OCCURRENCE OF SURFACE RUNOFF FROM GEORGIA PIEDMONT PLANTED AND MATURE FORESTS: THREE CASE STUDIES

by

JOAN V. SCHNEIER

(Under the Direction of C. Rhett Jackson)

ABSTRACT

This study evaluated overland flow exiting two clearcut, bedded, and planted areas plus an uncut reference area. Runoff cups were established at 30 m intervals along the boundary of streamside management zones (SMZs). Absence or presence of runoff was tallied for events exceeding 13 mm and concentrated flow tracks (CFTs) were grab sampled during large storms. Mean runoff cup response was 9.7% from the plantations and 2.2% for the reference. Cup responsiveness and bare ground decreased from the first to the second year after planting. Response frequency was best correlated to rainfall factors "R" from the Revised Universal Soil Loss Equation, total storm depth, and 24-hour and 6-hour maximum intensities. Runoff locations were well distributed and some CFTs fully penetrated the SMZ. Mean plantation concentrations of dissolved nitrates, dissolved phosphates and suspended solids were 2.1, 0.21, 54 mg/L the first year, and 0.1, 0.12, 36 mg/L the second year, respectively.

INDEX WORDS: Overland flow, surface runoff, concentrated flow tracks, forestry water quality, streamside management zones, buffer strips, sediment, nitrates, phosphates

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DEDICATION

Dedicated to:

My parents for their lifelong love of learning and work ethic;

Best of friends, Bill Andrews;

My former employer for redirecting my life;

The taxpayers of the state of Georgia for their continuing support of higher education.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

Timber is one of the leading agricultural crops in all southeastern states and is the highest valued crop in Georgia, covering about 2/3 of the state (Georgia Forestry Commission 2005a). Pine stands compose about 45% of Georgia timberland, with about 290,000 acres harvested and 340,000 acres regenerated annually (Thompson 1998). Favorable prices and higher land taxes for portions of the last 20 years have led to intensified management and shorter rotations by private landowners, timber corporations, and investment companies. For pine, this can include more frequent cutting and more intensive site preparation, both of which affect soil and water resources.

Desire for high timber production has run parallel with increased attention to off-site impacts, especially water quality. Congress mandated decreases for both point and nonpoint sources of pollution in the Clean Water Act of 1972. Land uses, such as forestry, are deemed nonpoint and utilize Best Management Practices (BMPs), a statewide set of operational guidelines, to minimize pollution, rather than numeric targets. However, the Act also established Total Maximum Daily Loads for watersheds classified as “impaired” under section 303(d) (Ice et al. 1997). These regulations, currently being established throughout Georgia, set the maximum amount and types of pollutants that can be handled by a river on a whole watershed basis. Total permissible loads are allocated to both point and nonpoint sources, with regulation and enforcement left to the states, subject to federal oversight. As of 2002, 164, or 13% of Georgia's approved 1223 TMDLs were for sediment (US Environmental Protection Agency 2002).

Streamside management zones (SMZs), also known as riparian, filter, or buffer strips, are at the heart of forestry BMPs. SMZs are intact or only lightly disturbed vegetated corridors between the intensively managed area and the streams. Buffer strips improve water quality by filtering sediments, slowing down surface runoff, increasing water infiltration, trapping nutrients and herbicides, and preventing damage to the stream. Additionally they supply woody debris and litter for fish and aquatic food and shelter, and provide biodiversity and wildlife travel corridors (Ga. EPD and GFC 1999).

Early BMP efforts focused on encouraging adoption by a wide constituency. Performance evaluation came later, resulting in BMP revisions in many states (Blinn and Kilgore 2001). Stream-based studies have found forestry BMPs, including SMZs, effective at reducing non-point pollution from clearcutting and site preparation, when damage to soil and water resources is potentially the highest for the timber rotation. Stream-based studies do not, however, adequately detail the mechanisms or processes by which SMZs or other BMPs perform. Due to the detail and expense involved, few quantitative measurements have been made of transport mechanisms and what is actually reaching the SMZ. In particular there is concern that surface runoff can detach and transport surface sediment and pollutants without filtration through soil. Due to good ground cover and high porosity of topsoils, overland flow rarely occurs in intact forests and has not been well studied. It is more problematic on regenerating forests due to soil disturbance and lack of plant cover, especially in the rolling to steep terrain and erodible soils found in the Piedmont.

A series of process-based SMZ effectiveness studies has been recently conducted at the University of Georgia. The first study quantified and characterized the occurrence of concentrated overland flow on regeneration areas that passed through SMZs and entered streams on 30 Piedmont sites (Rivenbark and Jackson 2004). The second evaluated the efficiency of SMZs in reducing sediment delivery to streams from these concentrated flows on two sites (Ward and Jackson 2004), and the third study used artificial runoff experiments to determine SMZ effectiveness in settling and sorbing clay, phosphorus (White 2003) and herbicides (de Pinho 2003) for dispersed flow.

This descriptive research evaluated the following hypotheses:

1) Overland flow occurs on forested site prepared and newly planted areas.
2) The occurrence of overland flow can be related to precipitation intensity and depth.

An associated goal of this research was to measure concentrations of major nutrients (nitrates and phosphates) and sediment in overland flow from newly regenerated areas.

No other studies were found addressing frequency of dispersed overland flow in the US during the literature search. However, two studies compared frequency of overland flow with a topographic index, one each in Peru (Elsenbeer and Vertessy 2000) and Panama (Godsey et al. 2004)

Background and Literature Review

Hydrology and Hillslope Processes

Rain passes through the landscape, en route to the sea or groundwater, in a variety of ways. These paths include direct precipitation on water bodies, infiltration, surface runoff, interflow, variable source area runoff, percolation, and groundwater flow (Figure 1.1). The varying paths have important implications for downstream water quality because they affect water transport time, ability to carry pollutants, and remediation by microbes and soil filtration. The worst case is a deep, relatively fast surface path, which can entrain and quickly carry sediment and pollutants into a receiving stream. Slowing and dispersing water promotes infiltration, settles sediment, and increases contact time for sorption. Nitrates in infiltrated water may undergo denitrification (Meding et al. 2001), and plant uptake of nutrients.

Direct precipitation on water bodies is simply rain that falls on the stream or lake. In very wet weather, the channels expand lengthwise, laterally, and establish temporary connections upslope (Hewlett and Hibbert 1967; Dunne and Black 1970b). Nutter said "In essence the stream channel 'reaches out' to tap the subsurface flow systems, which can no longer transmit water beneath the surface" (Nutter 1973, p.191). This expanded area captures more rain during storms, and has potential for both fast flow and the ability to transport upslope sediment. In an extreme example, a one to two order length expansion of streams was noted in poorly drained agricultural grass and crop lands in Oregon (Wigington et al. 2005), although these lands were more intensively ditched than most forests.

Surface runoff can be subdivided into infiltration excess and saturation excess flows, although in practice these may interact. In a process first described by Horton, infiltration excess flow is caused when rain falls faster than it can enter the soil surface, and the excess flows downhill over the soil surface. This process, later termed “Hortonian overland flow”, was originally conceived by Horton as happening more or less uniformly across the watershed. Among Horton’s conclusions were that infiltration capacity is an important soil property that is highest at the start of rainfall, and decreases to a steady level after wetting and packing. The reduction in infiltration capacity results mainly from the decreasing vertical hydraulic gradient as the moisture content of the underlying soil approaches that of the surface. Some of the mechanisms of decrease are the soil swelling and closing cracks, and fine particles sealing the surface. These processes reverse after the rain ends, due to soil shrinkage from drying, increased temperature differences, and increased biotic activity and resulting macropores. Seasonal factors are important to infiltration capacity, and the ability of the soil to retain and release soil moisture influences type and growth of vegetation (Horton 1933, 1940). Evidently even Horton suspected widespread uniform runoff was not the rule. He wrote “It can be shown that on a permeable drainage-area, direct surface-runoff to the stream after rain ends, takes place only from a restricted belt bordering the stream. From portions of the drainage-basin more remote from streams, all of the overland flow or water in transit as surface detention when rain ends, enters the soil as infiltration and none of it enters the stream” (Horton, 1933, p.455). However, this observation was not followed up by other researchers for several decades.

Throughout the 1960s various researchers worldwide realized that the Hortonian model did not fully explain field data of stream flow, hydrograph shape, and/or base flow in dry periods. This resulted in development of a key concept, sometimes termed as partial, dynamic, effective, or variable source areas.

The first U.S. journal article on this concept appeared in 1963, although Hewlett addressed the problem in an earlier 1961 US Forest Service publication. Hewlett and Hibbert (1963) built a sloping trough, filled it with sandy loam soil typical of the area, soaked it thoroughly, sealed it up, and recorded water drainage out the bottom for the next 145 days. This underscored the importance of the vadose zone in providing "dynamic storage" of some stormflow and a lot of baseflow in the relatively deep soils of the southern Appalachians. They also noted "…Stormflow may well be associated with temporary expansion of saturated aquifers along stream channels" (Hewlett and Hibbert 1963 p. 1087).

Betson (1964), using TVA data and a more mathematical approach, realized that the actual stream runoff produced was far less than the amount expected if the entire basins were generating storm runoff . The actual runoff contributing areas for six basins averaged 19% of the total watersheds, but Betson did not specify either locations or causal mechanisms. Amerman (1965) observed partial area surface runoff from random locations over the watershed, not necessarily near the stream.

The Tennessee Valley Authority (1965), working with hydrographs, came up with a conceptual hillslope diagram consisting of four zones. From bottom to top the zones were labeled saturated (near the stream), initial contributing area, dynamic zone, and soil moisture recharge area, with considerable overlap between zones. "Localized zones of intense contribution" were noted by Ragan (1967) covering 1-3% of the watershed. He observed that low intensity storms expanded contributing areas close to seeps, while high intensity storms of long duration produced flow through the base of the litter layer. However, he observed neither Hortonian overland flow nor interflow. These near-stream contributing areas changed seasonally and between storms, as dramatically shown by maps by Dunne and Black (1970a) in a Vermont watershed. A later study by Betson and Marius (1969) pinpointed areas of thin A-horizons as generating surface runoff and interflow and also noted the ability of upper parts of the watershed to store moisture.

To summarize, variable source areas (VSAs) usually occur close to streams and have water tables close to the surface even in dry times. During wet weather they expand laterally, upslope, and sometimes saturate to the surface, creating small flooded areas and surface runoff, with a potential for rapid flow, flooding, and pollution problems. During dry weather, they contract. VSAs can be increased by additional rain, return flow, interflow, Hortonian flow from upslope, and flooding from the stream, so, in practice, may not be readily separable from other processes. Saturation overland flow may also occur on other areas of the watershed and connect to the stream. This is often due to a temporary perched water table in a shallow surface layer in a gully (Kirkby and Chorley 1967) or over a confining layer, such as rock, a less permeable soil layer, or a high water table. For example, a 0.02 ha plot of 95% lichen-covered rock with about 3 cm soil depth generated a 69% runoff coefficient in the boreal forest (Allan and Roulet 1994).

Interflow, also known as subsurface lateral flow, or throughflow, is caused by a permeable but shallow soil surface layer over a relatively impermeable layer, such as heavy clays or bedrock, and relatively steep slopes. Water penetrates the surface but flows downhill over a confining layer within the subsoil. Weyman (1970) documented an

English watershed with base flow contributed nearly exclusively from this process, due to gentle rains, peaty topsoils, shallow subsoils over rock, and 21% convex slopes. Interflow also occurs in the Piedmont, where thin A horizons occur over shallow clay subsoils. Interflow may emerge on the surface farther downhill as return flow (Dunne and Leopold 1978) or exfiltration, and take on the problems of surface flow, especially above the SMZ. It also may remain subsurface and recharge directly into the stream.

Macropores, and the larger “pipes”, are relatively large pores formed by natural soil processes and also by live roots, rotting roots, and soil fauna (Germann 1986). Macropores are more common in forest than agricultural soils due to higher organic matter and biota. These larger pores can infiltrate water one to two orders of magnitude faster than normal in agricultural soils (Germann 1986), and can even carry unfiltered sediment deep into the soil or to the top of a shallow water table (Pilgrim et al. 1978), thus “short circuiting” the soil filtration processes. It is possible that macropores form complex networks in very wet weather, carrying relatively high quantities of water from upslope (Sidle et al. 2000).

As implied above, runoff, hillslopes, and streams interact in complex ways. If overland flow occurs, Hortonian (infiltration excess) flow predominates in places where infiltration rates and plant cover are low such as cities, roads and arid areas. It also can occur in high intensity storms anywhere and rain over snow events (Dunne and Leopold 1978). In most humid, temperate undisturbed forested watersheds, saturated overland flow predominates but only from relatively small portions of the basin.

Precipitation Effects on Overland Flow and Erosion

Runoff and soil erosion are highly interrelated and are closely tied to precipitation, especially rain, characteristics. Major rain factors include intensity, kinetic energy, and precipitation depth or amount. Antecedent soil moisture and seasonal components may also play a role, while event duration is usually too variable to be useful. Some of these factors are related to climate. As implied above, intensity and kinetic energy are most important in Hortonian (or infiltration excess) flow, and rain depth in longer- term soil saturation and, therefore, saturated overland flow and variable source areas.

Rain intensity is the amount of rain per unit area during a given amount of time, and closely related to rain energy, which assesses rain impact on the ground. Raindrops increase in size and energy with intensity (Wischmeier and Smith 1958). Higher impact causes soil erosion by breaking up soil aggregates, reducing their size, and making them easier to transport. These smaller particles create crusts or seals by clogging tiny soil pores, reducing infiltration (Agassi et al. 1981).

Soil erosion is caused by detachment and transportation of particles. Water-induced detachment is due to both raindrop splash and water flow. Higher intensity storms have bigger drops, which hit the ground with more force, displacing more soil. On level ground this tends to cancel out directionally, but on a slope, more particles are displaced downhill, causing a gradual soil migration. Bigger raindrops also contribute to turbulence, splashing more soil from the surface, keeping smaller particles suspended longer, and subjecting them to downhill transport. Ponded water, due to infiltration or saturation excess, flows downhill, causing surface runoff. While studies differ over the exact role of raindrop splash and water flow, splash plays a larger role in flatter topography, tops of slopes, uphill landscape positions, and coarser textured soils. Flow is more important on hillslope bases, steeper slopes and in soils with more clay (Sharma et al. 1995; Shainberg et al. 2003).

Intensity and/or kinetic energy were the most cited rain factors for runoff and soil erosion. Most researchers used maximum intensity figures between one minute and one hour duration, with 30 minutes being most common. Researchers have related sheet or interrill erosion to small powers of intensity, from nearly linear (Jayawardena and Bhuiyan 1999) for only rainfall detachment to the square of intensity for overall detachment and transportation in an NRCS computer-based soil erosion model (Liebenow et al. 1990). Occasionally factors have been combined. For example, the Water Erosion Prediction Project (WEPP) multiplies the intensity term by gradient (Liebenow et al. 1990).

Many studies show overland flow as a percentage of rainfall depth, usually called the runoff coefficient. Depth was considered important by Ferreira et al. 2000) in Portugal, Findeling et al. (2003) in Mexico; and Malmer (1996) in Malaysia. In contrast, Martinez-Mena et al. (2001), in a semi-arid area, found 30 minute intensity more important than rainfall depth. Depth is more important for saturation overland flow, since thin soils or soil layers of low hydraulic conductivity can saturate easily. However, greater rainfall depths may be associated with, and not easily separable from, higher intensity storms.

Large storm events cause a disproportionate amount of runoff and soil erosion. For example, the four top events of a study period caused 70-80% of annual runoff and sediment yields in a semi-arid area (Martinez-Mena et al. 2001). In Oklahoma, two storms of an entire season produced 71% of the sediment yield (Miller 1984).

In contrast, small storms sometimes had response thresholds, with virtually no runoff below a certain amount of rain or intensity (Godsey et al. 2004). Ten mm rain depth and a maximum 30 minute intensity of over 15 mm/hr was necessary to generate runoff in a semi-arid area (Martinez-Mena et al. 2001). Threshold is also recognized in the "initial abstraction" of the SCS curve number, used in estimating stream runoff from various land covers (Ponce and Hawkins 1996). Thresholds could be explained by soil storage, surface detention, and infiltration rates.

Some researchers recognized seasonal components, usually due to seasonal variation in rain intensity and/or growing season soil moisture demands. For example, kinetic energy was the most important factor for overland flow in the winter, and rain depth in the summer for eucalyptus regeneration plots (Ferreira et al. 2000). Lower evapotranspiration in winter resulted in higher soil moisture and saturation overland flow (Burt 1989).

Antecedent soil moisture, either measured in the soil, or by tracking previous rain storms, was important in connection with saturated overland flow and variable source areas (Betson et al. 1969; Burt 1989) in temperate climates and prediction of soil erosion in Tasmania (Teixera and Misra 1997). Five day antecedent soil moisture is an important component of the SCS Curve number method (Ponce and Hawkins 1996). In a model run over 2700 times with various soil moisture and storm scenarios for a semi-arid area, Castillo et al. (2003) found that while prior soil moisture was important for predicting overland flow for storms with a less than a 15 year return period, it did not apply to extreme events.

Rainfall duration is often not a reliable predictor of runoff due to high variation within and between storms; some long storms do not produce much rain. This was borne out by data from numerous studies. However, duration was used in at least one study (Betson 1964).

Dry climates tend to generate Hortonian flow due to intense rainfalls plus low infiltration rates due to low vegetative cover. Very wet climates may also have short, intense rains with high antecedent soil moisture and infiltration rates leading to canopy drip saturation overland flow, sometimes resulting in tree windthrow (Bonnell et al. 1978) and pit and mound type forests (Herwitz 1986).

Effects of Soils and Topography on Overland Flow and Erosion

Soils and topography are two very important environmental factors in overland flow and erosion. The soil properties of texture, structure, and hydraulic conductivity are most important in uncompacted soils.

