kochenderfer et al. 1997, Lowrance et al. 1997, Oklahoma Cooperative Extension Service 1984, Swank and Crossley 1988). It is unlikely that occasional forest harvesting would lead to further degradation of stream channels that already have an extensive history of agricultural land use. The Gini coefficient also indicates that all of these streams exhibit very “wide and flat channels” (Olson-Rutz et al. 1992), as indicated by Gini values approaching zero. This is in agreement with the large measured width/depth (W/D) ratios reported in Table 5-3.

The data collected two years after harvest (2007) do not indicate that clear-cut harvesting had a major impact on stream channel geometry with respect to cross-sectional area, W/D ratio, or the Gini Coefficient (Table 5-4) with respect to any of the SMZ treatments. The mean change values in all categories are quite low and unaffected by SMZ treatment.

Table 5-4: Post-harvest means by SMZ treatment for changes in the parameters of interest over the two-year monitoring period 2005 to 2007. Lower case letters indicate statistical significance at the α = 0.10 level.

	Cross-Sectional Area Change (%)		**W/D Ratio Change**		**Gini Coefficient Change**	
Treatments	**Mean**	**Std Error**	**Mean**	**Std Error**	**Mean**	**Std Error**
1 – 25 feet stringer	-5.01 a	27.18	-0.048 a	8.31	.00005 a	.0002
2 – 50 feet no thin	7.74 a	30.94	1.936 a	9.45	.00023 a	.0002
3 – 50 feet thinned	1.19 a	27.18	-2.078 a	8.31	.00004 a	.0002
4 – 100 feet no thin	-3.23 a	26.74	-1.797 a	8.17	-.00010 a	.0002

A negative cross-sectional area percentage indicates that the cross-section in 2007 was smaller than in 2005, which might indicate that new sediment aggradations are present in the second measurement. A positive cross-sectional area percentage generally indicates that some channel and/or bank degradation has occurred in the two years after harvest. A negative W/D ratio change value also indicates that the ratio is larger in the post-harvest (2007) measurement, indicating a slight decrease in channel depth. The inverse is also true for positive W/D values. Positive Gini differences indicate the channel is becoming deeper and narrower over time, and negative differences indicate that the channel is becoming shallower and wider (Olson-Rutz et al. 1992).

Figure 5-4 is an example of a stream cross-section from this study that did exhibit an increase in channel cross-sectional area and depth, while Figure 5-5 is an example of a stream cross-section that exhibited a decrease in cross sectional area and illustrates the Gini value approaching zero as well as a high W/D ratio. It is likely that the situation in

Figure 5-4 shows channel down-cutting as well as stream bank erosion due to high storm flows. It is also likely that Figure 5-5 shows a situation where the poorly defined stream channel is experiencing sediment deposition and bedload aggradations from higher in the watershed. Field evidence suggested that this situation was exacerbated by an old, unstable erosion gully receiving road runoff from a failed ditch and depositing large amounts of material in the SMZ.

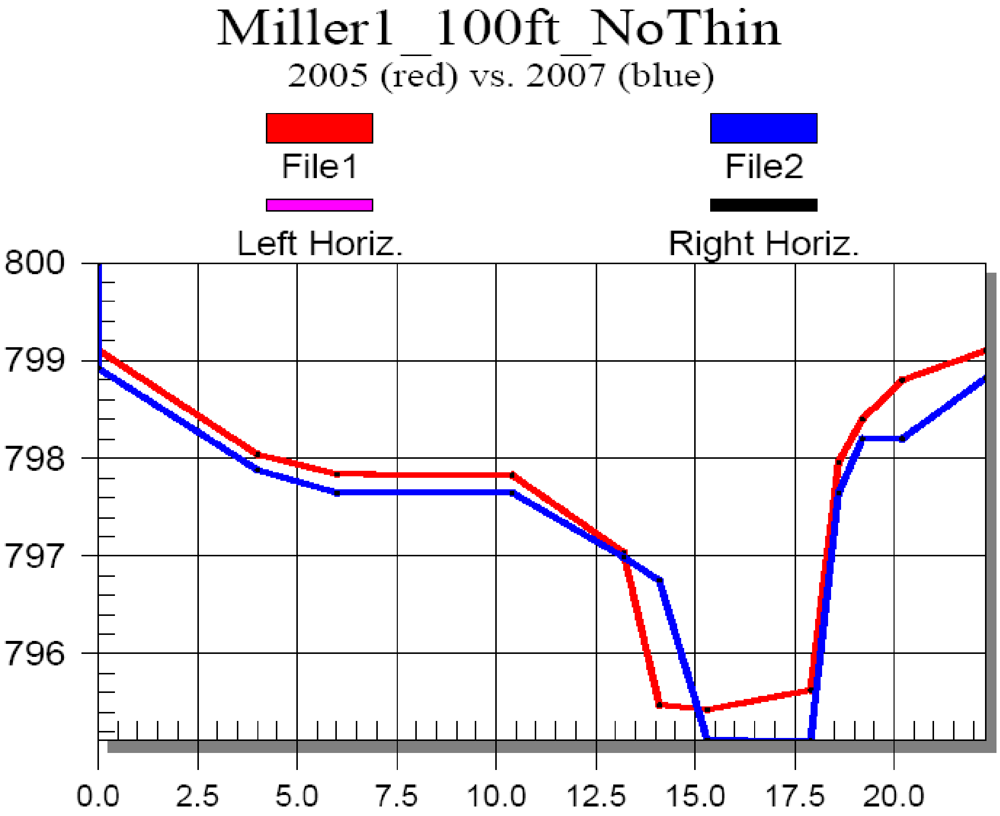

Figure 5-4. A representative plot showing a perennial stream channel cross-section with some post-harvest increase in channel depth for the SMZ study in central Virginia. Units are feet.