Clay is less erodible than sand (Quansah 1985; Sharma et al. 1995; Malmer 1996; among others) due to the superior holding power of clays. However, sudden exposure to water can break up some kinds of clays by differential wetting, especially with initially dry clay (Shainberg et al. 2003). Once clay is detached, it tends to be transported much farther as wash load due to its small size. Silts and loams, with intermediate texture and weak aggregates, are highly erodible by both water processes (and also wind). For example, over 2200 kg/ha/yr annual soil erosion were reported from modeled forest lands in the Loess Plateau of China (Zhang and Shao 2003) and higher than average erosion from a loessial area of Mississippi (Ursic 1991).

Higher soil strength and bigger aggregates lead to less soil erosion (Teixera and Misra 1997; Shainberg et al. 2003). Both larger size and higher quantities of pores caused higher infiltration and less runoff (Martinez-Mena 2001). These favorable properties are associated with higher percentages of clays and organic matter.

Several studies specifically mentioned high saturated conductivity values as a factor in lack of runoff or erosion (Findeling 2003; Ziegler et al. 2004). Other studies with no Hortonian overland flow listed high conductivity values (Dykes and Thornes 2000; Lesack 1993).

Extreme anisotropy was noted in the tropics, with surface saturated conductivity of 1350 mm/hr, decreasing two orders of magnitude to 13 mm/hr at 0.2 meters. This, coupled with annual rainfall of over 4100 mm per year, and clay soils, led to 97% saturated overland flow from one plot during an average wet-season storm, despite the presence of tropical rain forest vegetation. Saturated overland flow typically occurred all over the study area with no variable source areas noted (Bonnell and Gilmour 1978). Similarly, in the western Amazon, 317 mm/ hr surface saturated hydraulic conductivity decreased to 7 mm/hr at 0.2 meters. Large storms and 3300 mm annual rainfall quickly saturated the top soil through abundant macropores caused by extensive root systems, causing surface runoff (Elsenbeer and Vertessy 2000).

Conductivity differences can result in overland flow not only between adjacent soil layers but between the litter layer and the top mineral horizon (Ragan 1967; Allan and Roulet 1994). Similar saturated flows that moved a lot of water without scouring the litter layer were noted by White (2003) and observed in the current study.

Topographic factors, such as convergence, gradient, and microtopography also affect runoff and erosion. Converging landscapes or hollows were mentioned by Kirkby and Chorley (1967) and Burt (1989). Convergent subsurface flows can emerge above ground even at intensities less than infiltration rates (Godsey et al. 2004; Wallach and Zaslavsky 1991). Godsey et al. (2004); mentioned concentrated flow lines, usually associated with convergent topography, as the most important contributor to runoff frequency. Steeper gradients cause more runoff and erosion (Quansah 1985; Gabet and Dunne 2003). Rain-impacted flow erosion and runoff velocity increased with the square root of gradient, in the lab (Fox et al. 2000). Large upslope drainage areas direct more drainage to a given point (Beven et al. 1984; Burt 1989). Microtopography was cited by Gabet and Dunne (2003), and Godsey et al. (2004), among others.

Vegetative Cover and Disturbance in Overland Flow and Erosion

Good vegetative cover on both canopy and ground nearly always result in lower rates of runoff and erosion, while environmental and manmade disturbances resulting in bare compacted ground have the opposite effect. Typical disturbances are burning, farming, timber management, and associated road construction.

Burning produces highly permeable ash, which can quickly blow or wash away. Very hot fires can cause soil to become hydrophobic but this tends to break down under wet conditions and over several years (DeBano 2000). However, fires of this magnitude are rare in the southeastern US. Low intensity burns may only consume a small portion of the humus (Robichaud and Waldrop 1994) leaving the soil partly protected.

Mechanical cultivation operations may loosen the top soil temporarily (Horton 1933; Hewlett and Hibbert 1967) but result in a layer of lower hydraulic conductivity beneath, sometimes known as a “plowpan”. Field abandonment causes additional problems. A chronosequence in the mountains of Vietnam showed a gradual recovery from shifting cultivation over a 15-35 year “rotation” of upland fields to forest regrowth, with the highest erosion in abandoned fields (Ziegler et al. 2004). Historically in the Southern Piedmont, abandoned fields were a major component of the landscape during the nineteenth and early twentieth centuries, occupying 15-35% of this area in 1880 (Trimble 1974, p.72). Dismay at the highly gullied landscape of the Piedmont plus windblown erosion of the Dust Bowl spurred early US conservation work, with the first soil and water conservation district established in the Piedmont of North Carolina in 1937 (Trimble 1974).

Bare ground greater than 60% dramatically increased post burn sediment (Johansen et al. 2001), but even relatively light layers of mulch can provide good benefits. Working with cultivated sandy loam soils in Mexico, Findeling et al. (2003) cut the runoff coefficient in half using 1.5 tonnes per hectare mulch or about a 30% coverage rate. Mulch also increased tortuosity and friction but increased channelization of flow, during the first year. Hydraulic conductivity was 7 mm/hr in bare soil, and 63 mm/hr with the light mulch, and when modeled, the runoff velocity in the light mulch was cut in half. Over the longer term of four years, the extra organic matter protected soil structure and stability, and increased faunal activity, increasing infiltration. In another study of a 27%

grassy slope, cover decreased raindrop splash distance. Plots with 40% cover were modeled at five times the maximum soil detachment rate and four times the sediment discharge of plots with 80% cover (Gabet and Dunne 2003).Type and quality of cover area also important. Grass was better than forest at holding soils in Vietnam (Ziegler et al. 2004). Although forests usually provide excellent soil and water protection (NCASI 1994), a few highly exploited forests had surprisingly high rates of soil erosion. For example, secondary forests were no better than sugarcane in Argentina (Hunzinger 1997). In the Himalayas, pine forests eroded at 4 tons/ha versus 1.8 tons/ha for tea with a dense understory (Kothyari et al. 2004)

Most timber management activities have the potential to increase erosion and runoff. This is due to increased evapotranspiration and reduced interception following removal of trees and canopy, disturbance of litter and organic matter, and soil compaction associated with logging and machinery. Increased temperatures due to less shade may also increase carbon losses (Richter and Markewitz 2001), with the potential for loss of soil aggregates. For example, soil loss after mechanical skidding, burning and planting was 142 kg/ha/yr versus manual logging, no burn, and plant at 82 kg/ha/yr, with a 38 kg/ha/yr uncut reference in Malaysia (Malmer 1996). However these are low loads compared to agriculture.

Some forms of mechanical site preparation may loosen soil, as demonstrated by walking behind a site preparation job, but may still increase erosion. Rip-plowed and planted eucalyptus sites had more overland flow than post-burn coppice regrowth, with an interesting contrast in soil properties. At the ripped site, bulk density was 132%, infiltration 35%, organic mater 54%, and ground cover 10% of the coppice site in spite of more hydrophobic soil on the latter (Ferreira et al. 2000). In contrast, an undisturbed tropical rain forest in Brunei did not generate any overland flow even with 58% slopes and more than 4500 mm annual rainfall (Dykes 1997), although there was some return flow close to channels due to favorable interflow conditions. Subsoil infiltration at this site was up to 288 mm/hr (Dykes and Thornes 2000).

Compaction often causes major erosion and overland flow problems. In Malaysia, Malmer (1996) recorded 500 tons/ha/yr soil loss for the worst skid trails versus 38 kg/ha/yr for the control forest. In another Malaysian study, overland flow was 52% of precipitation on logging road plots versus less than 3% for forested plots (Sinun et al. 1992).

Field Studies of Overland Flow

Most overland flow studies measure relatively small plots. Research advantages for small plots are ease of measurement, ability to use rainfall simulators, replication and comparison opportunities, and more or less uniform conditions on the plot. Small plots do not scale up well to even small watersheds, resulting in a potential overestimate of surface runoff for larger areas. For example, van de Giesen et al. (2000) measured surface runoff coefficients of 29-37% of precipitation on small agricultural plots. Longer plots had coefficients of 6-27%, and 60 ha of watershed slopes produced stream (not just surface) runoff of only 3.9% of precipitation. In this semi-arid area, most runoff was attributed to Hortonian flow, but some of this streamflow was probably due to other hillslope processes. In general, reasons for scaling problems include variations in soil conditions, land use, rain storm variability over time and space, and microtopography.

Examples of microbasin or larger areas with overland flow are provided in Table 1.1. Most overland flow is shown as a percent of precipitation, but some researchers used percent area of the watershed, and two studied frequency. For uncompacted areas, the runoff coefficient never exceeded 10% of precipitation (Table 1.1). However, even a small runoff coefficient can quickly result in a large quantity of water, since rain falls over the entire watershed. For example, a runoff coefficient of only 1% of 1200 mm of annual rain in a 50 ha (124 ac) watershed, would produce 6,000 cubic meters (>1.5 million gallons) of overland flow.

Frequency of runoff was compared for two relatively undisturbed forested watersheds in Panama (Godsey et al. 2004), with a response rate of about 50% of collectors on one and 21% on the other. Another tropical study in a first-order forested basin in Peru mapped surface runoff frequency in relation to a topographic index, based on upslope contributing area (Elsenbeer and Vertessy 2000). There was no obvious topographic pattern and a crude map interpretation showed about 27% collector response. The authors noted rapid "near-surface" flowpaths including saturation overland flow, interflow, and return flow, often in rills, gullies, and pipes, due to high rainfall, high intensity and anisotropy.

Combinations of various types of overland flow are common. Some researchers have observed Hortonian flow, even though maximum infiltration rates were not exceeded. This was often attributed to either temporary conditions and /or actual field rates being less than theoretical rates, due to soil variation, air entrapment, and other factors. High spatial variation in infiltration can contribute to a phenomenon, sometimes called “run-on”, where water runoff rates high on the slope decrease lower down (Amerman 1965; Betson and Marius 1969; Stomph et al. 2002).

The Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) was an attempt by the Natural Resource Conservation Service to develop an agricultural soil erosion prediction model, tailored to each field, and simple enough to use in the days before common availability of computers. It was based on hundreds of years of cumulative research data from agricultural stations across the US. The best independent transformed variables were rain, soil erodibility, slope length, gradient, cover, and practice (treatment). This formula has been applied all over the world and modified for use in forestry, construction, surface mining, and Total Maximum Daily Loads (TMDLs). The rain factor “R” is obtained by multiplying energy by intensity. The energy term is a linear regression of log of intensity for each storm time segment, while the intensity term is the maximum 30 minute intensity for the entire storm (Wischmeier and Smith 1958). The rainfall or “R” is the factor most relevant to the current study.

Sediment and Nutrients in Southeastern Forest Regeneration

The regeneration window in southern pine management is always associated with increased streamflow and often associated with increased surface runoff (Table 1.2). Generally the more soil moved, the more intensive the operation and the greater number of passes over the site, the more runoff is created. More runoff is associated with more sediment and nutrient loss by adsorption to sediment or dissolved in water. Some site preparation activities such as discing, ripping, or bedding are intended to counteract past compaction, but have the disadvantage of baring more soil. Positive trends from an erosion standpoint have been a move from mechanical to hand planting and regeneration use of herbicides. When herbicides substitute for mechanical site preparation, there is less soil disturbance. When they are used in combination with mechanical site preparation and/or are applied post-planting, more soil is exposed for a longer time. Also repeated entries to a site during ongoing activities keep the road system active, and eroding longer, unless control measures are taken.

The following trends were commonly noted by researchers in the southern U.S: (1) a few of the largest storms caused a disproportionate share of runoff, (2) finer sediment was transported preferentially (3) sediment and nutrient loss concentrations and loads were usually absolutely higher, but not always statistically higher, for one or two years following site prep compared with uncut controls due to high variation between storms, and (4) the sites stabilized after several years.

Comparisons of concentration and yield data from available studies of ephemeral streams and runoff plots produces variable results. Each study is unique. For example, some watersheds had no major roads, decks, or stream buffers, while others did. Sites varied across time and space, with differences in parent material, climate, environmental loading, etc. Most watersheds studied were quite small (rarely greater than 5 ha), and some information came from small runoff plots, with potential scale-up problems, as noted previously. Table 1.3 lists southeastern forest comparison studies for sediment, nitrates, and phosphates.

Up to three orders of magnitude existed among sediment study means and ranges were even more variable. Legacy sediment may have been deposited in the stream channel, banks, and floodplains during former abusive agricultural, abandonment, and logging practices, and remobilized by increased flows after modern cutting. Higher flows also tend to extend the channel headwards, with more sediment released. Finally the storm flows sampled in studies of ephemeral streams carry more sediment than combined storm and base flows from regularly scheduled sampling programs often conducted on perennial streams.

Concentrations varied widely, with a few studies showing means of uncut control more than the treatment means. Loads were more consistent with respect to increased sediment produced by increased site preparation. For stormflow on the ephemeral studies shown, mean concentrations varied between 13 mg/L two years post clearcutting (Ursic 1991) and 2119 mg/L one year after a clearcut, shear, pile, burn and plant (Blackburn et al. 1986). The low mean load was 4 kg/ha/yr after a clearcut and low severity burn (Robichaud and Waldrop 1994) and after a clearcut, shear, rip, bed, and machine plant in the Piedmont (Grace 2004). Less sediment (in absolute terms but not statistical terms) was moved from the ripped and bedded site (4 kg/ha/yr) than a site which was only clearcut and machine planted with no site preparation (22 kg/ha/yr). In another ripped study site, Miller (1984) recorded higher sediment but lower water yield in the first year from a ripped area (23 cm) compared to uncut control plots (32 cm). This was attributed to increased surface roughness, detention storage, infiltration, and possibly disruption of subsurface macrochannels. A high annually adjusted sediment load of 4255 kg/ha/yr was recorded in Piedmont swales at the top edge of the SMZ by Ward and Jackson (2004), one year after a clearcut, chemical site preparation, rip, bed, plant, and post-emergence spray treatment. However, this site was selected due to known problems with the sandy soils and off-contour bedding, and was therefore atypical. The two highest loads (6502 and 12086 kg/ha/yr) were recorded in upper Mississippi on loessial soils the year following clearcutting with a cable yarder and planting, and one year later respectively. This dropped to 34 kg/ha/yr during a dry second year post treatment (Ursic 1991) . Although some of these loads sound high, they typically only occur during a two to three year regeneration window out of an entire timber rotation and are less than agricultural soil losses. In agriculture the NRCS typically sets an annual target soil loss of (2,200-13,500 kg/ha/yr (one to six English tons per acre). However, those figures are set from a standpoint of maintaining soil productivity, not from off-site damages to stream health.

The overall nitrate picture was similar to sediment, in that concentrations and loads tended to increase for a year or two after clearcutting and site preparation. Again, these data were often absolutely higher but seldom statistically higher than the controls, and concentrations were more variable than yields. Means concentrations ranged from a low of 0.03 mg/L for seedbed burn and clearcut (Van Lear et al. 1985) to 3.81 mg/L for clearcut, shear, pile, disc, burn, and plant (Fox et al. 1986) with most values under 1.0 mg/L. Uncut controls or calibrations were between 0.01(Blackburn and Wood 1990) and 0.23 mg/L (Fox et al. 1986). Ephemeral stream or runoff plot loads of southeastern studies varied from a low of 0.01 (Blackburn and Wood 1990) one year after a clearcut, chop, burn and plant to 8.47 kg/ha/yr on a clearcut, shear, pile, disc, burn, and plant (Fox et al. 1986). Uncut controls or calibrations varied from a low of 0.01 (Blackburn and Wood 1990) to 0.85 kg/ha/yr (Fox et al. 1986). The higher surface runoff and flows associated with clearcuts tend to move nitrates because they are readily leached in water. The EPA nitrate plus nitrite target for the southeastern Piedmont, based on the cleanest 25^{th} percentile of existing perennial streams is 0.17 mg/L concentration (US Environmental Protection Agency 2000). However, nitrates are only one of many forms of nitrogen. For instance, McDowell and Omernik (1977) listed a mean of 0.11for inorganic nitrogen (which includes nitrates) and 0.51 mg/L total nitrogen for 68 perennial streams in US forested watersheds.

Phosphates had similar trends to nitrates but effects of regeneration were less marked. Only four concentrations were statistically higher in treatments than controls and only for one year each, in the studies listed. Concentrations went from a low of 0.001 two years after intensive site prep (clearcut, shear, pile, burn, and plant) (Blackburn and Wood 1990) to a high of 0.235 mg/L post clearcut, chemical site prep and burn (Field et al. 2005). Yields were from a low 0.004 two years after intensive site prep (clearcut, shear, pile, burn, and plant) to a high of 0.039 kg/ha/yr immediately after the same treatment (Blackburn and Wood 1990) . The EPA orthophosphate target for the southeastern Piedmont, based on the cleanest 25^{th} percentile of existing perennial streams is 0.012 mg/L concentration (US Environmental Protection Agency 2000). By comparison, McDowell and Omernik (1977) listed phosphate concentrations of 0.009 mg/L and yields of 0.041 kg/ha/yr for 68 and 53 US perennial streams in forested watersheds respectively. Once again dissolved phosphates are only a small portion of total phosphorus but the part most readily plant available and likely to cause immediate nutritional excesses.

Pollution prevention strategies include keeping sediment on site with adsorbed nutrients, and infiltrating water with its dissolved nutrients.

Effectiveness of Streamside Management Zones

Agricultural and forestry buffer strips have similarities and differences. Agricultural strips, often termed vegetative buffer strips, can be grass, shrubs, trees, or a combination. They are sometimes intentionally planted; usually more intensively managed than forestry strips, and are expected to handle larger quantities of agricultural pollutants nearly permanently. Grasses are favored for the area nearest the field border due to less shading of crops than provided by trees. Forestry strips, often termed streamside management zones, are generally "leave" strips of native vegetation either lightly or not perturbed when cutting. They are primarily intended to reduce harvest impacts when clear cutting and/or during the regeneration window of intensive forest management but are sometimes used for less intensive regimes with fragile environmental conditions (Keim and Schoenholtz 1999). Therefore, they are expected to have less input for shorter periods of time or only sporadically. Some benefits, such as stabilizing stream banks, reducing stream temperatures, providing woody debris to aquatic life, or increasing biodiversity are more long term.