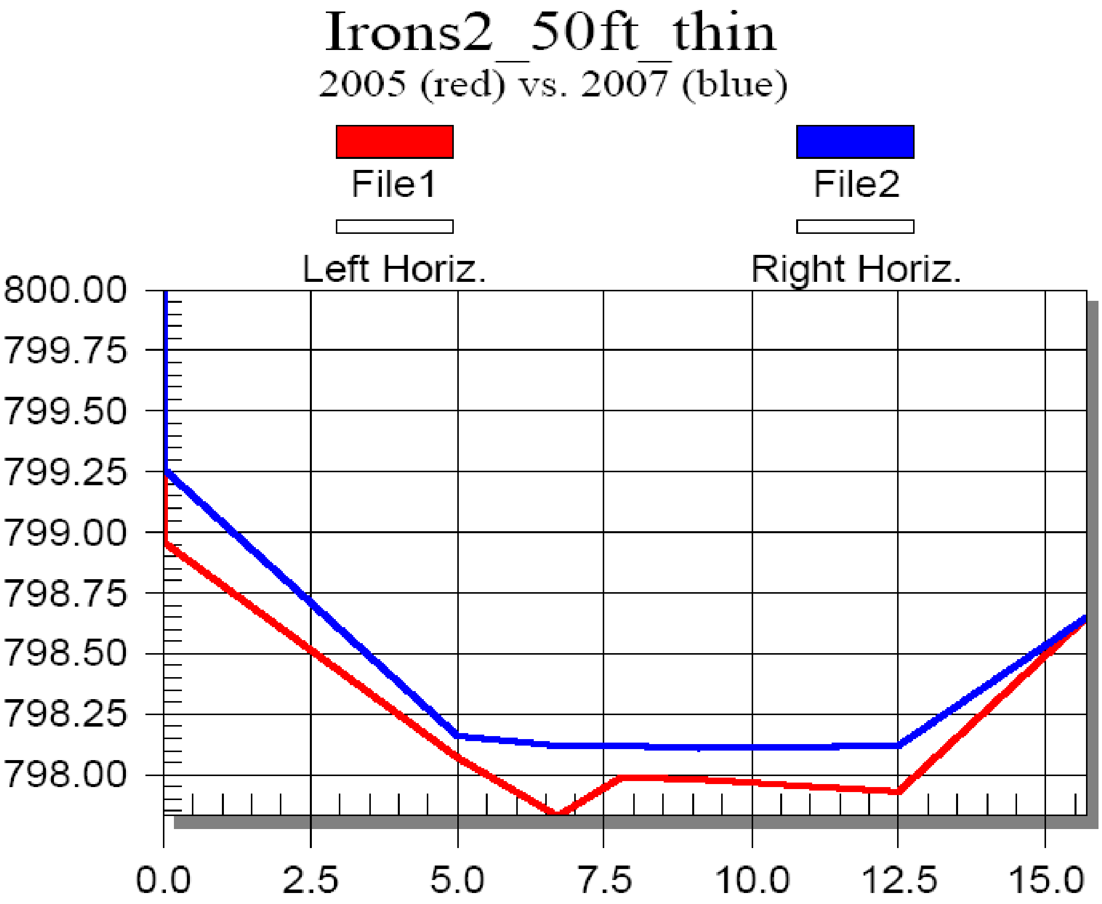

Figure 5-5. A representative plot showing an intermittent stream channel cross-section with some post-harvest decrease in channel depth and cross sectional area in central Virginia. Units are feet.

Variability is quite high between stream cross-section changes over the two-year post-harvest period (Table 5-4), and results were not affected by the width of the SMZ left along the streams or whether or not tree thinning was practiced in the SMZ as part of the commercial harvest operation. With this data in mind, it is difficult to conclude that SMZ width is important for protecting stream channel stability in the short term following commercial timber harvests in the piedmont of Virginia. It is also unlikely that the thinning of SMZs creates any additional risk. The first two years would likely witness the most increases in water yield from the harvested watersheds to the stream channels (Douglas et al. 1980, Hewlett and Doss 1984, Hornbeck et al., Swank and Crossley 1988, 1997, Kochenderfer et al. 1997, Lowrance et al. 1997, Oklahoma Cooperative Extension Service 1984), and that is the time period in which stream channel and bank changes would likely be most severe.

Conclusions

The data indicate that SMZ width and commercial thinning within SMZs had no apparent impact on stream channel stability or shape during the first two years following clear-cut timber harvesting of the surrounding uplands. This indicates that landowners would not likely realize benefits to stream channel stability if they elect to leave SMZs in excess of 25 feet on each side of their streams in the southern piedmont. It is also clear that these streams in rural forested watersheds do not exhibit the type of channel geometry that other studies have recorded in the piedmont in urban watersheds with moderate to high levels of impervious surface. These streams exhibit high width/depth ratios and very low Gini coefficients, which indicate wide and shallow channels. The apparent maintenance of these conditions might indicate that continued management of these headwater watersheds for timber production is perhaps the best and most practical land use from a hydrologic standpoint. It also indicates that continued management of timber on these sites is unlikely to cause increased stream channel instability unless management practices become more intensive with regard to road construction, mechanical site preparation, and soil exposure. Maintenance of the organic soil horizons as well as moderate levels of slash residue is important for the maintenance of adequate water infiltration and storage on site.

Chapter 7: Timber Management Opportunities within Streamside Management Zones in the Virginia Piedmont

Abstract

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, stream channel stabilizations and enhancement of in-stream and riparian habitat. In 2003, 16 forested watersheds were clear-cut harvested for commercial timber production. Four SMZ treatments were installed across four experimental blocks during harvest. Each of the 16 watersheds was subsequently site-prepared with prescribed burning and planted with loblolly pine (*Pinus taeda*). Within the watersheds, the established treatments were a 100-foot width with no thinning, a 50-foot width without thinning, a 50-foot width with thinning, and a 25-foot "stringer". Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). It is important to quantify the value of timber left in SMZs and the associated economic impact on landowners as well as to determine if future management of these SMZs is economically and operationally feasible. It was determined that very little value was left in the SMZs in many cases, and future selective cuttings would likely lead to a prevalence of low-value shade-intolerants in the long term.