Diffuse runoff can concentrate in distances as short as 5 m (Abu-Zreig et al. 2001). White (2003) noted that full width 5 meter plot flow reduced to 90 % width after only 2 meters in length, and averaged 47% after 10 meters, in plots chosen for uniform slopes. Once concentrated, runoff can travel long distances, for example, over 95 m (>300 ft) from roads in the southern Appalachians (Swift 1986), and over 60 m (200 ft) from site preparation in the Piedmont (Rivenbark and Jackson 2004). These lengths would obviously exceed the width of most buffers. Concentrated flow increases speed, turbulence, and transport ability of water, whereas the buffer objective is slow, smooth flow, which drops the load. In effect, concentrated flow can "short-circuit" the buffer.

In a reconnaissance of 30 clearcut and/or site prepared industrial forest areas on the Georgia Piedmont, (Rivenbark and Jackson 2004) found that SMZ "breakthroughs'' that deposited sand, silt, and/or clay into the stream channel were occurring at the rate of 1 per 8 ha (20 ac) of the intensive management area. About 50% of these breakthroughs were found in areas of convergent topography, and another 25% were in areas of runoff from compacted logging roads and skid trails. Many involved long or relatively bare slopes. Breakthroughs occurred in 45% of concentrated flow draining over 0.04 ha (0.1 ac) but contributing area alone was not a good predictor of breakthroughs. Instead the product of contributing area and percent bare ground, or the resultant product multiplied by slope was a better metric. Over 50% of the sites had three or fewer breakthroughs, so the SMZs were quite effective even in the relatively erodible Piedmont However, at 23 m width (75 ft) the actual topographically based SMZs averaged wider than state minimum recommendations.

Early agricultural studies and later forestry studies have shown filter strips to be very effective in reducing sediment and particulates in diffuse runoff. Laboratory flume studies with grass and nail beds show that most of the sediment drops out just before it enters the strip, as the water pools and slows when meeting the resistance of the dense edge with little or no sediment dropping in the bed (Ghadiri et al. 2001). In more realistic experiments with less uniform conditions, sediment is seen dropping throughout the strip but most sediment still drops out in the first few meters. The coarsest sediment drops out first at the top, while clay size particles usually pass through the strip unless the water is infiltrated (White 2003; Ward and Jackson 2004). Studies of effective strip length often show the rate of additional filtration tapering off at some point, typically from 10-30 meters. In a study of eroding small swales on two sites, one newly planted and one a year older, following intensive site preparation, Ward and Jackson (2004) found coarse sediment trapping efficiencies of 12 m (40 ft) SMZs of 71% to nearly 100 %, with a mean of about 86%. In this study, the buffers were set at the minimum recommended by state BMPs (12 m or 40 ft) and one of the sites was picked for being far worse than average. In another Georgia Piedmont study, a 10 m plot riparian plot reduced sediment concentration by 62% and mass by 72%. Over two thirds of the filtered sediment dropped out in the first two meters (White 2003). In Austrailia, 10 m undisturbed plots trapped nearly 100% of sediment from 20 meters of sheet flow from heavily disturbed skid trail simulations (Lacey 2000). However, dropped sediment in one storm can be flushed farther downhill or into the stream by a later larger storm (Barling et al. 1994). Flow pathways through filters may also vary over time, with vegetation growth and rearrangement of debris patterns.

Particulate nutrients are often bound to sediment, so the trapping effect also helps them. Results vary considerably between studies. Working with corn and a 19 m forested buffer, Peterjohn and Correll (1984) reported trapping efficiencies of 81% for organic particulate nitrogen and 74% for total particulate phosphorus concentrations in surface runoff. Schmitt et al. (1999) estimated that 87% of total phosphorus was bound to particles, so trapping sediment automatically lowers P.

Vegetation is an important component of buffer strips. Height of vegetation does not matter, as long as it is higher than the flow (Pearce et al. 1998). As vegetation gets flattened by water, the increased leaf contact area may increases the hydraulic resistance. If the water depth overtops the vegetation height, resistance and filter effectiveness decrease. Increasing vegetation density helps, up to a point (Han et al. 2005; Pearce et al. 1998) and type of vegetation sometimes matters (Schmitt et al. 1999). Floating debris can mat in vegetation, increasing effectiveness (Ghadiri et al. 2001). Transpiration from plants in the buffer increases in the summer, making the soil drier and contributing to infiltration. Aside from hydraulic roughness, plant roots stabilize the soil. One year old alfalfa increased shear resistance four times, while pines and oaks had a similar effect but only after 3-5 years (Waldron and Dakessian 1982). Buffer functions can also influence vegetation. Wetlands sediment accumulation as low as 3 mm a year negatively impacted fine root growth, probably by suffocation (Cavalcanti and Lockaby 2005).

Buffer strips are less effective for dissolved nutrients than sediments but still provide important benefits. Dissolved nutrients spread out over the entire plot, making buffer width more important for them than for sediment (Phillips 1989). Any water that infiltrates will drop sediment and has a chance of loosing dissolved nutrients by adsorption to organic or mineral soils. Infiltration in 10 m plots was 31% of water in one study (White 2003), 69% in another (Abu-Zreig et al. 2001), and 46% at 7.5 m and 51% at 15 m (Schmitt et al. 1999). The clays and iron in Piedmont soil generally contain more cation and anion exchange sites for adsorption than sandier soils, such as found on the Coastal Plain (Miller et al. 1999). Buffers also help by providing a dilution effect, although this is more pronounced in agricultural situations. Since the pollutant inputs are less from the buffer, and rain also falls on that area, the concentration is decreased, providing the rain has fewer nutrients than the runoff.

In a study of filter length, filtering effectiveness of grass for soluble nitrate concentration from poultry litter in relatively light doses was 38% after 3 meters, 65% after 9 meters, and 79% after 15 meters (Srivastava et al. 1996). In another study, a 60% nitrate concentration reduction was reported in 19 meters (Peterjohn and Correll 1984). A lower value of 43% for nitrate reduction was reported for a 15 m grass-shrub-tree buffer, but the buffer was only 2 years old and the initial nitrate concentration was very high at 28 mg/L (Schmitt et al. 1999).

Although only a small fraction of total phosphorus, dissolved phosphates are readily plant available, and cause eutrophication concerns. In a Piedmont forest study, ten meter riparian plots filtered about 50% of soluble orthophosphate concentration and 67% of mass. Total soluble phosphorus concentration was reduced by 43% and mass 59% (White 2003). In an agricultural study, filtering effectiveness of grass for phosphate concentrations of light doses of poultry litter was 33% after 3 meters, 75% after 9 meters, and 92% after 15 meters (Srivastava et al. 1996). Peterjohn and Correll (1984) reported a 58% concentration reduction for orthophosphates in 19 meters. Lower values of 35% concentration reduction for dissolved bioactive P were probably due to high initial values of 1.8 mg/L and a young buffer (Schmitt et al. 1999).

Organic matter increases contact time of flow, increasing chances of infiltration, adsorption, or uptake by organisms. Travel time of runoff on 10-meter plots with an intact litter layer was two to three times that of plots with the O-layer removed, and higher depths of organic matter were thought to counteract the effect of higher gradient (White 2003).

In summary, cutting and regeneration of stands creates roads, log decks, and areas of bare and compact soil, all likely to produce Hortonian overland flow. In addition, reduced interception and evapotranspiration cause water tables to rise and variable source areas associated with saturation overland flow to expand. However, the frequency and extent of surface runoff entering streamside management zones is unknown.

Table 1.1. Examples of rural overland flow from large plots or small watersheds worldwide[1,2]

Location	Topo	Slope (%)	Climate[3]	Ann. Rain (mm)	Soils[4]	Size	Cover (%)	Disturbence[5]	-----Maximum Rain---- Intensity[6] (mm)	Time (min)	Ksat or Infiltration[7] (mm/hr)		----Overland Flow---- Amount[8] (%)	Type[9]	Study[10]
AZ	mtn	15-37	Te-SA	794	C	<1.0	35	Cut					0.4		1
S. CA		20	Te-SA		LS	1.1	19	Bu	8-16	10	K	20-50			2
W.Africa		4	Tr-SH	1077	S,LS			Ag	150	60			<3.9 p	H	3
East US		23	Te-Hu	1372	SL	36 med	99						<3 p,e		4
VT		30-100	Te-Hu		SL	0.2	pasture				I	>80	8 a	S,R	5
Japan	mtn	63	Te-Hu	1459	volc.ash	2.5			13	30	K	22	1.3 p	S	6
Vietnam	mtn	0-173	Te-Hu	1800	SCL				57, 85	30,10	K	63	.01 p	H	7
Vietnam	mtn		Te-Hu	1800	SCL			AF	57, 85	30,11	K	28	8.8 p	H	7
Vietnam	mtn		Te-Hu	1800	SCL		0	Rd	57, 85	30,12	K	7	47.2 p	H	7
Panama		5-10	Tr-RF	2600		25							49.9 f		8
Panama		5-10	Tr-RF	2600		40							21.3 f		8
Panama		20	Tr-RF	2600	SiC	10			160	5			6.9 p,e	S	9
Brazil		low	Tr-Rf	2870	SC,SCL	23							2.8 a	S	10
Peru	foot.		Tr-RF	3300		0.75			23, 52	60, 5	I	317	27 f	S,R	11

[1] Not a comprehensive list. [2] Some of the data were estimated from graphs or figures.

[3] Climate- Te=temperate, SA= semi-arid, Hu= humid, RF= rain forest. Cover- Past.= pasture

[4] Soils- C= clay, L= loam, S= sand, Si = silt.

[5] Disturbance- Bu= severe burn, Ag= upland rice, AF= abandoned field, Rd= road

[6] Intensity (x) = maximum intensity for x minutes. These could be mean,median, or absolute maximums.

[7] Ksat (K) and Infiltration (I) could be field or lab values. Infiltration could be final or an intermediate value.

[8] Overland flow amount-a=area, e=estimated, f=frequency, p=precip depth.Type-H= Hortonian, R=return flow, S=saturation overland flow

[9] Type- H= Hortonian, R= return flow, S= saturation overland flow

[10] Studies:

1	Heede	1987	5	Dunne & Black	1970a	9	Dietrich et al	1982
2	Wohlgemuth et al.	2001	6	Sidle et al.	2000	10	Lesack	1993
3	van de Giesen et al.	2000	7	Ziegler et al.	2004	11	Elsenbeer &Vertessy	2000
4	Hewlett and Hibbert	1967	8	Godsey et al.	2004			

Table 1.2. Presence of overland flow in southeastern US regeneration studies[1]

Location[2]	Slope (%)	Area (ha)	Bare Soil (%)	Treatment: Cut[3]	Treatment: Regeneration[4]	Overland Flow	Reference: Author	Reference: Year
UCP TX	4-25	2-3	3	n/a	n/a	No	Blackburn et al.	1986
			16	CC	C,Bu,HP	No		
			57	CC	S,P,Bu,HP	Yes		
UCP TX		plot		CC	CC,Bu	Yes	Field et al.	2003
				CC	CC	Yes		
UCP MS	38	<1	37	CC	C,B,HP?	Yes	Beasley	1979
			53	CC	S,P,Bu,HP?	Yes		
			69	CC	S,P,Be,HP?	Yes		
UCP MS		0.7		CC	n/a	Yes	McClurkin et al.	1987
				Th	n/a	No		
P NC	4	0.1	18	CC	S,Pi,D,HP	Yes	Pye and Vitousek	1985
	3	0.1	32	CC	S,Pi,D,Ch,HP	Yes		
P GA			50	CC	2C,MP	Yes	Hewlett	1978
							Hewlett et al.	1984
P AL	10	plot		CC	S,Pi,Be,MP	Yes	Grace	2004
				CC	MP	Yes		
Mtn SC		plot	7	CC	Bu	Yes	Robichaud and Waldrop	1994
			63	CC	Bu	Yes		
Mtn OK	57	1-5	15	CC	Cr,Bu,R,HP	Yes	Miller	1984
Mtn WV		35		CC	n/a	Yes	Patric	1980
		39		CC	n/a	No		

[1]Not a comprehensive list.

[2]Location- UCP = Upper coastal plain, P= Piedmont, Mtn = Mountains

[3]Cut - CC= Clearcut, Th= hin

[4]Regeneration- Be= Bed; Bu=Burn; C=Chop; Ch= Chemical; Cr=Crush; P=Pile; R= Rip; S=Shear; HP= Hand Plant; MP= Machine Plant

Table 1.3. Citations and locations for southeastern pine regeneration stormwater studies for small streams and runoff plots

Study No.	Location	Data Source	Author	Year
1	Upper Coastal Plain AR	Ephemerals	Beasley et al.	1986
2	Lower Coastal Plain AR	Intermittent	Beasley and Granillo	1988
3	Upper Coastal Plain TX	Ephemerals	Blackburn et al.	1986
4	Upper Coastal Plain TX	Ephemerals	Blackburn and Wood	1990
5	Piedmont SC	Ephemerals	Douglass and Van Lear	1983
6	Upper Coastal Plain TX	Plots	Field et al.	2003
7	Upper Coastal Plain TX	Plots	Field et al.	2005
8	Piedmont VA	Ephemerals	Fox et al.	1986
9	Piedmont AL	Plots	Grace	2004
10	Piedmont GA	Perennials	Hewlett et al.	1984
11	Upper Coastal Plain TN	Plots	McLurkin et al.	1985
12	Upper Coastal Plain MS	Plots	McLurkin et al.	1987
13	Eastern US[1]	Perennials	McDowell and Omernik	1977
14	Eastern US[1]	Perennials	Patric et al.	1984
15	Piedmont NC	Plots	Pye and Vitousek	1985
16	Mountains SC	Plots	Robichaud and Waldrop	1994
17	Upper Coastal Plain MS[2]	Ephemerals, Swales	Schreiber et al.	1980
18	Upper Coastal Plain MS	Unspecified headwater	Ursic	1991
19	Piedmont SC	Ephemerals	Van Lear et al.	1985
20	Piedmont GA	Swales	Ward and Jackson	2004

[1] Regional average, all stages of rotation

[2] 36 years old

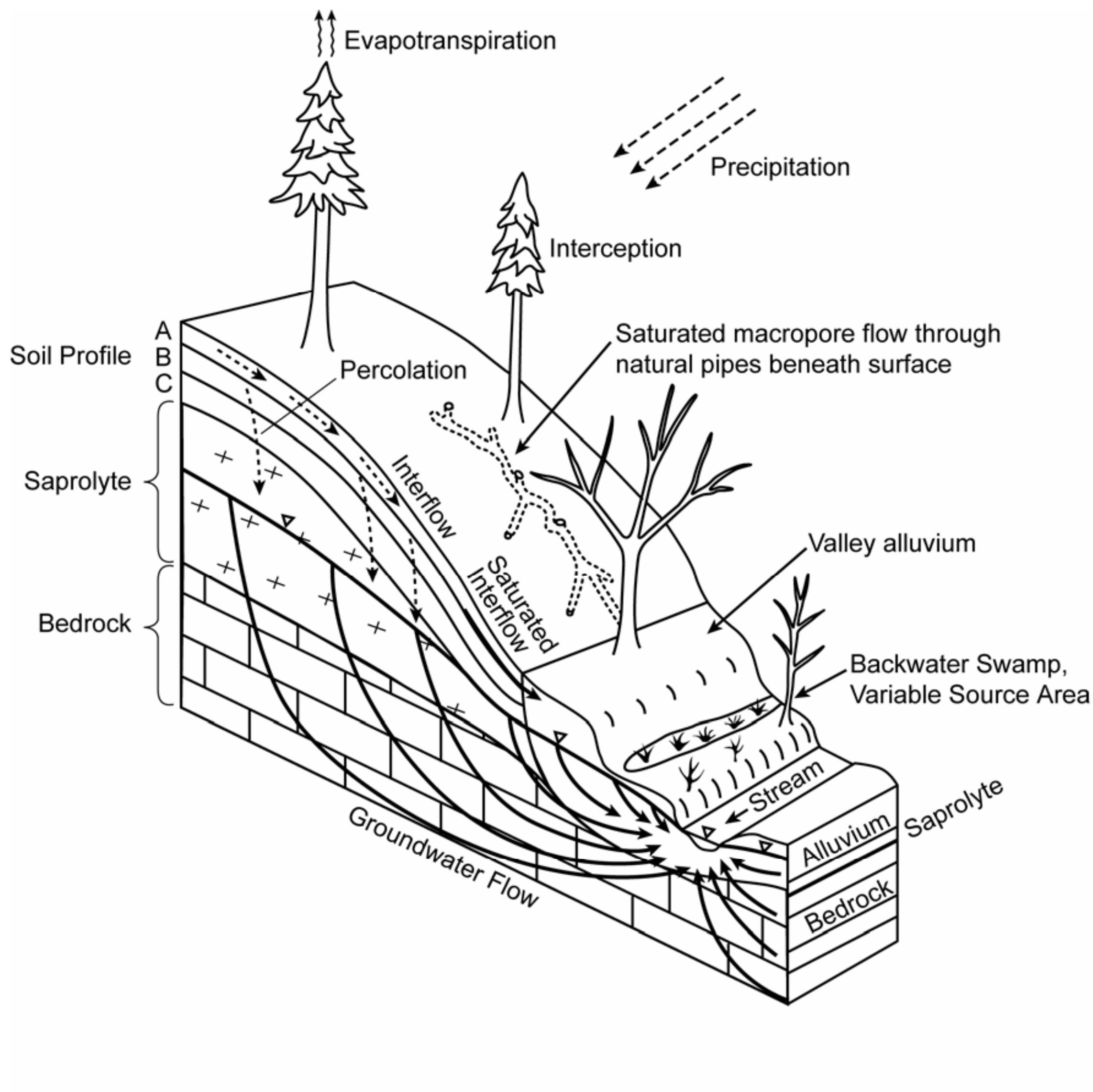


Figure 1.1.Rainfall and hillslope hydrology processes.
From Jackson (in press) and Atkinson (1978)

CHAPTER 2

METHODS

Study Sites

Three study sites were established in Greene County, Georgia, about 40 km (25 miles) southeast of Athens, latitude 33^0 40’, longitude, 83^0 15’ (Figure 2.1). The Lewis and Vanir tracts were portions of recently regenerated Plum Creek Timber Company pine stands, and the Watson Springs tract was a mature pine-hardwood forest managed by the UGA Warnell School of Forestry and Natural Resources. The upland areas of the tracts were 82 ha (203 ac) for Lewis, 27 ha (67 ac) for Vanir, and 30 ha (74 ac) for the Watson Springs reference site.

Elevations ranged from 139 to 197 meters (456 – 646 ft), and slopes from 0 - 23 % (Table 2.1). Median slopes were 6.7 % on the two plantations and 8.2 % at the reference site. Topsoils textures at Lewis were 93% sandy loam (mostly Cecil and Pacolet series), 88% sandy loam or loamy sand at Vanir (mostly Cecil, Pacolet, and Rion series), and 75% sandy loam or loamy sand at Watson Springs (mostly Louisberg, Pacolet, Vance, and Cecil series). The soils were mostly well-drained Ultisols, although Lewis had wet areas, concentrated on the south and west sides (Figures 2.2 -2.4). The reference site was steeper than the plantations but also had sandier subsoils and lower erodibility as shown by the USLE “K” values. Stream and gully conditions and also archaeological artifacts indicate all sites were intensively row cropped in the nineteenth and early twentieth centuries, ass is common in the Piedmont. before modern conservation practices (Trimble 1974). Aerial photos from 1942 showed that about 30% of Lewis, 30% of Vanir, and 16

% of the reference site were in crops, pastures, or open canopy areas, sometimes with evidence of terraces. Major portions of the forested areas appeared understocked. Agriculture created numerous relict gullies which were reasonably stable when covered by forest and litter but subject to reactivation when disturbed (e.g. Hewlett 1978; Rivenbark and Jackson 2004). Even when stable, they were sometimes observed collecting and channeling water during large storms.

The two regeneration sites were selected from 12 candidates based on presence of streams with SMZ buffers, typical industry treatments, topographic variation, access, size, and lack of non-forestry perturbations. Only two were chosen due to the labor intensive nature of the research. On each site, 45-55 year old pines of the previous rotation were clearcut to commercial specifications in 2001 (Table 2.2). The sites were aerial sprayed with 6.7 kg/ha (6 lbs/ac) hexazinone (Velpar® ULW) for hardwood control in May of 2002 without burning. Areas of heavy debris were spot piled in August. The entire tract was then ripped to a depth of 0.5 m (18 inches), and simultaneously low bedded with a combination plow. The beds were planted in loblolly pines in January 2003 at 1579-1678 trees/ha (635-679 trees per acre) and had no subsequent treatments (Joelle Hairell and Grady Britt, personal communication). An excellent job of contour bedding was done. The SMZs below the plantations were only minimally disturbed during logging, which left basal areas of about 24 m^2 / ha (105 ft^2 / ac), canopy shading of over 87%, and bare ground of less than 3% (Table 2.3). This far exceeded minimal Georgia BMP requirements of 11 m^2 (50 ft^2) of basal area or 50% canopy coverage for SMZs (Ga. EPD et al 1999).

The reference site was established in about 70- year mature timber in February 2004 at the Watson Springs Research Forest, about 4 km north of the Lewis tract. This tract was acquired by University of Georgia in 1933 (Dustin Thompson, personal communication) following the burning of a resort in 1930 and the consequent abandonment of the small support town (Roper 1996). The land regenerated naturally to mixed pine and hardwood, with the pine stands thinned and salvaged infrequently and burned more regularly. Most of this study site was prescribed burned shortly after study setup, resulting in a patchy, thin litter layer, and reactivation of some gullies. The reference area had 25 sq m/ha (110 ft^2 / ac) timber basal area, 10% bare ground post-burn, and canopy shading of 97%, in the SMZ.

Rainfall Measurements

At each site, rainfall was measured with an Onset RG-2 tipping bucket rain gauge with a HOBO event recorder, which recorded every 0.03 cm (0.01 inch of rain). The tipping bucket gage readings were within 5 % of standard gauge (True-Check brand) readings for the same sites. Freezing rain and snow events practically never occurred. However, several months of data were lost on the plantations due to malfunctions, launch failures, and plugging of the bucket outlet by seeds. During periods of tipping gage malfunction, the standard gage totals were distributed using data from the USGS gauge at Penfield (#02218300) 2 km (1 mile) north of one site and/or data from the other sites. Storm data for February 2004 prior to installation at the reference site were interpolated by averaging the data from Lewis and USGS Penfield, since winter storms tend to have uniform rainfall over a wide area and the reference was between these two sites. Only rain depth values were adjusted, with no attempt made to reconstruct intensity or duration, since these are highly localized. In spite of these problems, most of the tipping bucket data were good for most of the study. No other nearby published rain data were found during an internet search.

The spring and summer of 2003 were wetter than normal and the following fall, winter and spring drier than normal. The summer of 2004 was wetter than normal with the final study month of September far exceeding the norm (Tables 2.4, 2.5, Figure 2.5).

Runoff Data Collection

Runoff cups (Dunne et al. 1975) were placed in a single line at 30 meter taped intervals along the top edge of the SMZ at the plantations and along the simulated edge for the reference site. Heavy logging debris or roots occasionally necessitated slight placement adjustments. A 9 cm (3.5 inch) diameter bulb planter was used to drill a smooth-sided hole in the ground and a Solo 270 ml (nine ounce) plastic beverage cup placed inside the hole with the lip level with the ground. Two 30 cm (12 inch) stakes were driven on the uphill side of the cup and a 900 cm^2 (144 in^2) piece of a roofing shingle tacked onto the stakes covered the cup from rain (Figure 2.6). A total of 271 runoff cups were installed, 123 cups at Lewis, 69 at Vanir, and 79 on the reference site (Figures 2.2 -2.4). The path for checking line was established downhill of, or connecting, the cups except in a few places where areas of heavy debris or gully hazards necessitated walking uphill. In those cases, an effort was made never to step directly in front of a cup, especially during wet weather, to avoid compacting the soil.

After each rainfall in excess of 13 mm (0.5 inches), as shown on the standard gauge, cups were checked for absence or presence of water, emptied, and the setup reset and repaired as needed. In practice, cups were often checked after 9 cm (0.35 in) events. Even in the absence of rainfall, the cups required inspection every two weeks for minor repairs. Cups were usually checked within 48 hours post-storms. The two planted sites were each checked about 60 times over the 20 month study period, and the control site 27 times over eight months (Tables 2.4, 2.5).

Early in the study a bimodal distribution of volumes was observed, resulting in a rough classification system. Volumes of water in the cups were estimated by quarters plus two additional categories of "trace" and "submerged" were added (Table 2.6). "Trace" was just a few drops of water insufficient to cover the bottom of the cup, while submerged meant the cup was underwater in a puddle or ephemeral flow and the cup could not be emptied and/or replaced in the hole.

Several problems were caused by either too little or too much water. "Trace" tallies (<5 ml) were thrown out due to possible confounding effects of raindrop splash, condensation, blowing rain, and drip from the underside of shingles. However, at least some of these small cup volumes could have actually been due to runoff. Excess water sometimes caused full or partial displacement of cups from holes ("risers"), particularly in wet areas of Lewis. Other causes of elevated cups were: filling of the hole under the cup with mud, dirt, or roots, animal activity, or cups sticking to the glue on the shingles in hot weather. The most consistent "risers" on the south end of the Lewis tract were eventually weighted with 2300 g (5oz) of fishing sinkers. While the glue problem was not solved, replacement shingles were installed gravel side up, leaving the largest glue patch on top of the shingle. Since the vast majority of risers seemed to be caused by high ground water in variable source areas, this tally was included in the frequency data.

Submerged cups were counted until the area dried around them. The tally was thrown out once at that point, since the contents could not be positively assigned to an individual storm, they were then emptied and reverted to normal status.

Frequently occurring repairs were: tacks pulling through the shingles, loss of shingle integrity over time, stake rotting or splitting, holes filling, and ant poisoning. In most cases these issues were corrected before they became major problems. The tally was thrown out for individual cups with serious problems, until fixed. The shingles evidently provided attractive cover for ants (especially fire ants, *Solenopsis spp*.). When ant nest building became a problem uphill of the cup, the cup setup was moved up or downhill by a meter, perpendicular to the cup line. About 15% of the cups were moved during the study, and ants were poisoned on nearly every trip in the summer. The immediate areas in front of the cups were clipped during the first season to minimize canopy drip from vegetation and brush, but trees (> 7.5 cm or 3 inch stump diameter) on the SMZ boundary were left in place.

Grab Sampling and Collectors

A limited amount of water chemistry data (sediment, nitrates, and phosphates) were obtained from grab sampling during six major events, which included five named tropical storms (Table 2.6). Two storms were sampled in the summer of 2003, one in the winter of 2004, and three in the summer of 2004. Sampling locations were generated from a random number list of cups at each planted site. Runoff water from concentrated flow tracks was located near each sample number, collected in an acid-washed Nalgene bottle, and the location flagged for later mapping (Figures 2.7, 2.8). If no flow was found in the area, puddles were grab sampled that had been recently flowing into the SMZ as shown by matted vegetation. The samples were iced down at the truck, brought to the lab, and filtered for sediment, using coarse and medium prefilters if necessary, ending with a fine filter. The fine filters were Whatman 934-AH borosilicate fiberglass with 1.5 *u*m diameter pores, as specified in Standard Methods (Eaton et al. 1995). The filters were weighed for Total Suspended Solids (TSS) and the filtrate analyzed for nitrates and phosphates using a Hach DR890 Colorimeter. The concentrated flow tracks noted during the storms were often not discernible afterwards due to small size, non-disturbance of litter, and only temporary disturbance of vegetation. Runoff effects, frequency, duration, and visibility of flow tracks decreased noticeably during the latter period of the study.

Seven metal collectors, as described by Franklin et al. (2001) and Sheridan et al. (1996) were installed at Vanir during the summer of 2003 a little farther uphill than the runoff cups to avoid effects of canopy drip. TSS data from nine storms was obtained from them the following summer.

Cover Plots

All vegetation data were taken at the stand scale, and not linked to specific runoff cups. Cover plots were taken at the end of the first and second growing season (Sept 2003 and August-September 2004) but before leaf drop (Figures 2.7 – 2.9). The two plantations were surveyed using a line plot method by hand compass and pacing, similar to standard timber cruising procedure. Categories were bare ground, gravel/rock, litter, plant, and woody debris. Litter was defined as dead leaves, dead plants, or twigs under ½ inch (5 cm) in diameter, or small or nearly rotted bark flakes. Readings were made just off the side of a two-meter pole laid on the ground. Nine readings were taken at each plot at one meter intervals in a cross pattern (four in the line of travel, four at right angles, and one at plot center). Other parameters measured were depth of lightly compressed litter at plot center and tallest height of dominant vegetation (almost always herbaceous) within a two meter radius of plot center.

Plots were also taken in the SMZ of the plantations. In addition to the plot system described above, other data included timber basal area, midstory, and densiometer canopy readings (Table 2.3). Basal area of pine and hardwood was taken with a 10 factor prism, for trees greater than or equal to 13 cm (five inches) diameter at breast height (DBH) and converted to square meters per hectare. Midstory was counted inside of a 1/1000 hectare plot for stems from 0.1-13 cm at DBH. In both cases, all live woody (but not vines or herbaceous) stems were counted. Two spherical densiometer readings of canopy cover were taken at each plot. The directions of the readings were generated from a random number list. Because of the linear and directionally erratic nature of the SMZ, the plots followed the corridor with a fixed distance between plots. Directions were set at 10 degrees off the stream or SMZ edge and reset whenever a boundary was reached. The entire SMZ was traversed in the area covered by the cups. A similar system was also used on the reference area, except a cardinal direction line plot system was used for upland plots, with zigzag plots in the SMZ (Table 2.3).

Mapping and GPS

Site features were mapped with a Trimble GeoExplorer 3 GPS unit with a theoretical maximum Horizontal Dilution of Precision (HDOP) below three meters (Table 2.7). Most features were mapped as points with the more important or problematic points repeated 3-10 times for better accuracy. The cups were mapped during the dormant season due to heavy canopy in the SMZ. Due to canopy interference, streams at Vanir and the control site and cups at the control site were remapped with a Trimble ProXR with an external antenna with a theoretical mean HDOP below 1.1 m.

All readings were differentially corrected. Features such as public roads near the study site were obtained from the Georgia GIS Clearinghouse (http://gis1.state.ga.us), county maps and 1999 Digital Ortho Quarter Quads (DOQQs). Soil maps of the planted sites were obtained from the landowner and digitized in. NRCS (in Greensboro and Athens) supplied ArcView shapefiles for the Watson Springs area, since the soil survey is unpublished. They also supplied "K" values and other soils information. Decks and larger skid trails were traced from large- scale (1:7920) post –logging aerial photos taken by the landowner, scanned and digitized, rubber sheeting from the roads shown on the photos and previous GPS work.

Gullies and larger active or inactive concentrated flow tracks that were near the SMZ were also GPS mapped. Partway through the project, a switch was made from mapping gullies with line features to mapping with points (usually 10 per position), which gave more accurate positions. Relevant streams were point mapped in a similar fashion to gullies. Downloading and clean up were done as soon as possible post field work.

GPS features and other digitized data were converted into ArcView 3.2 shape files used for generating maps. Frequently used extensions were Spatial Analyst and XTools. Elevations and slopes used in site description were derived from Digital Elevation

Models (DEMs) downloaded from the Georgia GIS Clearinghouse, and converted to raster using 30 meter cells.

Concentrated Flow Tracks (CFTs)

Measurements were taken on concentrated flow tracks (CFTs) which were still active and which crossed into the SMZ, in July through August 2004 (second growing season of the study). The SMZ boundary used in the plantations was the runoff cup line or standline established by management. Since all the timber was standing at the reference site, the minimum distances and slopes suggested by the forestry BMP manual (Ga. EP Division et al. 1999) were used for the SMZ boundary (Table 2.8). These did not always coincide with the runoff cups, which were visually estimated factoring in slope, distance, and vegetation, according to common industry practice for establishing SMZs.

The classification system for CFTs was the same one used by Rivenbark and Jackson. (2004) (Table 2.9), based on texture delivered to the stream. “Active” was defined as having a visible path cut through the litter into the SMZ. Measurements, which were more quantified in this study, included length and width of eroding areas and ground cover in the channel, sidewall, contributing area, and nearby area. The same five categories of ground cover used in the cover surveys were classified at 50 intersects within a 0.5 meter (1.6 ft) by 0.25 meter (0.8 ft) PVC frame stung with wires. Slopes were measured by clinometer. CFT width was measured at the flat part of the channel bottom. “Contributing area” was considered to be visibly eroding areas near the CFT, and slopes likely to erode into the CFT, and usually consisted of a narrow strip to each side.

“Hydrologic area” was basically the watershed of the CFT. Short distances were taped, hip chained, or measured with a pole to the nearest 0.5 meter. Long or inaccessible distances, typically the hydrologic area, were paced or estimated. Since many areas of concentrated flow visible during high rainfall events do not have enough energy to cut through the litter layer, the active CFTs recorded were only a small fraction of potential contributors to runoff in the SMZ during actual rain events, and a much smaller number than observed at the beginning of the study.

Data Analysis

Runoff frequency statistics were analyzed by storms, cups, seasons and years for storms greater than 13 mm in depth, but the entire dataset, including smaller storms, was used for regression analysis . Descriptive statistics (after log-x transformations) and regression analyses were done in Microsoft Excel ™. One storm was defined as having a minimum 24 hour dry interval during the dormant season (Nov. 1 - April 30) and 12 hours during the growing season (May 1 - Oct 31). In cases of multiple storms between cup checks, the data were attributed to the storm of greatest total amount, which nearly always coincided with greater intensities. Storm durations and mean intensities were calculated using the last or second to last tip (Onset Computer Corporation 2001). The second last tip was used if there was a very long interval between the second last and last tips, as compared to the preceding tips. The RUSLE “R” factor was adjusted upwards as suggested by McGregor et al. (1995), and practiced by Ward and Jackson. (2004), for other Piedmont study sites.