Introduction

Forested streamside management zones (SMZs) are widely recommended for the protection of water quality from sedimentation, nutrient inputs, thermal pollution, and stream channel instability, and for enhancement of in-stream and riparian habitat (Castelle et al. 1994, Blinn and Kilgore 2001, VDOF 2002, GFC 2005, NCDFR 2006, USEPA 2007). It is widely accepted that SMZs positively affect soil erosion, sediment deposition, and water quality in and around headwater streams where forestland management activities often occur; however, little research has been done to determine the most effective and efficient widths of SMZs and to examine the implications of SMZ maintenance for forest landowners. Forestry Best Management Practices (BMP) guidelines vary across the eastern United States with regard to riparian management and SMZ specifications. However, most research on forestry riparian areas has not focused on headwater streams but has commonly been conducted on larger streams, and widespread interest in headwater streams is quite recent (MacDonald and Coe 2007). Lakel et al. (2008) determined that SMZ width or thinning in SMZs had no impact on soil erosion and sediment deposition in managed riparian buffers and also had no impact on water quality in streams. It was clear that narrower SMZs (25 ft) were just as effective as wider SMZs (50 and 100 ft) at protecting water quality, and thinning within SMZs had no detrimental impact either.

The costs of leaving timber along streams can be substantial for landowners and timber buyers (Shaffer et al. 1998, Kluender et al. 2000, Cubbage 2004, Lakel et al. 2006,). Therefore, it is imperative that management options for SMZs be considered, since a significant amount of acreage and timber volume is withheld from normal management and research has shown that management of SMZs is generally acceptable from a water quality standpoint (Kiem and Schoenholtz 1999, Sheridan et al. 1999, Carroll et al. 2004, Lakel et al. 2008).

Study Area and Site Descriptions

The study watersheds are located in and around Buckingham County in central Virginia (37^{o}32’57” N latitude, 78^{o}43’28” W longitude). This area is the western part of the piedmont plateau directly east of the Blue Ridge Mountains and approximately 110 miles west of the Chesapeake Bay (Fig. 6-1). The James River flows west to east through the central piedmont approximately 10 miles to the north of the study area. The typical elevation of the surrounding area ranges from 500 to 1200 ft above mean sea level. Average January maximum and minimum temperatures are 8.3^{o}C (46.9^{o}F) and -2.8^{o}C (27.0^{o}F), respectively. Average July maximum and minimum temperatures are 30.3^{o}C (86.5^{o}F) and 18.0^{o}C (64.4^{o}F), respectively (USDA 2004).

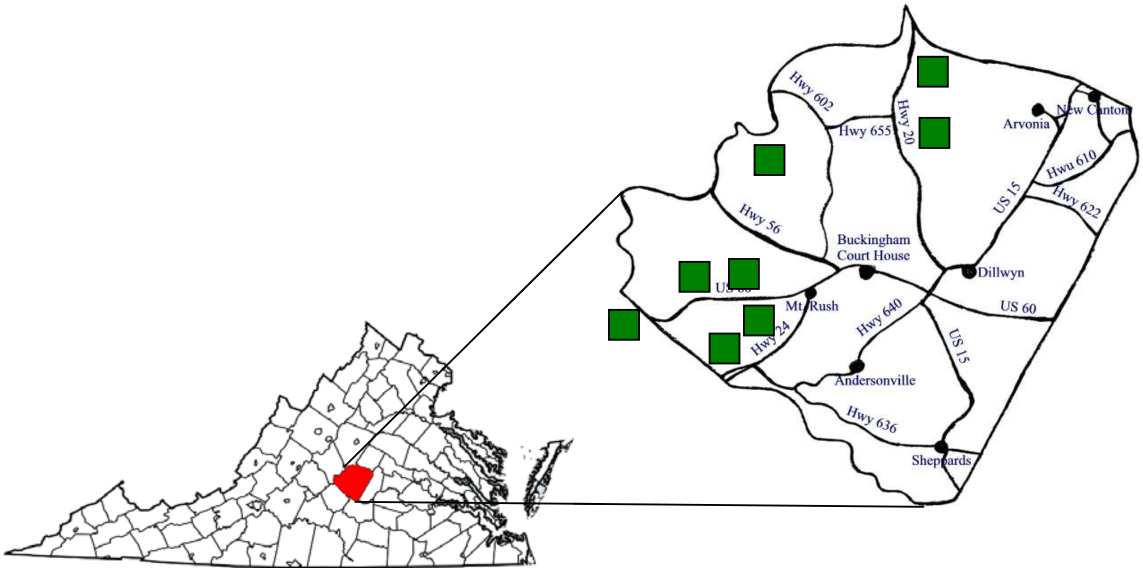

Figure 6-1: Approximate locations of study areas in green in and around Buckingham County Virginia.

Soils are typically highly eroded, often-shallow ultisols with argillic horizons overlain by shallow Ap horizons. Due to past agricultural abuse and related soil erosion, very little organic matter remains in the Ap horizon and eluvial E horizons are generally minor or absent. Soil textures are generally clay to clay loam with significant coarse fragments (USDA 2004). Common upland soil series include Spears Mountain silt loam (fine, mixed, semiactive, mesic, typic, hapludults), Fairystone channery loam (clayey-skeletal, parasesquic, mesic, typic, hapludults), and Bugley channery silt loam (loamy-skeletal, mixed, semiactive, mesic, lithic, dystrudepts). Common bottomland soils include Hatboro loam (fine-loamy, mixed, active, nonacid, mesic, fluvaquentic, endoaquepts), and Delanco gravelly loam (fine-skeletal, mixed, semiactive, mesic, aquic, hapludults).

Past land use in this area was dominated by intensive agricultural practices from the mid-1700s to the late 1800s. Most of the southern piedmont's farmland was highly degraded due to agricultural erosion and consequently abandoned (Van Lear et al. 2004). The subsequent upland natural pine and hardwood forests were dominated by various oak species (*Quercus spp*.), red maple (*Acer rubrum),* hickories (*Carya spp*.), Virginia pine (*Pinus virginiana*), and shortleaf pine (*P. echinata*). Bottomlands were dominated by red maple, river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), elms (*Ulmus spp*.), alder (*Alnus rugosus*), black willow (*Salix nigra*) and yellow poplar (*Liriodendron tulipifera*) (Gemborys 1974). Many of these second-growth forests were subsequently harvested at least once during the 1900s, and many areas were replanted with loblolly pine (*P. taeda*), which is not native to the Virginia piedmont in general (Schultz 1997). Loblolly pine, a coastal plain native, has performed well overall in plantations east of the Blue Ridge and has become a major part of forested ecosystems in the piedmont.