Table 2.1. Description of surface runoff study sites, Greene County, in Georgia Piedmont

	Lewis			Vanir			Watson Springs		
	Upland	SMZ	Str[1]	Upland	SMZ	Str[1]	Upland	SMZ	Str[1]
Area (ha) or length (km)	82	8	3.3	27	4	1.1	30	6	1.6
Elevation Range[2] (m)	140 -197	139 -174		145 -179	141-158		140 -179	140 -165	
Median Elevation[2]	169	152		162	149		161	148	
Slope Range[2] (%)	0 - 20			0 - 19			0 - 23		
Median Slope[2] (%)	6.7	4.5	1.8	6.7	8.5	2.9	8.2	6.6	3.4
Stream Orders (field mapped)			0-2			0-1			0-2
Perennial Stream Density (km/km^2)			2.3			1.2			2.8
Stand Type	Pine Plt.	Hdwd		Pine Plt.	Hdwd		Nat.P/H	Nat.H/P	
Year Established	2003	1955*		2003	1955*		1933*	1933*	

[1]Str = Stream

[2]Elevation and slopes derived from USGS 1979 DEM, downloaded from Ga. GIS Clearinghouse

* Estimated

Table 2.2. Timeline of treatments and research for surface runoff study in Georgia Piedmont

Period	Year	Activity
-----------------Plantations (Lewis and Vanir Sites)-------------------		
	2001	Clearcut
May	2002	Herbicide
August	2002	Spot Pile
		Subsoil / Bed
Jan	2003	Plant pines
Feb	2003	Install cups
		Start monitoring
Summer	2003	Install collectors (Vanir only)
		First grab sample event
		Cover Plots
Summer	2004	Collector data
		Cover plots
		CFT measurements
Sept	2004	Complete monitoring
		Last grab sample event

Period	Year	Activity
-------------------Reference (Watson Springs Site)--------------------		
Spring	2003	Control burn of west side
Feb	2004	Install cups
		Start monitoring
March	2004	Plow firelanes east side
		Control burn of east side
Summer	2004	CFT measurements
		Start cover plots
Sept	2004	Complete monitoring

Table 2.3. Description of cover on overland flow study sites in Georgia Piedmont

	Older Stands			
	Lewis	Vanir	Watson Springs	
	SMZ[1]	SMZ[1]	Upland[2]	SMZ[1]
End of Growing Season	2 (2004)	2 (2004)	(2004)	(2004)
Age (years)	50 Est	50 Est	72 Est	72 Est
Canopy Shading (%)	88	87	90	97
Total BA (sq m/ha)	23.9	24.2	24.0	25.3
Pine Basal Area	2.4	0.9	12.5	7.9
Hardwood BA	21.5	23.3	11.6	17.4
Midstory (stems/ha)	2500	1500	2600	2800
Ground Cover (%)				
Bare	0	2		10
Litter	73	87		81
Plant	20	6		3
Woody Debris	6	5		5
Gravel/Rock	0	0		1
Tamped Litter Dep.(mm)	9	10		3
	Young Pine Plantations			
	Lewis		Vanir	
End of Growing Season	1 (2003)	2 (2004)	1 (2003)	2 (2004)
Age (years)	0	1	0	1
Max.Herb. Height (cm)	155	175	170	175
Planted Pine Hgt.(cm)		150		130

[1]SMZ conditions in first growing season assumed to be similar to second.

[2]Cover and litter depth for upland area of Watson Springs are shown in the results section.

Table 2.4. Summary of rain events by month during overland flow study period, Greene County, in Georgia Piedmont.

Month	Total Rain[1,2] (mm)	Storms 1-13 mm[3] (number)	Storms >13 mm[3] (number)	Max Single Storm[3] (mm)	Max 1 Hr Intensity[3] (mm/hr)	Runoff Checked (number)
--Lewis Study Site--						
Feb-03	122	1	5	32	16	6
Mar-03	170	3	4	76	17	3
Apr-03	100	2	2	59	9	0
May-03	210	3	5	91	25	4
Jun-03	274	4	4	104	*	5
Jul-03	175	5	3	86	*	4
Aug-03	121	3	4	37	*	3
Sep-03	31	1	2	15	12	2
Oct-03	21	5	0	9	4	1
Nov-03	79	2	2	49	19	3
Dec-03	59	4	2	20	8	2
Jan-04	59	4	1	32	4	3
Feb-04	120	1	5	30	11	5
Mar-04	20	3	0	13	5	1
Apr-04	23	1	1	14	6	2
May-04	42	2	1	33	17	2
Jun-04	241	6	7	57	33	8
Jul-04	131	3	6	30	*	6
Aug-04	95	5	2	48	*	1
Sep-04	311	0	4	145	36	4
Total 20	2406	58	60			65
Mean	120	3	3	49	15	3
Maximum	311			145	36	

[1]Some data were obtained from nearby gages on this project or USGS at Penfield.

[2]Monthly totals summarized by time and date, including small amounts 0.02-1.3 mm.

[3]All other data summarized by storms and grouped into the storm with more rainfall.

* Missing tipping bucket rain gauge data

Table 2.5. Summary of rain events by month during overland flow study period, Greene County, in Georgia Piedmont.

Month	Total Rain[1,2] (mm)	Storms 1-13 mm[3] (number)	Storms >13 mm[3] (number)	Max Single Storm[3] (mm)	Max 1 Hr Intensity[3] (mm/hr)	Runoff Checked (number)
--Vanir Study Site--						
Feb-03	146	0	5	49	31	5
Mar-03	177	3	4	73	14	3
Apr-03	121	1	3	62	15	1
May-03	165	1	6	52	26	4
Jun-03	172	3	4	52	16	5
Jul-03	175	7	3	118	34	6
Aug-03	75	5	3	24	21	2
Sep-03	32	2	1	25	8	1
Oct-03	36	5	1	17	15	2
Nov-03	80	2	2	52	25	3
Dec-03	58	4	2	24	6	2
Jan-04	64	4	1	37	5	2
Feb-04	139	1	5	36	10	5
Mar-04	18	4	0	11	4	1
Apr-04	32	2	1	19	10	2
May-04	45	4	1	33	13	3
Jun-04	145	4	4	36	*	5
Jul-04	49	6	1	24	*	2
Aug-04	136	3	3	71	*	2
Sep-04	320	1	3	148	25	3
Total 20	2184	62	53			59
Mean	109	3	3	48	16	3
Maximum	320			148	34	
-----------------------------------Watson Springs Study Site----------------------------------						
Feb-04	124	1	5	30	*	3
Mar-04	22	3	1	16	5	1
Apr-04	24	1	1	14	6	2
May-04	41	1	1	31	17	2
Jun-04	291	3	9	50	44	9
Jul-04	152	3	4	48	43	5
Aug-04	88	3	2	50	30	1
Sep-04	322	0	4	134	28	4
Total 8	1063	15	27			27
Mean	133	2	3	47	25	3
Maximum	322			134	44	

[1]Some data were obtained from nearby gages on this project or USGS at Penfield.

[2]Monthly totals summarized by time and date, including small amounts 0.02-1.3 mm.

[3]All other data summarized by storms and grouped into the storm with more rainfall.

* Missing tipping bucket rain gauge data

Table 2.6. Storm depths, dates and numbers of storm samples analyzed, overland flow study, Greene County, in Georgia Piedmont

Storm Date	Storm Depth (mm)	TSS	Dissolved Nitrates	Dissolved Phosphates
		Number of Samples		
Lewis Study Site Grab Samples				
6/7/2003	104	11	11	11
7/1/2003	86	10	0	10
2/6/2004	30	11	11	11
8/12/2004	48	8	9	9
9/7/2004	81	8	10	10
9/17/2004	51	10	10	10
Total Year 1[a]		21	11	21
Total Year 2[b]		37	40	40
Total Lewis		58	51	61
Vanir Study Site Grab Samples				
6/7/2003	52	6	6	6
7/1/2003	118	6	0	6
2/6/2004	34	6	6	6
8/12/2004	71	0	0	0
9/7/2004	114	7	7	7
9/17/2004	52	5	5	5
Total Year 1		12	6	12
Total Year 2		18	18	18
Total Vanir		30	24	30
Vanir Study Site Collectors				
6/9/2004	36	3		
6/24/2004	35	2		
6/27/2004	28	2		
7/2/2004	24	2		
8/12/2004	71	3		
8/30/2004	26	3		
9/7/2004	114	2		
9/17/2004	52	4		
9/29/2004	148	5		
Total Year 2		26		

[a] Year one included nine months post planting from 2/2003-10/2003

[b] Year two included 11 months from 11/2003-9/2004

Table 2.7. Sources of GIS data for surface runoff study in Georgia Piedmont

Item	Data Source [1,2]	Tract [3]	Unit [4,5]
Burned Areas	GPS	WS	
CFTs	GPS		
Contour Lines	DRG		
County Map	ESRI database		
Cover Lines	GPS, taped distances		
Culverts	GPS		
DEMs	Spatial Clearinghouse		
Fire Lines	GPS		
Food Plots	GPS 4,5		
Grab Sample Points	GPS, taped distances	L,V	
Gullies	GPS		
Logging Decks	Landowner uncorrected aerial photos		
Pond	Spatial Clearinghouse		
Pond	GPS		
Property Boundaries	GPS, landowner maps		
Rain Gauge	GPS		
Roads, County	GPS, DOQQs, DRGs		
Roads, Internal	GPS		
Runoff Cups	GPS		
Skid Trails	Landowner uncorrected aerial photos	L,V	
Skid Trails	GPS		
Soils	Landowner maps	L,V	
Soils	NRCS	WS	
Stand Lines	GPS, estimated, landowner maps		
State Map	ESRI database		
Streams	GPS	L	Geo 3
Streams	GPS	V, WS	ProXR
Utility Lines	GPS	L, WS	
Utility Lines	GPS, DOQQ	V	
Variable Source Areas	GPS	L,V	

[1]DRGs were downloaded from the Georgia GIS clearinghouse

[2]1999 DOQQs were downloaded from the Warnell School of Forestry & Natural Resources database

[3]Location = L, Lewis; R, Watson Springs; V, Vanir.Unspecified locations refer to all sites.

[4]Except as noted, nearly all GPS work at Lewis and Vanir used the Trimble GeoExplorer 3

[5]Nearly all GPS work at Watson Springs used the Trimble ProXR.

Table 2.8. Georgia forestry Best Management Practices recommended minimum Streamside Management Zone widths per side [1]

Slope Class	Slope	------------------Minimum Width--------------------			
		-------Perennial----------		-------Intermittent-------	
	(%)	(m)	(ft)	(m)	(ft)
Slight	< 20	12	40	6	20
Moderate	21 - 40	21	70	11	35
Steep	> 40	30	100	15	50

[1]Adapted from Ga. EPD and GFC 1999, p.9, excluding trout streams

Table 2.9. Definitions of situations in concentrated flow tracks (CFTs)[1] for overland flow study in Georgia Piedmont.

Situation	Definition	Evidence
	Active concentrated flow track	Litter scour enters SMZ
1	Sand, silt and clay reaching stream	Sand piles near creek
2	Silt and clay reaching stream	Staining of leaves
3	Clay reaching stream in flow of water	Other visible scoured channel
4	Sediments filtered out in SMZ	Scoured channel ends in SMZ before reaching stream

[1] Adapted from Rivenbark and Jackson (2004)

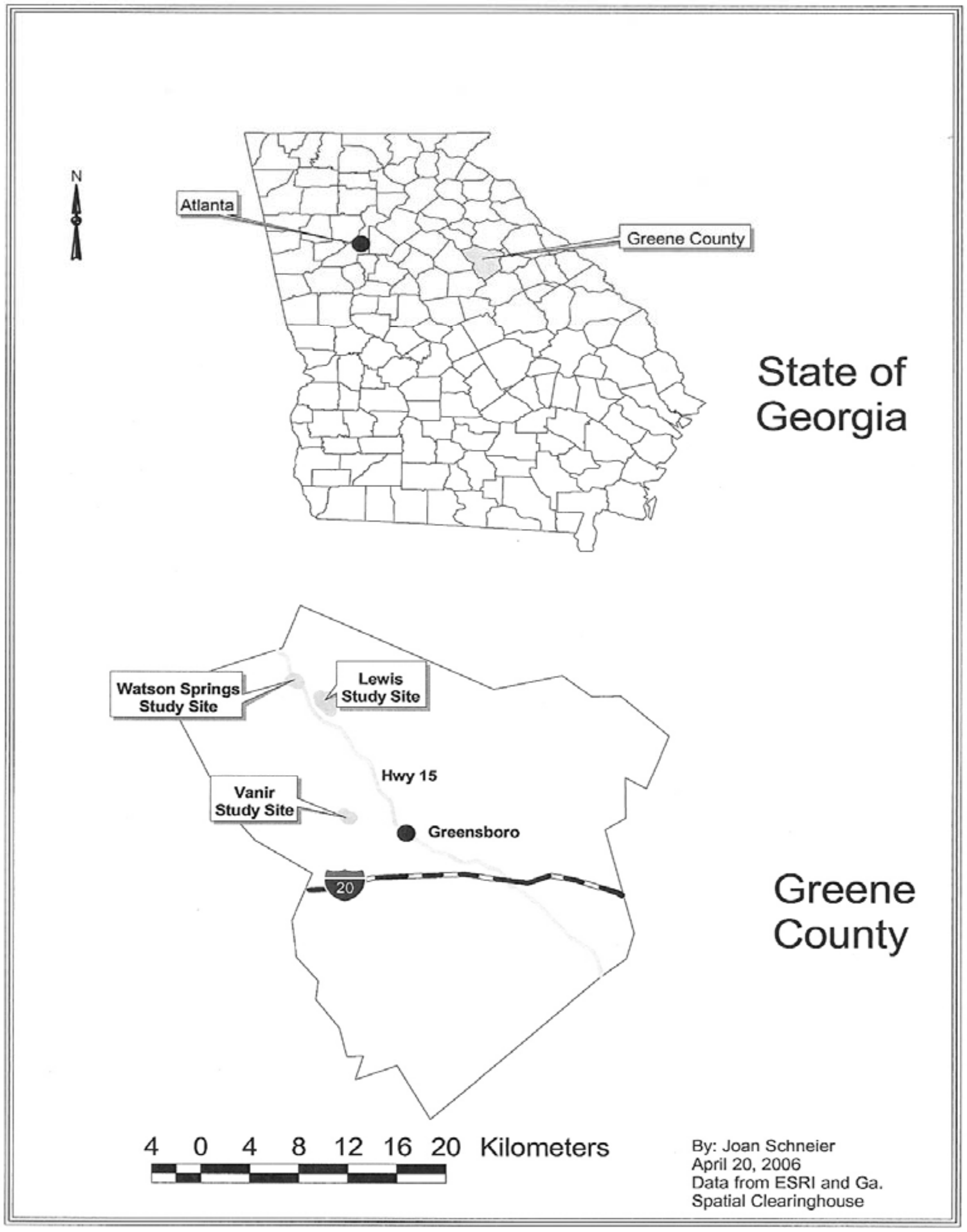
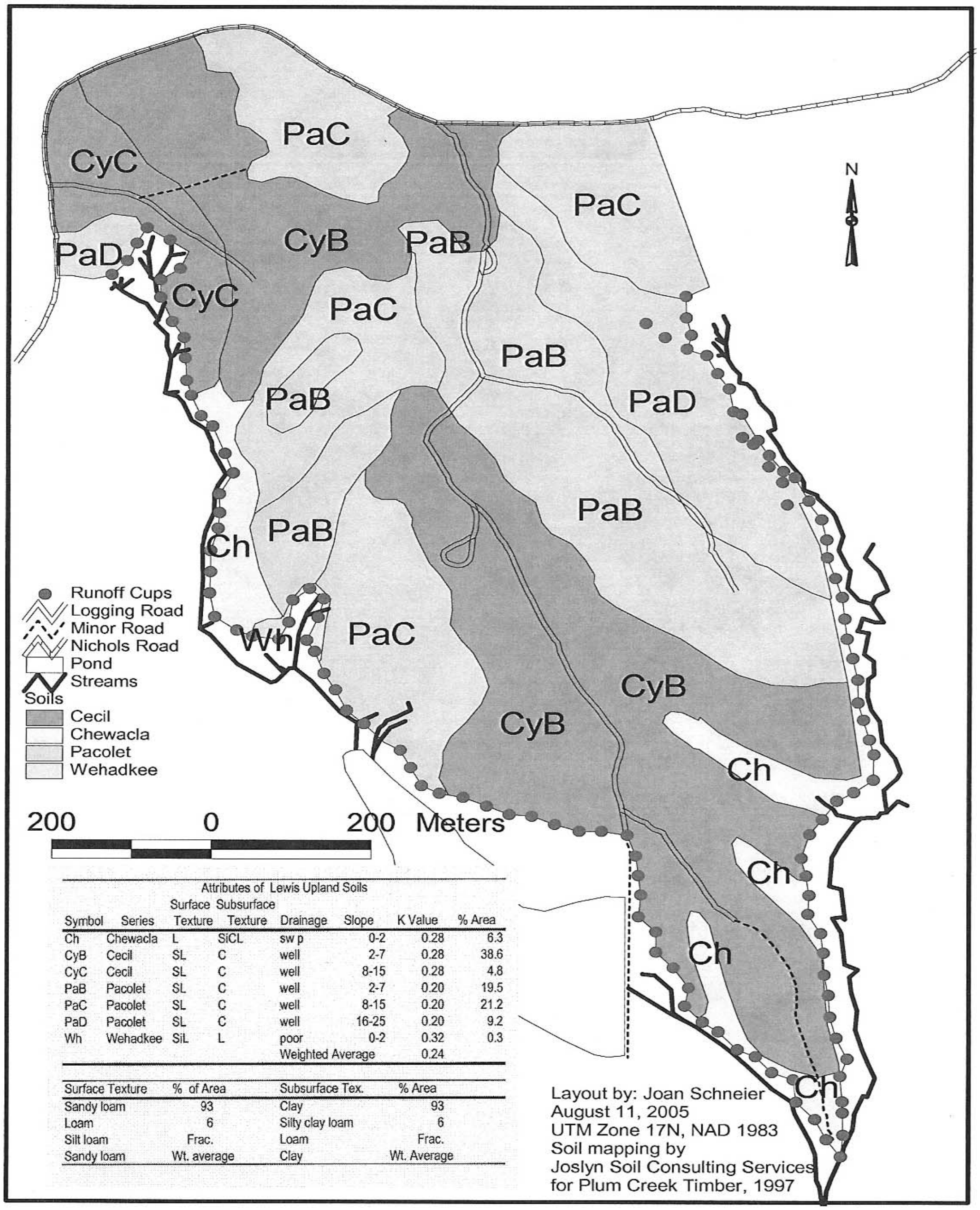


Figure 2.1. Location of three overland flow study sites, Greene County, in Georgia Piedmont