Watershed Treatments and Study Layout

Beginning in 2001, 16 first-order streams/riparian areas and associated forested watersheds on MeadWestvaco timberlands were monitored for baseline data prior to treatment installation, but little stream water data were obtained due to three years of severe drought in the region (Easterbrook et al. 2003). Four treatments were installed across four blocks during 2003-2004. Each of 16 watersheds was clear-cut harvested, site-prepared with prescribed burning, and planted with loblolly pine. Within the watersheds, the streamside management zone treatments were established on each side of the stream channel as a 25-foot "stringer" (treatment 1), a 50-foot width with no thinning (treatment 2), a 50-foot width with 30% to 50% basal area thinning (treatment 3), and a 100-foot width with no thinning (treatment 4) . Each of the four treatments was conducted within one of four blocks (Incomplete Block Design). The study watersheds were blocked according to local geology and watershed size (Table 6-1).

Table 6-1: Organization of watersheds, blocks, and treatments and associated information relating to the study layout and data analysis for the SMZ study in central Virginia.

Watershed Name	County	Block #	Trt #	SMZ Treatment	Acres	Mean Acres per Block
Gunstock 1	Buckingham	1	3	50 ft-thinned	20	20
Gunstock 2	Buckingham	1	2	50 ft-not thinned	14	
Gunstock 3	Buckingham	1	4	100 ft-not thinned	29	
Gunstock 4	Buckingham	1	2	50 ft-not thinned	16	
Irons-North	Buckingham	2	2	50 ft-not thinned	36	24
Irons 1	Buckingham	2	1	25 ft-not thinned	19	
Irons 2	Buckingham	2	3	50 ft-thinned	31	
Fisher-North	Buckingham	2	4	100 ft-not thinned	10	
Doe 1	Buckingham	3	3	50 ft-thinned	103	142
Doe 2	Buckingham	3	1	25 ft-not thinned	178	
G-Union Camp	Buckingham	3	2	50 ft-not thinned	112	
Breezy Bee	Nelson	3	2	50 ft-not thinned	174	
Baird-Payne	Buckingham	4	1	25 ft-not thinned	130	79
Baird-Payne	Buckingham	4	2	50 ft-not thinned	51	
Miller	Buckingham	4	4	100 ft-not thinned	77	
Miller	Buckingham	4	2	50 ft-not thinned	59	

Data Collection and Analysis

All data were collected on a systematic grid as is typical of most timber inventory operations (Avery and Burkhart 1994). The grid dimensions measured 3 chains by 3 chains with 1/20-acre fixed area plots in order to adequately represent the stands being sampled. At each plot trees were tallied by species and commercial product along with diameter at breast height (dbh) and merchantable height. Storm-damaged timber was also tallied independently.

All data were analyzed using a combination of Excel™ spreadsheets, TwoDog™ cruising software, and The SAS™ System. The Tukey-Kramer adjusted mean separation test was used to determine significance between treatment means and transect means. The watersheds and treatments were organized in an incomplete block design (Table 6-2) and each treatment was replicated at least three times.

Table 6-2: The generalized model used for the analysis of variance procedures for the SMZ study in central Virginia. This is an incomplete block design with four blocks and four treatments.

Source	Degrees of Freedom	
Treatment	(t-1)	3
Block	(b-1)	3
Error a	(t-1)(b-1)	9
Total (Corrected)		15

Results and Discussion

The timber inventory data for the SMZ stands are included in Table 6-3 by SMZ treatment. Pine products included loblolly, Virginia, and shortleaf species, while hardwood products were primarily chestnut oak, white oak, multiple red oak species, and red maple, among others. There were no significant differences among the treatments for any of the categories, and all values are reasonable for lower-grade stands of mixed hardwood and pine on these eroded sites in the upper piedmont of Virginia. In general, these stands are dominated by hardwood products by volume with a significant southern pine component. The commercial thinning performed for treatment 3 was generally light and more of a selective harvest or “high-grade,” targeting only the highest-value trees. The contractors involved were reluctant to thin SMZs heavily, due to environmental concerns and lack of value in the stands. In many cases, the timber was dominated by low-value hardwoods with dense mid- and understories, which made thinning impractical unless larger trees were encountered. Thinning consistency varied greatly among the experimental units, leading to greater variability among units within treatments. The per-acre stand values are relatively low for industrially managed stands, due largely to previous lack of management along streams. Few opportunities existed for wide-scale thinning in many stands, and contractors were forced to pick from the valuable pockets of available timber in the thinned stands. P-values among treatments ranged from 0.80 to 0.96 (Tukey).

Table 6-3: Post-treatment timber volume and value (lsmeans) per acre by SMZ treatment for the SMZ study in Buckingham County, Virginia. Specific data headings include total basal area (BA), total trees per acre (TPA), pine sawtimber (PST), mixed hardwood sawtimber (HST), mixed hardwood pulpwood (HPW), and pine pulpwood (PPW).

Treatment	**BA (ft^2)**	**TPA (#)**	**PST (bd ft)**	**CNS (bd ft)**	**HST (bd ft)**	**HPW (cds)**	**PPW (cds)**	**Value ($)/acre**
1 – 25 feet stringer	84.4 a	164.9 a	427.12 a	177.93 a	3771.03 a	4.62 a	0.41 a	523.79 a
2 – 50 feet no thin	71.0 a	142.3 a	924.45 a	1487.39 a	2320.50 a	5.47 a	2.39 a	635.23 a
3 – 50 feet thinned	56.9 a	116.5 a	248.41 a	533.49 a	3011.75 a	7.43 a	1.00 a	490.22 a
4 – 100 feet control	68.9 a	136.0 a	889.77 a	462.46 a	2875.42 a	6.93 a	2.43 a	597.93 a

There is great variability between stands with regard to value per acre and total stand value (Table 6-4). Per-acre values ranged from less than $100 for stands dominated by smaller hardwood pulpwood to greater than $1,200 for better stands of pine and hardwood sawtimber. Local per-unit prices were developed using a combination of the TimberMart South report and personal contact with local forestry consultants. Prices applied here were $175 per MBF for PST, $100 per MBF for CNS, $15 per cord for PPW, $10.40 per cord for HPW, and $100 per MBF for mixed HST. Overall, HST grade was low to poor, leading to a lower valuation. Mean values for PST are much higher in stands that were not thinned, but the differences were not significant at the $\alpha = .10$ level. This value may show that loggers had a propensity to remove PST where possible and leave lower-grade products behind.

Table 6-4: Acreage and value of SMZ timber stands (means) by treatment for the SMZ study in Buckingham County, Virginia.

Treatment	**Stand Name**	**Acres**	**Value ($/acre)**	**Stand Value ($)**
1 – 25-ft stringer	Irons 1	1.15	498.66	573.46
	Doe 2	1.95	507.97	990.54
	Baird Payne 2	4.78	1010.26	4829.04
2 – 50-ft no thin	Gunstock 2	3.79	123.96	469.80
	Gunstock 4	2.72	55.06	149.76
	Irons-North	2.33	1266.75	2951.52
	G. Union Camp	8.35	647.28	5404.78
	Breezy Bee	4.75	529.6	2515.60
	Baird Payne 1	3.98	767.15	3053.26
	Miller 2	3.23	1023.07	3304.52
3 – 50-ft thinned	Gunstock 1	2.39	158.29	378.13
	Irons 2	2.11	309.53	653.11
	Doe 1	3.87	588.23	2570.57
4 – 100-ft control	Gunstock 3	3.61	239.25	863.69
	Fisher-North	4.37	307.21	1342.51
	Miller 1	6.11	1250.19	7638.66
Project Totals		**59.49**		**37688.95**

These data (Table 6-4) also show that most stands have adequate growing stock to validate future attempts to remove more valuable timber when the next rotation of pine in the adjacent uplands reaches rotation age in approximately 30 years. These removals would likely target ample supplies of oak and yellow poplar along with the remaining pine products, which will be much larger and valuable at that time. This next rotation could potentially remove greater than 50% of the value from all stands if harvesting techniques were to specifically target SMZ timber. This type of management would remove much of the shade-intolerant species over time which are most valuable (oaks, poplar and pine) over the next two rotations (60 years) and would lead to stands dominated by shade-tolerant species (Smith, 1996) such as red maple, American beech (*Fagus grandifolia*), and various hickory species which are shown to be abundant in these stands (Table 6-5). Uneven-aged management such as continuous selective harvests and thinning will undoubtedly increase the shade-tolerant component over time, which generally has low market value and does not lend itself to active management or higher-value product production. This geographic region lacks the capability to produce higher-value shade-tolerant stands as in other regions of the country.

Table 6-5: Overall species composition by trees per acre (TPA) of SMZs in the Buckingham County, Virginia, study.

Product	Species	TPA	Std Error
Sawtimber	loblolly pine	19.74	2.98
	white oak	5.30	1.37
	yellow poplar	4.67	1.98
	chestnut oak	1.70	0.57
	red maple	1.42	0.85
	Virginia pine	0.72	0.53
	red oak	0.68	0.42
	blackgum	0.42	0.42
	ash	0.36	0.26
	hickory	0.23	0.17
	beech	0.16	0.16
Pulpwood	red maple	23.32	2.89
	yellow poplar	21.27	3.68
	loblolly pine	18.69	3.77
	chestnut oak	12.72	2.61
	white oak	10.87	2.18
	Virginia pine	6.16	1.92
	red oak	4.56	0.90
	hickory	2.99	1.26
	American beech	2.97	0.95
	black cherry	1.96	0.92
	blackgum	1.37	0.51
	river birch	0.40	0.40
	white pine	0.23	0.17

A concern among landowners in Virginia with regard to SMZ maintenance, health, and value is the likelihood of these stands to be damaged by storms and pests after the adjacent timber stand is harvested and these narrow strips are exposed to wind, ice, and snow. The upper piedmont of Virginia is frequently impacted by freezing rain and wet snow events in the winter, and significant stand damage does occur. Damage to SMZ stands was recorded and quantified during the timber inventory process (Table 6-6). Seven of the 16 stands received some level of damage.

Table 6-6: Assessment of timber damage due to ice and wind storms in the first two years after harvest for the SMZ study in Buckingham County, Virginia.

Stand (#)	**SMZ Treatment**	**Species Damaged**	**Products Damaged**	**Value ($/ac)**	**Value ($)**	**Value (%)**
5	50 ft no thin	loblolly pine	PST, CNS, PPW	122.19	284.70	22.5
6	25 ft no thin	loblolly pine	PST,CNS,PPW	133.17	153.15	30.7
7	50 ft thinned	loblolly pine	CNS,PPW	46.60	98.12	31.7
8	100 ft no thin	loblolly pine	CNS,PPW	46.50	203.21	66.1
9	50 ft thinned	loblolly pine	CNS	61.40	237.62	40.4
10	25 ft no thin	loblolly pine	CNS	102.70	200.27	39.4
14	50 ft no thin	loblolly pine	PPW	4.50	21.51	2.8

Storm damage was evenly distributed among the different SMZ treatments, and no treatment was immune to damage entirely (Table 6-6). Thinned and narrow stands were not more likely to be damaged, and no treatment was shown to be hardest hit by weather. The only species tallied as storm-damaged was loblolly pine. It is common for loblolly pine to succumb to storm damage in this part of Virginia, due largely to its inability to resist bending, breakage, and throw during periods of ice accumulation (Muntz 1947, Shepard 1975, Amateis and Burkhart 1996, Aubrey et al. 2007). It is important to note that one ice storm did occur in February 2007, which was particularly damaging to pine stands in this part of the country.

Seven out of 16 stands had some damage tallied, and five out of 16 had at least $100 per acre lost to damage. One-fourth of all stands had at least $200 per acre lost. These losses led to some stands losing as much as 66.1% of their remaining value to storm damage, as many of the trees lost were higher-value products (CNS and PST) (Table 6-6). It is also important to note that nine out of 16 stands had no storm damage tallied in the timber cruise for the same post-harvest period, but that period was only two years.

Conclusions

It is clear that SMZ treatments did not have a large impact on per-acre values of the SMZ stands, largely because loggers were only willing to thin stands where higher-value products could be selected, and they also had a preference for pine sawtimber (PST), which was locally scattered. The thinned stands were actually high-graded locally because loggers were generally unwilling to broadcast-thin all stands that did have marginal value. Future commercial removals from these stands is viable as a continued thinning or high-grading scenario along with the period rotational harvesting of the surrounding upland pine stands, but that will eventually lead to dominance of shade-tolerant species such as red maple, American beech, and hickory. These species are already present in large numbers in these stands, especially as pulpwood-sized material. These species lack the markets required to actively manage them, so long-term management of these stands for timber production and value is quite limited.