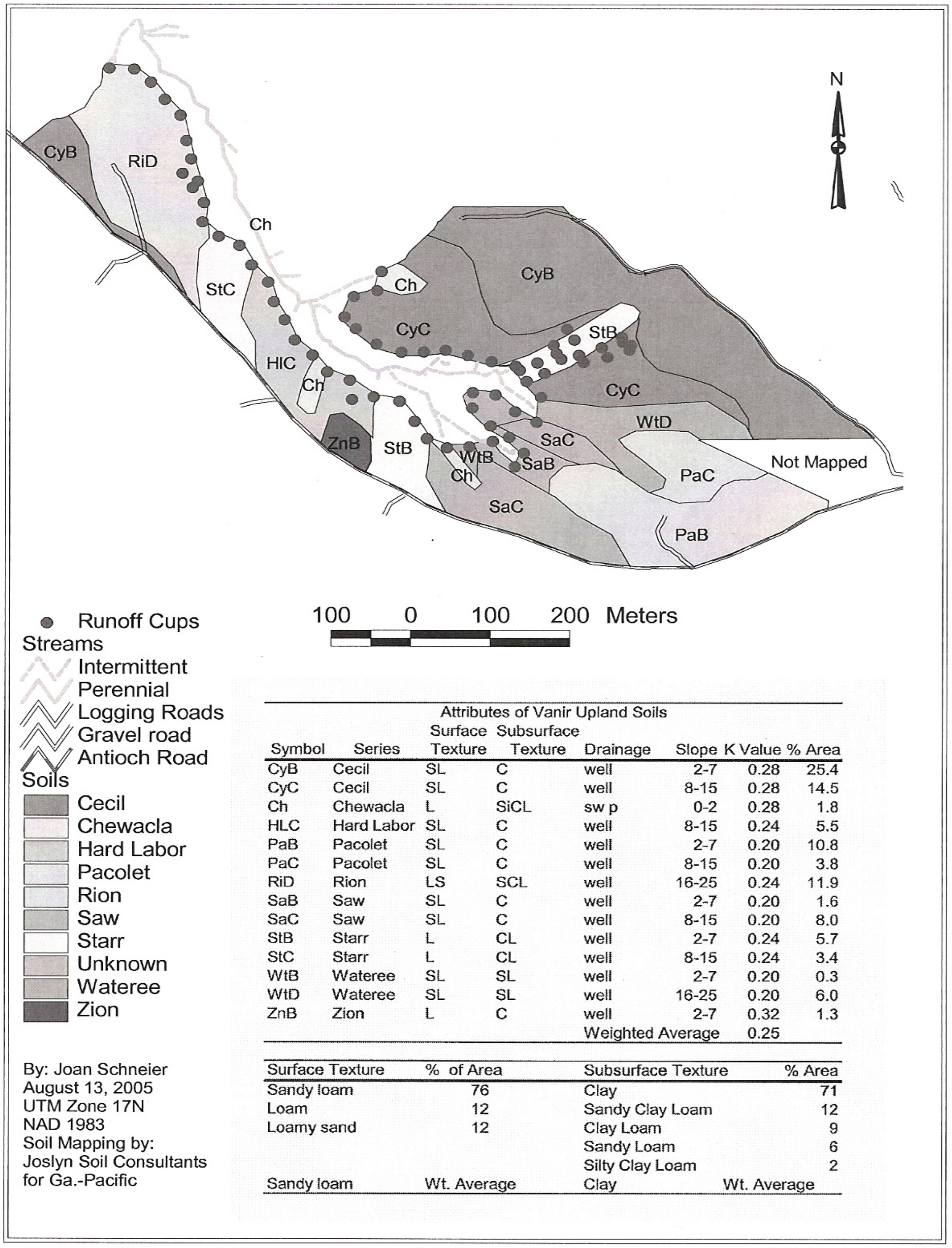


Attributes of Lewis Upland Soils

Symbol	Series	Surface Texture	Subsurface Texture	Drainage	Slope	K Value	% Area
Ch	Chewacla	L	SiCL	sw p	0-2	0.28	6.3
CyB	Cecil	SL	C	well	2-7	0.28	38.6
CyC	Cecil	SL	C	well	8-15	0.28	4.8
PaB	Pacolet	SL	C	well	2-7	0.20	19.5
PaC	Pacolet	SL	C	well	8-15	0.20	21.2
PaD	Pacolet	SL	C	well	16-25	0.20	9.2
Wh	Wehadkee	SiL	L	poor	0-2	0.32	0.3
				Weighted Average		0.24	

Surface Texture	% of Area	Subsurface Tex.	% Area
Sandy loam	93	Clay	93
Loam	6	Silty clay loam	6
Silt loam	Frac.	Loam	Frac.
Sandy loam	Wt. average	Clay	Wt. Average

Figure 2.2 Soil map of Lewis study site, Greene County in Georgia Piedmont.

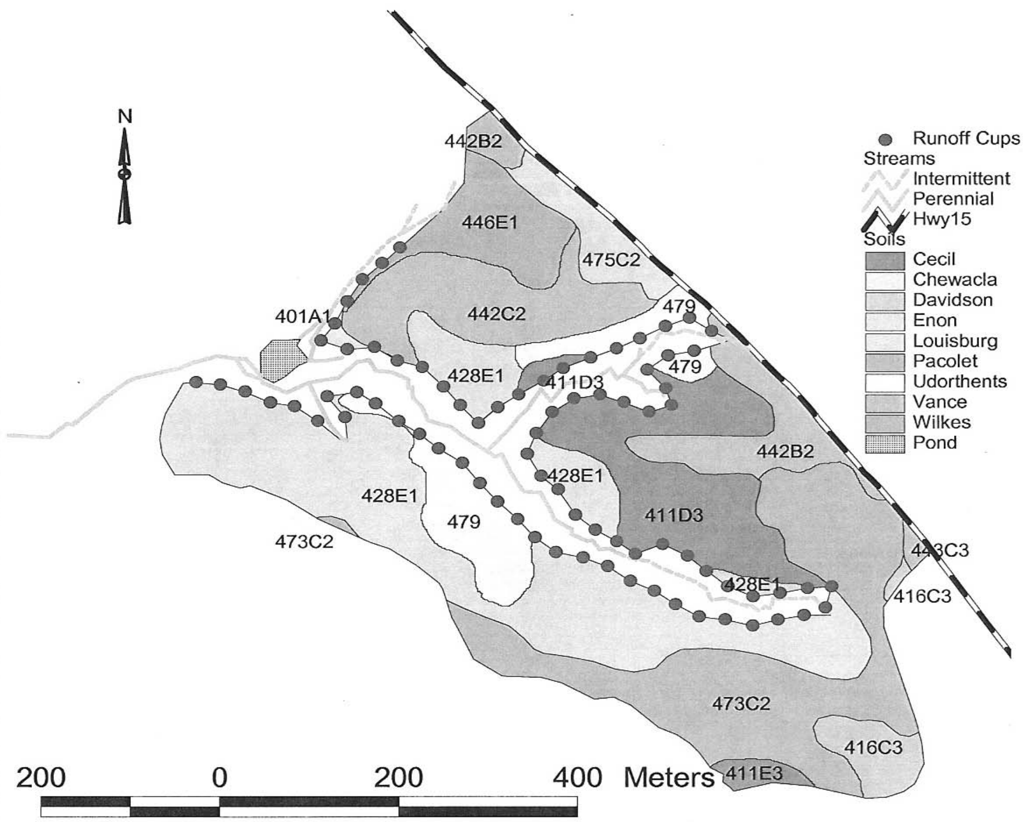


Attributes of Vanir Upland Soils

Symbol	Series	Surface Texture	Subsurface Texture	Drainage	Slope	K Value	% Area
CyB	Cecil	SL	C	well	2-7	0.28	25.4
CyC	Cecil	SL	C	well	8-15	0.28	14.5
Ch	Chewacla	L	SiCL	sw p	0-2	0.28	1.8
HLC	Hard Labor	SL	C	well	8-15	0.24	5.5
PaB	Pacolet	SL	C	well	2-7	0.20	10.8
PaC	Pacolet	SL	C	well	8-15	0.20	3.8
RiD	Rion	LS	SCL	well	16-25	0.24	11.9
SaB	Saw	SL	C	well	2-7	0.20	1.6
SaC	Saw	SL	C	well	8-15	0.20	8.0
StB	Starr	L	CL	well	2-7	0.24	5.7
StC	Starr	L	CL	well	8-15	0.24	3.4
WtB	Wateree	SL	SL	well	2-7	0.20	0.3
WtD	Wateree	SL	SL	well	16-25	0.20	6.0
ZnB	Zion	L	C	well	2-7	0.32	1.3
				Weighted Average		0.25	

Surface Texture	% of Area	Subsurface Texture	% Area
Sandy loam	76	Clay	71
Loam	12	Sandy Clay Loam	12
Loamy sand	12	Clay Loam	9
		Sandy Loam	6
		Silty Clay Loam	2
Sandy loam	Wt. Average	Clay	Wt. Average

Figure 2.3. Soil map of Vanir study site, Greene County in Georgia Piedmont.



Attributes of Watson Springs Upland Soils

Symbol	Series	Surface Texture	Subsurface Texture	Drainage	Slope	K Value	% Area
401A1	Chewacla	SiL	CL	sw p	0-2	0.28	0.3
411D3	Cecil	SCL	CL	well	10-15	0.28	12.6
411E3	Cecil	SCL	CL	well	15-25	0.28	1.0
416C3	Davidson	CL	C	well	10-15	0.28	2.7
428E1	Louisberg	LS	SL	well	10-25	0.10	29.8
442B2	Vance	SL	C	well	2-6	0.24	6.5
442C2	Vance	SL	C	well	6-10	0.24	9.0
443C3	Vance	SCL	C	well	2-10	0.28	0.4
446E1	Wilkes	SL	C	well	10-25	0.24	5.7
473C2	Pacolet	SL	C	well	10-15	0.20	20.8
475C2	Enon	SL	SCL	well	2-10	0.24	3.4
479	Udorthents	clayey	clayey	sw p	0-2	variable	7.9
				Weighted Avg.		0.19	

Surface Texture	% of Area	Subsurface Tex.	% Area
Sandy loam	45	Clay	53
Loamy sand	30	Sandy loam	30
Sandy clay loam	14	Clay loam	14
Clay loam	3	Sandy clay loam	3
Clayey	8		
Silt loam	Frac		
Sandy loam	Weighted Average	Clay	Wt. Average

By: Joan Schneier
August 13,2005
UTM Zone 17N
NAD 1983
Soil mapping by:
NRCS

Figure 2.4. Soil map of Watson Springs study site, Greene County in Georgia Piedmont.

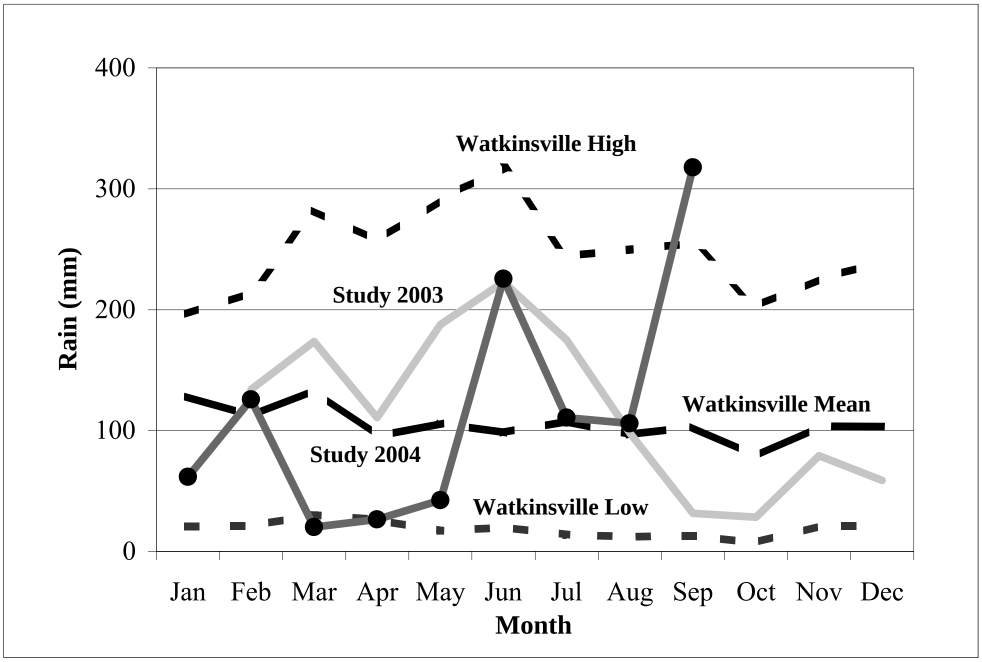


Figure 2.5. Comparison of historic rain at Watkinsville UGA Plant Farm[1] 1961-2002 (42 years) to surface runoff study period[2,3], Greene County in Georgia Piedmont.

[1]Watkinsville data from Ga. State Climatology Office

[2]Missing study data supplemented by USGS data from Penfield (#02218300)

[3]Average of study site rain gauges.

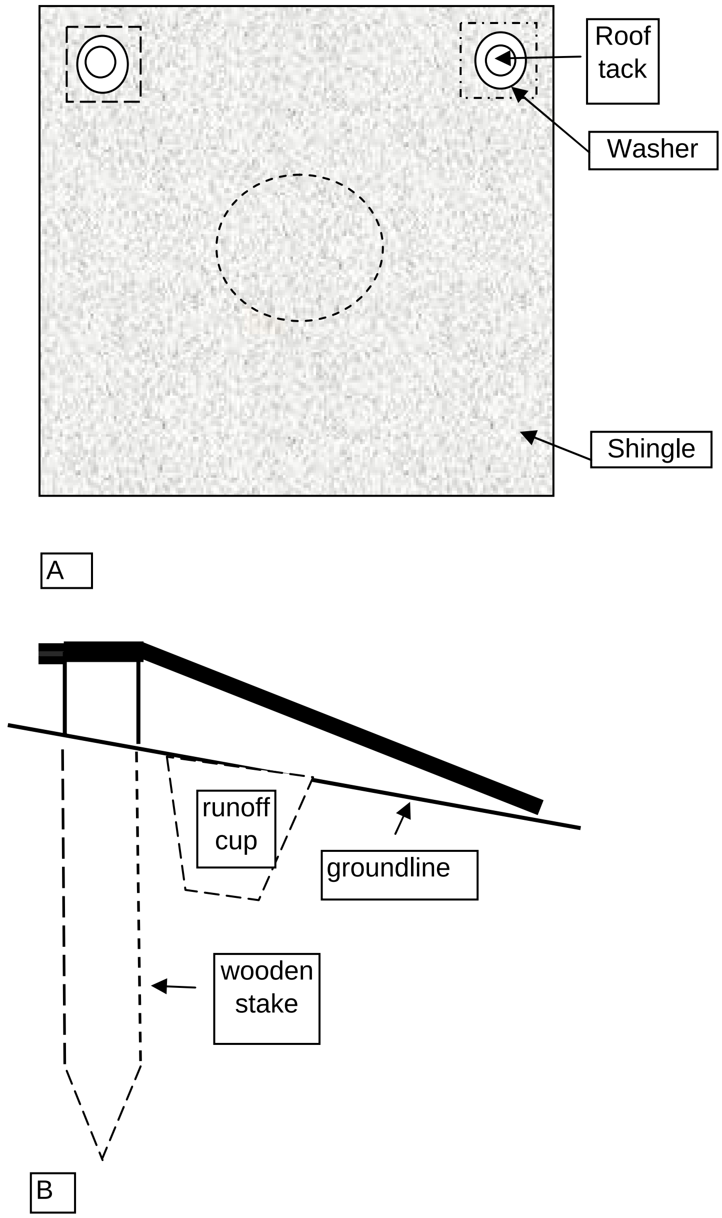


Figure 2.6. Diagram of typical runoff cup.
a) Top view[1] and b) Side view[2]

[1]Plastic washer or milk jug lid lessens shingle damage.

[2]On steep slope, cup should be normal to slope, not vertical.