These findings are the opposite of those of Sharp et al. (2003), who worked in similar SMZ treatments in the Allegheny Plateau region of West Virginia and concluded that desirable species would continue to be present within the SMZ. The major difference is that Sharp was working in northern hardwood stands having a significant sugar maple component. The shade-tolerant sugar maple is far more likely to regenerate following selective harvesting and is much more valuable commercially than the tolerant species in these piedmont study sites.

It is also important to note that the landowner in this scenario gave up 59.49 acres of productive timberland for the maintenance of these SMZs as well as $37,688.95 of immediate income across all 16 stands. That value does not include the thousands of dollars lost for the next rotation of productive pine plantation.

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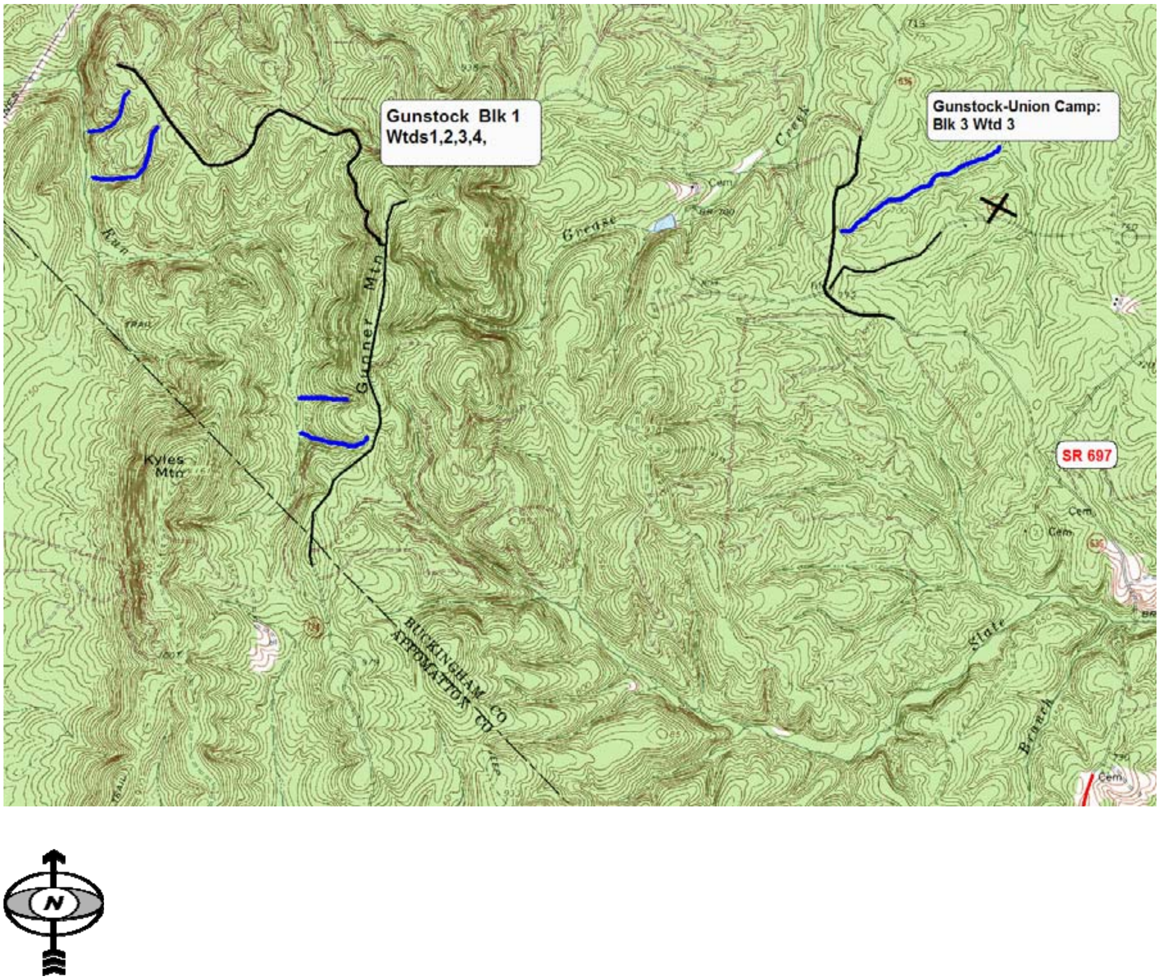
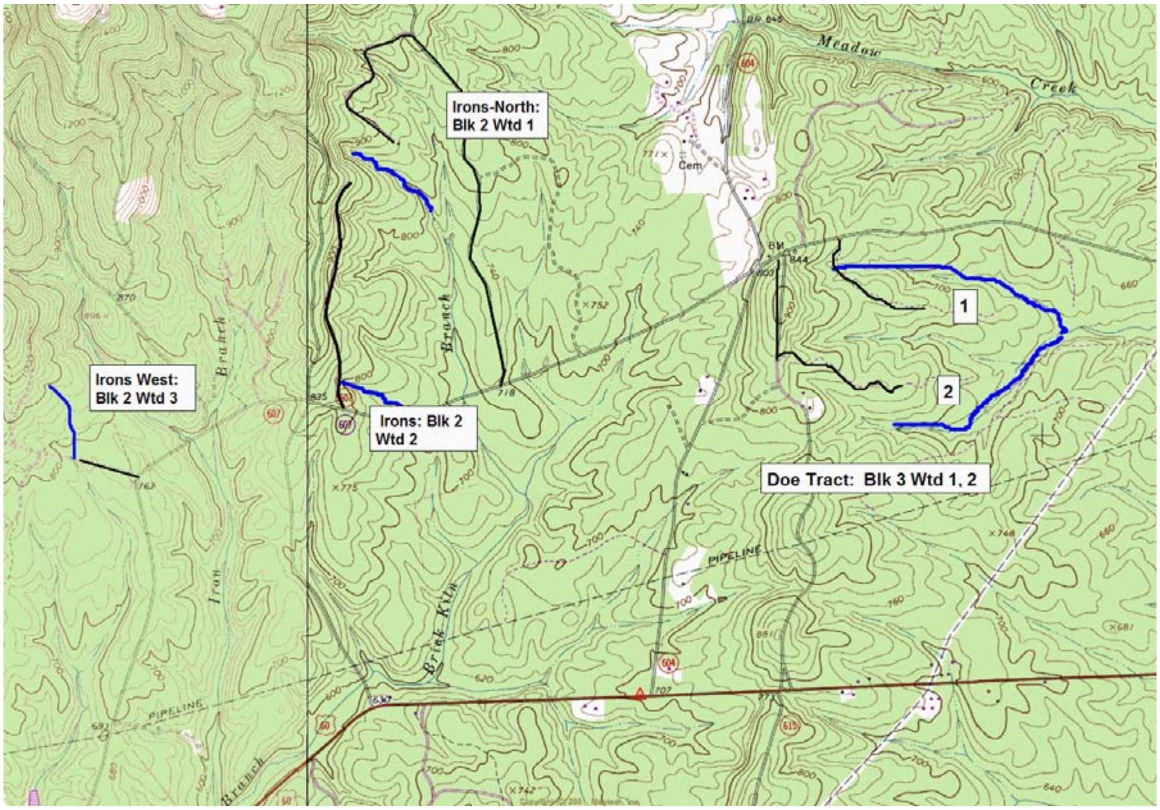
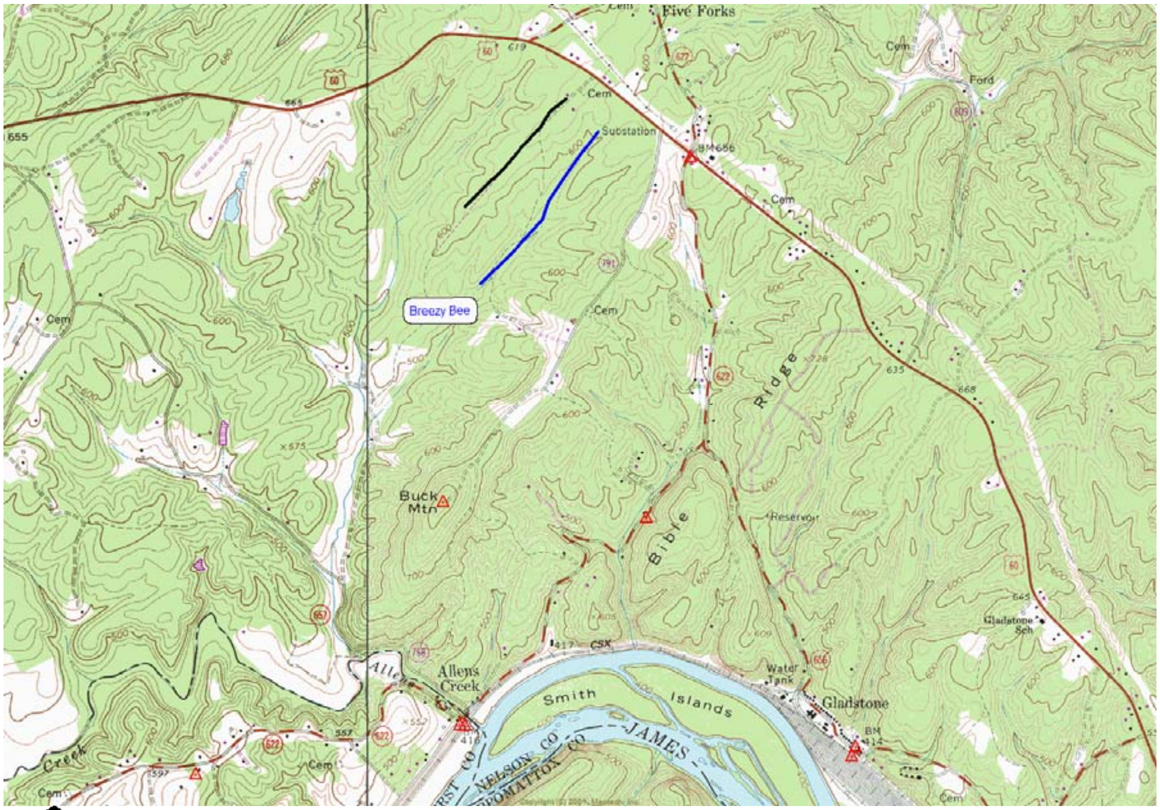
Appendix A: Tract Maps