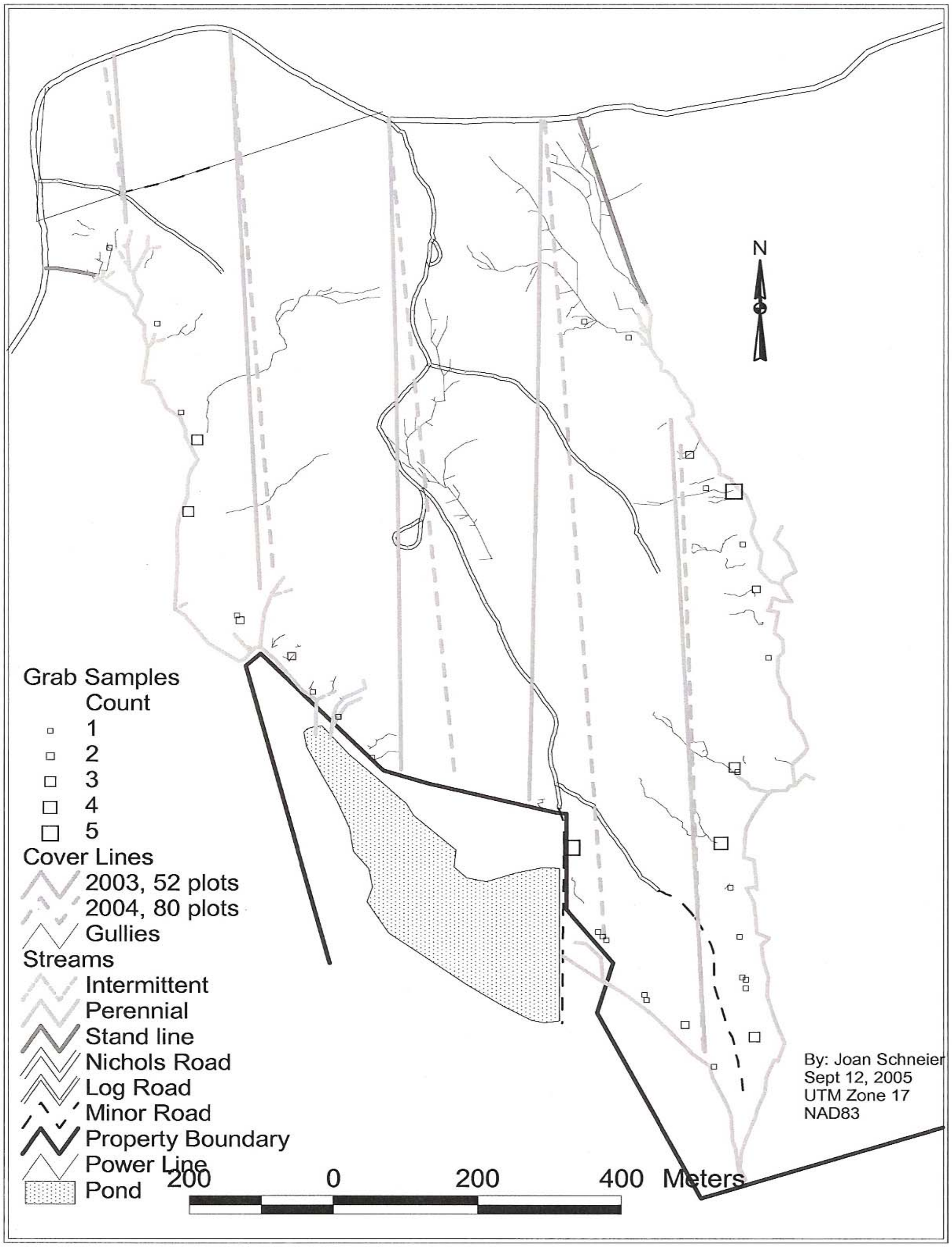


Figure 2.7. Map of cover plot lines and grab sampling points for Lewis study site, Greene County, in Georgia Piedmont.

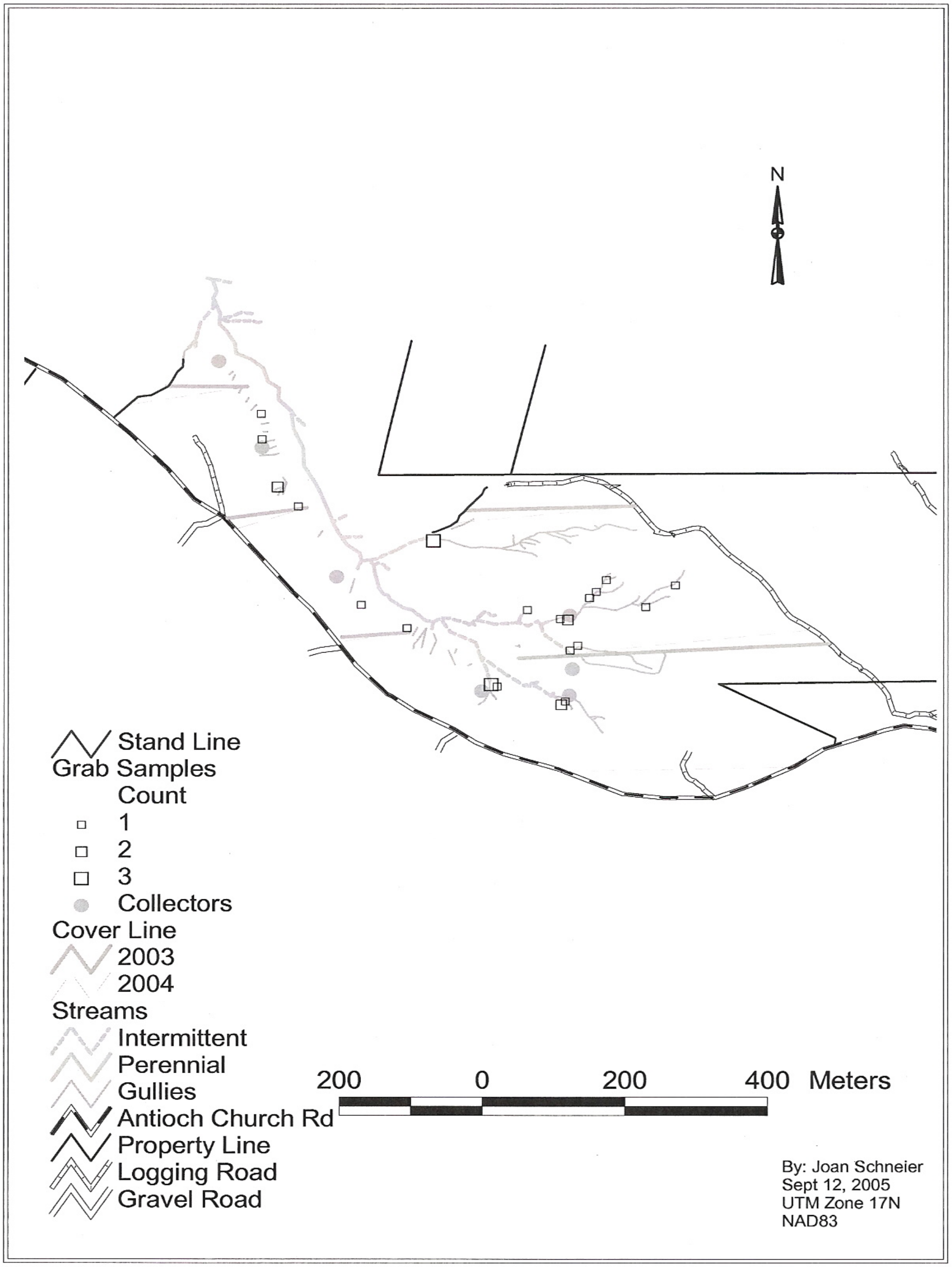


Figure 2.8. Map of cover plot lines and grab sampling points for Vanir study site, Greene County in Georgia Piedmont.

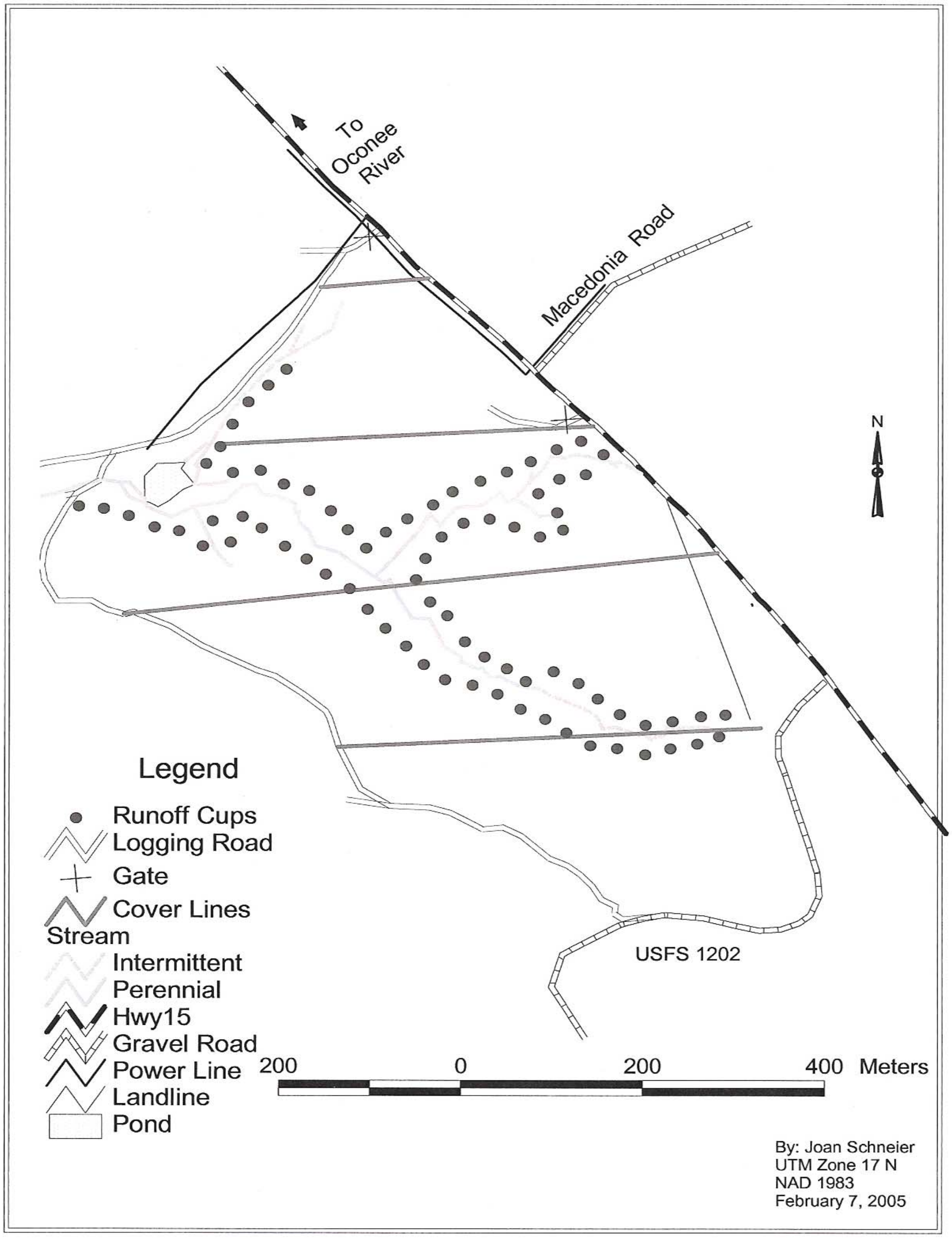


Figure 2.9. Map of cover plot lines for Watson Springs study site, Greene County in Georgia Piedmont.

CHAPTER 3

RESULTS AND DISCUSSION

Rainfall

Rainfall among the plantation sites was similar in the winter, due to widespread convective patterns with long durations. It was more variable in the summer in intensity, due to more localized thunderstorm activity (Figure 3.1). During the study period 2000 mm (79 inches) total fell at Lewis and 1728 mm (68 inches) total at Vanir, with high variations between storms (Tables 2.4, 2.5). Comparison of intensities between sites by seasons showed no statistical differences. However, combined data from both sites for 15 minute intensities showed a statistical difference between winter (8.1 mm/hr) and summer (19.3 mm/hr) (Table 3.1). This would imply that for surface runoff on these sites, Hortonian flow should be more important in the summer.

Surface Runoff Characteristics

Surface runoff frequency was highly variable within and between sites, and between storms. Lewis had the highest fraction of cup response with a mean of 14.3% and a standard deviation of 3.3% (Table 3.2, Figure 3.2). Only 2.1% of the storms generated no response whatsoever, and the highest single-event response rate was over 77%. Nearly all cups (96.7%) collected runoff at least once during the study. Vanir showed less surface runoff activity. The mean response was 6.4% with a standard deviation of 3.0%, and a high of 39.1%. About 2% of the storms generated no response and about 19% of the cups never received runoff. The reference site also had very low runoff frequency. The mean was 2.2% with a standard deviation of 7.2% and a high of 38.0% (Table 3.3, Figure 3.2). Nearly 21% of the storms generated no runoff and over 35% of the cups never had runoff. The reference data were collected over a shorter period but included four tropical storms. Frequency of runoff at Lewis differed statistically from Vanir for the dormant seasons and the combined total, and from the reference site in all categories. Vanir and the reference site were statistically similar. The combined plantations differed statistically from the reference site for year two and combined totals. All of the above was done by z and t-tests at alpha equal to 0.05.

Both plantations showed a drop in mean frequency from the first to the second year, but these were not statistically significant. The Lewis median moved from 22.5% to 11.7% and Vanir from 10.1% to 5.9% (Table 3.2), for storms above 13 mm. The second year cumulative distribution plot for the combined plantations much more closely resembled the reference site than the first year (Figure 3.3). This decrease in runoff over time, agreed with all similar southeastern studies. Seasonal differences of runoff frequency were variable. The logging debris plus beds created hydraulic roughness and depressional storage, which appeared to slow runoff and aid infiltration.

Frequency maps and field observations showed high variation in spacing and frequency within and between storms on each site, and between sites, (Figures 3.4 - 3.10) pointing to localized and microsite factors. More runoff was tallied in areas of concentrated flow and variable source areas, especially at Lewis. Some of these high frequency areas coincided with old gullies or the Chewacla soil series at Lewis (Figure 2.2), and old gullies at the other sites, but others did not.

Volumes of runoff were categorized by quarter runoff cups and exhibited a bimodal distribution (Figure 3.11). Readings below ¾ cup were reasonably accurate, but readings of full cups were only a minimum since an unknown quantity overflowed. Cups receiving only small volumes in one storm might be full in the next storm. During large storms, sheet flow could be 10 cm (four inches) deep. Some cups that usually had high volumes were not located in obviously concave topography or microsites. Old stable gullies, rills, and surface depressions leading into the SMZ were observed moving water in large storms, but later showed no disturbance of the litter layer. So while the extremes of sheet flow and concentrated flow were separable, the middle ground was ambiguous. Concentrated flows were sometimes observed inundating cups during grab sampling of large storms. Even following routine storms, fresh mud was sometimes seen on top of the shingle cup roofs.

Possible sources of variation were small storms, interpretation of risers, and small sample size. Smaller storms were not sampled but sometimes generated runoff, and this accumulated in the cup until the next check, less evaporation. Cups that were displaced from the bottom of the hole (risers) were assumed to be evidence of high water tables or variable source areas in low areas and subsurface lateral flow (or interflow) in better drained areas.

The greater frequency (and volume) of runoff at Lewis compared to Vanir was attributed to three factors: finer soil textures at the runoff cups, lower landscape positions, and slower regrowth of vegetation. Wohlgemuth et al. (2001) suggested that stream density provides an indicator of soil storage and drainage. This may have played a role in counterintuitive results in his runoff study on two otherwise well-matched sites. In the current study, the perennial stream density at Lewis was nearly double that of Vanir (Table 2.1).

Topographic analysis using USGS maps was foiled by coarseness of the 1:24000 scale. Extensive field experience shows that forested zero through second order streams are sometimes missed in USGS mapping or displaced in location (Figures 3.12, 3.13) (Hansen 2001). While mapping CFTs it became apparent that minor slope breaks on the ground were not always indicated on the contour maps.

The low frequencies at the reference site were attributed to the evapotranspiration pull of a mature forest and partial coverage of the site with a deep litter layer and relatively high organic matter in the O and A horizons over most of the surface. Conventional wisdom would hold that a mature undisturbed forest would generate runoff only in large rain events; however some runoff was tallied even in moderate events below 15 mm (0.6 in), following a litter-disturbing prescribed burn on this tract. The frequencies of runoff in the current study at all sites were lower than the other two frequency studies in the tropics in mature forests (Elsenbeer and Vertessy 2000; Godsey et al. 2004).

Rainfall Runoff Relations

Since rainfall is the most important driver of runoff, regression analysis was done on different rainfall components. Independent variables were storm depth, various maximum intensities plus mean intensity, antecedent moisture, and storm duration, compared with the dependent variable of runoff frequency. The "R" factor (rainfall erosivity) from the Revised Universal Soil Loss Equation and the SCS Curve Number method were also evaluated. The “R” factor was corrected by 28% for this section of the South, as recommended by McGregor et al. (1995).

Storm depth, all maximum runoff intensities evaluated, and the R factor were significant predictors of the response of runoff cups, with p- factors less than 0.001. The best correlations were for storm depth, maximum storm intensities greater than six hours, and for the R factor (Tables 3.4 – 3.6, Figures 3.14 - 3.22). The single best overall predictor was the R factor with r^2 values of 0.56 - 0.75. Storm depth had an r^2 of 0.46 - 0.66, 24 hour maximum intensity 0.47 - 0.64, and six hour intensity 0.49 - 0.59. The Lewis tract had the most runoff and best correlations. Most rain variables at both plantations showed a decreasing effect from the first to the second years, although differences were not always statistically significant. The reference site had a slightly different pattern, with best fit from RUSLE “R”, but best intensities for six-hour and two-hour intervals, and only minor differences between maximum intensities for any time interval.

Fits of the regressions for all sites deteriorated from longer duration maximum intensities to shorter intensities, (the 15 minute r^2 = 0.27- 0.49) but these shorter duration intensities still had predictive power, as shown by a low p-value (Table 3.4-3.6). Mean intensity (depth/duration), storm duration, 5 or 10 day prior rainfall, and the SCS curve number had weak or no correlations. Thirty day prior rainfall had a p-value below 0.05 at the two plantations but the r^2 was less than 0.15. This low p-value but low correlation paralleled the experience of Wischmeier and Smith (1958), which caused them to leave antecedent rainfall out of USLE. The SCS curve number greatly underpredicted runoff frequency but improved after deletion of its threshold (initial abstraction).

It was inferred that Lewis responded more to total rainfall due to more variable source areas caused by flatter topography near the SMZs, producing saturation overland flow. The other two sites had runoff in higher intensity events, as the Hortonian overland flow model suggests. The lower coefficients of determination (r^2) for shorter time maximum intensities were likely due to higher seasonal variability, noted above in the rainfall section. Unfortunately, good seasonal data for the first summer were only available from Vanir, which did not have much runoff at all. The reference site, with more evotranspiration demand, less compaction and perturbation, and presumably more macropores, could infiltrate most rainfall. Consequently, it had runoff only in the higher intensity events, and was less influenced by antecedent soil moisture. RUSLE “R” is based on a combination of kinetic energy of the storm, 30 minute maximum rainfall intensity, and indirectly, rainfall duration, and therefore blends factors. Since the 30-minute maximum intensities were less highly correlated than most other intensities, and rain duration had no relationship in this study, the energy portion of the equation presumably made up for these deficiencies.