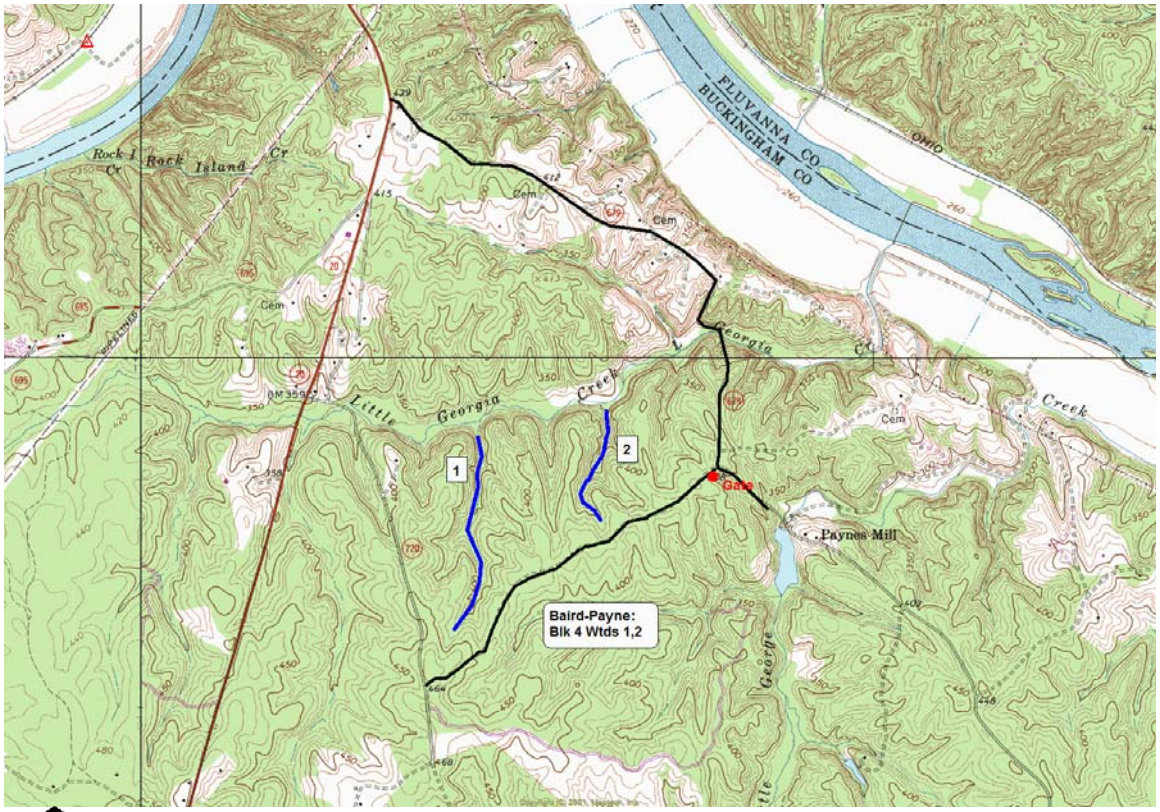
Each map scale is 1:34,265 or 1 inch = 2,855 feet (1.85 inches per mile). Black lines represent haul roads used to access the watersheds and blue lines represent the study stream length in each watershed. North is oriented to the top of each page.

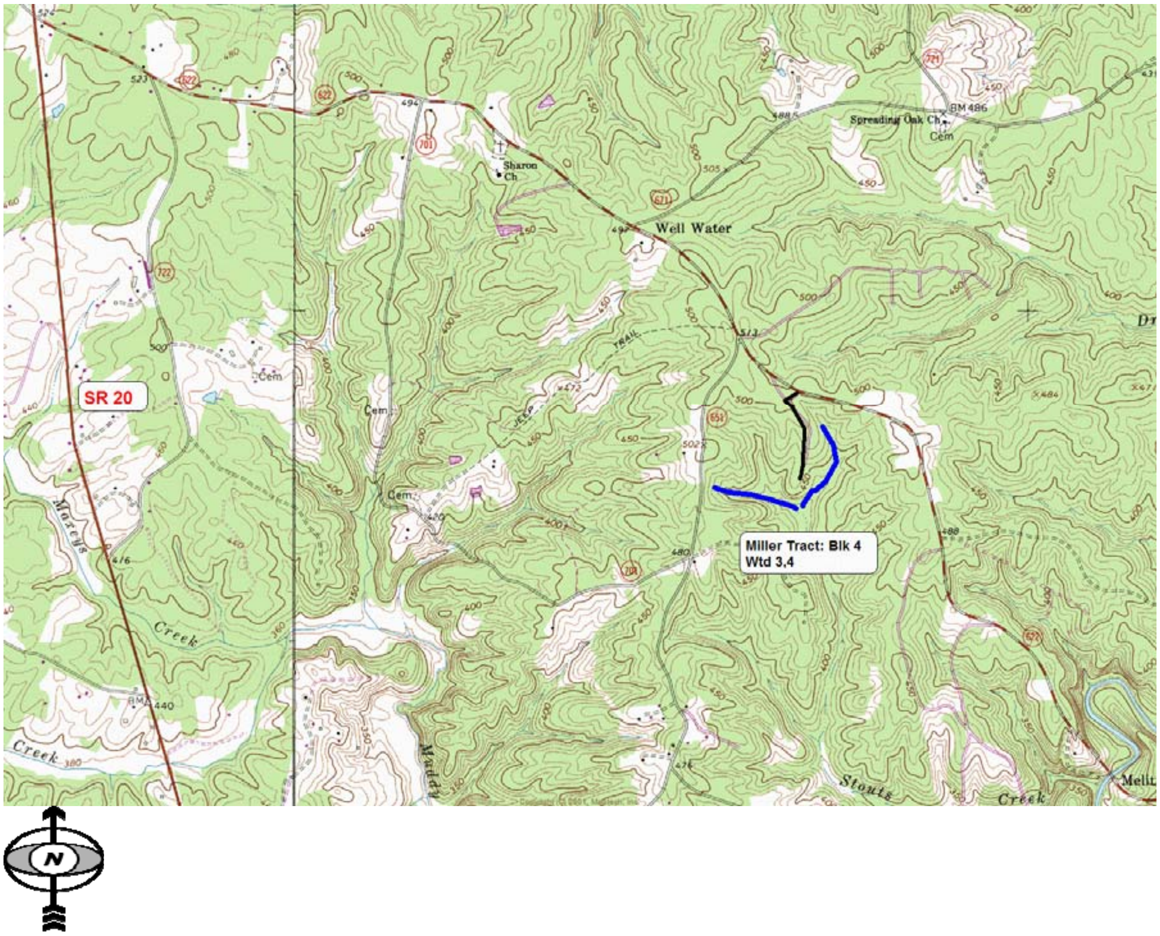



Irons-North:
Blk 2 Wtd 1
Irons West:
Blk 2 Wtd 3
Irons: Blk 2
Wtd 2
1
2
Doe Tract: Blk 3 Wtd 1, 2
Meadow
Creek
Cem
Branch
Iron
Branch
Brick Kiln
PIPELINE


Five Forks
Cem
Substation
Breezy Bee
Ford
Ridge
Buck
Mtn
Bible
Reservoir
Allens
Creek
Smith
Islands
JAMES
NELSON CO
APPOMATTOX CO
CSX
Water
Tank
Gladstone
Gladstone
Sch


Fisher North:
Blk 2 Wtd 4
SR 606
BUCKINGHAM CO
NELSON CO
RIVER
Negro Den Hollow
Alabama
Creek
Cem


FLUVANNA CO
BUCKINGHAM CO
Rock Island Cr
Little Georgia Creek
Georgia Cr
Creek
Cem
1
2
Gate
Paynes Mill
Baird-Payne:
Blk 4 Wtds 1,2


SR 20
Miller Tract: Blk 4
Wtd 3,4
Well Water
Spreading Oak Ch.
Sharon Ch
Cem
JEEP TRAIL
Creek
Muddy
Stouts
Creek
N