Ground Cover

Despite the application of herbicides eight months before planting, vegetation made a rapid recovery throughout the first spring and summer, aided by plentiful rainfall (Figure 2.5). Bare ground at Lewis was 31% after the first growing season and 27% after the second growing season. Bare ground at Vanir was 27% after the first growing season and 11% after the second growing season (Table 3.7, Figure 3-23). The reference site had 29% bare ground the second year of the study, due to a prescribed burn over part of the area but still averaged 5 mm litter depth (Figure 3.10). The plantation litter depth layer increased from 2 to 4 mm from the first to second years. The tallest brush in the plantations was 178 cm and planted pines were 138 cm high at the end of the second growing season (Table 2.3).

Revegetation has many effects on water quality. On the plus side, the canopy breaks the impact of rainfall, and returns some directly to the atmosphere by interception. Vegetation creates evapotranspiration demand, and therefore drier soil between storms in the summer, causing more infiltration. Stems create hydraulic roughness, which slow down runoff and leaf drop contributes to the litter layer. Litter breaks the force of rain drops and acts as a sponge, slowing water movement by absorption and adsorbtion, allowing more infiltration and creating hydraulic roughness. Organic matter has a high surface area similar to fine clays (Brady and Weil 1999). On the minus side, runoff carrying leaf litter and other plant byproducts can export nutrients from the site, particularly water soluble nitrates. Also, herbaceous competition for on-site resources slows pine growth, so foresters like to “capture the site” by intensive site preparation and use of herbicides, baring more soil longer.

Although not formally studied, revegetation seemed to be the greatest factor in reducing runoff over the study period for both sheet and concentrated flow. This was particularly noticeable in the variable source areas at Lewis, where logging ruts were covered by a dense stand of sedges and other plants by the end of the first summer. At the reference site, of 23 active CFTs in early August 2004, 14 had stabilized nine months later, after leaf drop and spring growth.

Water Chemistry

Grab samples of plantation runoff were taken during six large storms and analyzed for soluble nitrates, soluble phosphates, and total suspended solids. Differences in water chemistry between plantations were minor, so the results were combined by year. Soluble nitrates decreased from the first to the second year (mean 2.1 versus 0.8 mg/L and median 3.4 versus 0.0 mg/L), but the number of samples was small in the first year (Figure 3.24). The phosphate mean was 0.21 mg/L the first year and 0.12 the second year, and the median 0.23 the first year, and 0.17 mg/L the second year. TSS data were highly variable between samples and storms; with up to a three order of magnitude range (Figure 3.25). The first and second year means were 54 and 36 mg/L, and the medians were 42 and 29 mg/L. Two samples were greater than 1000 mg/L, with the maximum 1436 mg/L, both from active concentrated flow tracks. TSS data from fixed collectors (mean = 66 and median = 80 mg/L) were only obtained during the second year and were slightly higher than the grab samples, although not statistically different. Collector data were cumulative throughout each storm, and between storms. Differences between years were not statistically significant for any of the water chemistry data in the same category.

EPA recommended targets for Southern Piedmont perennial streams at baseflow are 0.17 mg/L for nitrates, 0.01 mg/L for phosphates, and 6 NTU for turbidity (US Environmental Protection Agency 2000), which is equivalent to 6 mg/L TSS, in this area (Barnes 1998). Observed stormflow nutrients and sediment were 9-18 times these recommendations for perennial streams the first year, and 5-11 times these recommendations the second year. However, observed values were in the same range as other southeastern regeneration studies of ephemeral streams and runoff plots (Figures 26-28, Table 1.3). Reviewed studies of southeastern forest regeneration showed decreases in nutrients over time, typically one to three years.

Higher sediment concentrations from the collectors seemed somewhat counterintuitive because sheet flow would have less transport power and velocity than the grab samples of more concentrated flow. However these collectors were constructed in places assumed conducive to sheet runoff in terms of slope and bare soil, and measured quasi-cumulative sediment from storms, since sediment did not always wash through. By contrast, the grab samples represented one instant in time, usually several hours into the storm and long past first flush. For comparison, a current study of 42 third through seventh order streams in the Georgia Piedmont showed base flow TSS with a mean of 6 and a median of 5 mg/l, from 454 samples (G. Denise Carroll, unpublished data). The larger perennial streams in that study have a lot more transport power than the tiny ephemeral gullies and flow tracks in this study, yet have low TSS readings.

Collection of water quality data presented several problems. Grab sampling shallow tracks and puddles usually stirred up some sediment, in spite of best efforts. Available locations with concentrated flow for grab sampling decreased over the course of the study, and by the end could only be found in the most active rills and gullies. The metal overland flow collectors were designed for agricultural research and seemed overly elaborate in terms of capacity, expense, installation, and servicing requirements for a descriptive forestry study generating only small amounts of runoff. An attempt to establish pitfall traps in gullies failed, due to the buckets floating and the severity of the environment. However, at least one researcher has reported success with pitfalls in streams by use of a securely fastened outside collar and wedging the inside collector (Sutherland et al. 2002).

Concentrated Flow Tracks (CFTs)

Active concentrated flow tracks (as shown by a scoured path through the litter) decreased in power and number during the study period. In a large rainstorm during the first spring, 84 areas of concentrated flow were observed at Lewis (or an average of one per 44 m of SMZ boundary), but few of these scoured to mineral soil. Five scoured CFTs were tallied at the beginning of the second summer and there were only three left when measured towards the end of the second growing season (Figure 3.29). At Vanir, seven active CFTs were observed during a large storm two months post-planting (March 2003), two were measured in the spring of 2004, and all were stabilized by the late summer. In contrast, the reference site had 23. This relatively high number was attributed to steeper slopes (Table 2.1) and reactivation of old gullies due to burning. Of the 23, 18 were old agricultural gullies, four were attributed to converging topography, and one was mixed. The burned area contained 16 of the 23 CFTs, including 13 of the old gullies (Figure 3.30). Most of these stabilized, following leaf fall and spring greenup, leaving only six active by May 2005 (Figure 3.31), prior to a planned timber cut. Even these remaining active ones were observed to have more clogged flowpaths than previously, decreasing speed and cutting power of runoff. However, the trend in CFTs was not uniformly toward stabilization. Over the study, some were observed to open up or lengthen at least temporarily after big storms, showing the dynamic between vegetative regrowth and the erosive force of water. Also, even stabilized CFTs and old gullies could move significant quantities of water in large storms without scouring the leaf litter down to soil.

Statistical differences among attributes of the CFTs were inconclusive due to high variation and small numbers involved. Generally the CFTs that carried sediment to the creek were shorter, deeper, and drained a larger area than the ones that did not (Table 3.8). Also, most CFTs had more bare ground on the bottom and sidewalls than on the actively eroding slope and nearby areas. Comparisons of the current study to the previous study of 30 forest regeneration sites in the Georgia Piedmont (Rivenbark and Jackson 2004) were likewise inconclusive .

All three of the active CFTs at Lewis connected into previous agricultural gullies for at least part of their length. Two were very long, at 106 and 146 meters (348 and 479 ft). These drained either roads or decks at ridge or shoulder landscape positions, and traveled all the way down the 10% backslope to the toeslope and floodplain, funneling into previous gullies on the lower part of the slope (Figure 3.29). One was stopped by the SMZ and the other fed directly into a deep gullied tributary. Even the latter had some sediment filtered by a fortuitous pile of logging slash at the edge of the SMZ. The first was not a complete success, although it normally did not tie into the stream. The sediment which it deposited on the floodplain would likely remobilize during future big storms. The third 3.8 meter deep gully was at the downhill end of a long series of old gullies (Figure 3.29). These were partly stabilized on the bottom but had the potential to contribute sediment during major events, especially from the sidewalls, and probably were major contributors early in the study. However, it also should be noted that nearly all flow tracks on both plantations were stabilized after two seasons of regrowth without herbicides.

The 70 year old reference forest would not normally be considered a major sediment source. However, it became a temporary contributor, following a burn, and given old agricultural gullies. When the runoff cups on site were first established, the streambed was relatively clean and stable. Following the burn, fresh sand deposits were observed all throughout the stream system in the study area, although it is unclear how much was contributed from firelanes, sheet flow from the burn area, highway embankment runoff, and CFTs (Figure 3.30). Some deposits were upstream of all firelanes and active CFTs.

Implications and Considerations for Management

Of the many factors influencing runoff, the land manager typically only has some short run control of vegetative cover, management practices, and land use. Even mature forests generate some runoff and sediment, especially in connection with logging roads, skid trails, fire lanes, and during the cutting and regeneration window. Walking around on a tract with all-weather access during a heavy rainstorm is a good way to raise awareness of runoff, where it happens, and how the road drainage system is functioning.

In the Piedmont, old gullies are ubiquitous (Trimble 1974) and may be reactivated by any land disturbing activity (e.g. Hewlett et al. 1984). These activities may also create independent concentrated flow tracks, some of which may create new gullies or tie into old ones. Flow tracks, ruts and small depressions are often present and can also channel water. People working on the land should be aware of impacts to sensitive areas. These include wetlands and wet areas, deep gullies, active gullies, gully “nests”, toeslope areas, and areas of convergent topography (vallies). Compaction should be minimized in sensitive areas by proper road and deck placement. The question of “How do we get the water off the road?” needs to be followed by “Where is the drain water going?” In some cases, it might be necessary to flatten and/or revegetate a place at the end of wing ditches or below decks on steep hillsides to facilitate infiltration and dropping of sediment load.

Examples of management for water quality for gullies might include leaving at least a thin “picket fence” border of brush or trees on the sides, and especially the heads, and minimizing roads, compaction, and intensive site preparation in the immediate area. Herbicides should be minimized in this low impact area, since revegetation is so important in preventing runoff. If logging debris were being piled, it could be pushed into gullies that do not penetrate to groundwater, to help slow runoff. However, debris should be moved only short distances to the nearest small or medium sized gully, to minimize tract compaction and risk of washing debris downstream during floods in large gullies, with possible bank and structural damage. Slash should be pushed only horizontally or uphill, to avoid convergent water flow paths. Also it should be pushed into gully sides, with minimal disturbance to gully cover, leaving the gully head undisturbed. The areas freed up for planting would help compensate for the less intense management in the sensitive areas, and improve management access. Site preparation rakes and blades should be run a little above ground to minimize moving dirt and cover, even if the results look sloppy due to small limbs dropping on the ground.

In Georgia, along with some other southeastern states, recommended SMZ widths are based on slope gradient (Table 2.8). While these guidelines are reasonably effective for sheet flow, areas of concentrated flow due to old gullies or converging terrain (vallies) can exceed even the maximum 22 meter (70 ft) non-trout stream buffer width, as shown by long travel distances on this study. Toeslopes, wet areas, and concentrated flow tracks route a disproportionate share of water into the SMZ. A more site-specific prescription might widen the SMZ to include sensitive areas and narrow it in less problematic places. On the plantations studied, a short uphill extension of the SMZ while delineating the timber sale boundary would have protected places where deep gullies intersected ground water and small seeps near the SMZ, since these sensitive areas were close to the delineated boundary. Some management activities on sensitive tracts could possibly be timed to take advantage of green up or leaf drop for site stabilization.

Table 3.1. Comparison of rain by seasons for combined plantations, Greene County, Ga., in Georgia Piedmont, 2/2003 - 9/2004.

	Mean	Median	Std Dev
Rain Depth (mm)	10.6	12.2	3.3
Winter[1]	11.4	13.2	2.9
Summer[1]	10.7	10.7	3.2
24 Hour Maximum Intensity (mm/hr)	0.4	0.4	3.0
Winter	0.4	0.5	2.8
Summer	0.4	0.4	3.3
15 Minute Maximum Intensity (mm/hr)	11.8	11.2	2.8
Winter (a)	8.5	8.1	2.5
Summer (b)	15.5	19.3	2.8

[1]Winter = November - April; Summer = May - October

(a) (b) Means and medians are statistically different between seasons at alpha= 0.05

Table 3.2. Descriptive statistics of response cups in plantations by seasons and years, for storms above 13 mm threshold, in Greene County, Georgia Piedmont overland flow study.

Statistic[1]	Combined Dormant[2]	Combined Growing	Combined Year 1[a]	Combined Year 2	Total
	--------------------------Lewis Study Site----------------------------				
Runoff Frequency per Storm (%)					
Mean[3,4]	17.0	12.7	20.3	10.9	14.3
Standard Deviation	1.9	4.0	3.0	3.3	3.3
Median	20.5	16.0	22.5	11.7	17.4
Maximum	52.5	77.1	77.1	59.3	77.1
Cups Without Runoff in any Storm (%)	22.0	7.3	8.9	18.7	3.3
Number of Storms Studied	17.0	31.0	21.0	27.0	48.0
	--------------------------Vanir Study Site------------------------------				
Runoff Frequency per Storm (%)					
Mean	6.2	6.6	8.7	4.7	6.4
Standard Deviation	2.5	3.5	2.6	3.3	3.0
Median	6.0	7.8	10.1	5.9	7.6
Maximum	39.1	30.9	39.1	30.3	39.1
Cups Without Runoff in any Storm (%)	36.2	24.6	30.4	37.7	18.8
Number of Storms Studied	19.0	26.0	23.0	22.0	45.0

[1]Data were log x transformed for statistics.

[2]Dormant = Nov - April; Growing = May - Oct; both years included.

[a]Year 1 = Feb - Oct 2003 ; Year 2 = Nov 2003 - Sep 2004 for plantations.

[3]Means are statistically equivalent within sites.

[4]Lewis and Vanir means statistically differ for the same column for dormant and total.

Table 3.3. Comparison of response cups in plantations to reference site by seasons and years, for storms above 13 mm threshold, in Greene County, Georgia Piedmont overland flow study

Statistic[1]	Combined Dormant[2]	Combined Growing	Year 1[a]	Year 2	Total	Dormant	Growing	Year 2[b]
	Combined Plantations					Watson Springs		
Runoff Frequency per Storm (%)								
Mean[3,4]	10.0	9.5	13.0	7.4	9.7	1.4	2.5	2.2
Standard Deviation	2.6	3.9	3.0	3.5	3.4	5.3	7.9	7.2
Median	10.7	11.8	16.2	9.1	11.6	1.3	2.5	1.8
Maximum	52.5	77.1	77.1	59.3	77.1	8.2	38.0	38.0
Cups Without Runoff in any Storm (%)	27.1	13.5	16.7	25.5	8.9	88.6	35.4	35.4
Number of Storms Studied	36.0	57.0	44.0	49.0	93.0	5.0	19.0	24.0

[1]Data were log x transformed for statistics.

[2]Dormant = Nov - April; Growing = May - Oct; both years included for plantations, only second year for reference.

[a]Year 1 = Feb - Oct 2003 ; Year 2 = Nov 2003 - Sep 2004 for plantations.

[b]Year 2 = Feb-Sep 2004 for reference.

[3]Means are statistically equivalent within sites at alpha= 0.05.

[4]Means statistically differ between sites for total at alpha= 0.05.

Table 3.4. Investigations of surface runoff frequency (%) as explained by precipitation metrics, at Lewis site, in Greene County, Georgia Piedmont, all storms tallied.

Independent Variable	P-value	r^2	Best Fit Equation[1]	No.of Storms	Res. Outliers	Res. Bias
Storm Depth - Both yrs (mm)	*	0.66	0.5273 x + 2.976 (ab)	65	0	N
1st Yr	*	0.78	0.6312 x + 5.630 (a)	28	0	N
2nd Yr	*	0.69	0.4096 x + 1.687 (b)	37	1	?
RUSLE "R" (English)	*	0.56	0.6592 x + 9.878	44	0	N
Maximum Intensities (mm/hr)				44		
24 Hr	*	0.64	11.26 x + 3.900		0	N
12 Hr	*	0.60	6.386 x + 3.755		0	N
6 Hr	*	0.59	4.092 x + 2.454		1	N
2 Hr	*	0.50	1.989 x + 1.592		0	N
1 Hr	*	0.32	0.9543 x + 5.294		0	N
30 Min	*	0.24	0.4584 x + 7.774		0	N
15 Min	*	0.27	0.3200 x + 7.367		0	N
Mean Int.	0.663			44		
Duration (hrs)	*	0.24	0.5404 x + 8.568	44	1	Y
Prior Rainfall (cum mm)						
30 Day	0.005	0.13	0.0862 x + 7.376	58	1	?
10 Day	0.072	-	CI for slope included 0	62	1	Y
5 Day	0.154	-	CI for slope included 0	63	1	Y
SCS Curve # Runoff Depth (in)			Unusable	51	0	Y
SCS Curve # with no threshold (in)			Unusable	51	0	Y

* P-values less than 0.001.

[1]Slopes of multiple equations for the same independent variable with the same letter are statistically equivalent at alpha= 0.05.

Table 3.5. Investigations of runoff frequency (%) as explained by precipitation metrics, at Vanir site, Greene County, Georgia Piedmont, all storms tallied.

Independent Variable	P-value	r^2	Best Fit Equation[1]	No.of Storms	Res. Outliers	Res. Bias
Storm Depth - both years (mm)	*	0.51	0.2221 x - 1.424 (a)	58	1	N
1st year	*	0.53	0.2942 x +2.175 (a)	28	1	N
2nd year	*	0.78	0.1874 x - 0.1675 (a)	30	0	N
RUSLE "R" - both years (English)	*	0.54	0.5255 x + 4.400 (a)	49	1	N
1st year	*	0.54	0.5789 x + 6.185 (a)	26	0	N
2nd year	*	0.67	0.4445 x + 2.459 (a)	23	0	?
Intensities (mm/hr)						
24 Hr - both years	*	0.51	5.508 x + 2.1639 (a)	49	1	N
1st year	*	0.57	7.968 x +2.225 (a)	26	1	?
2nd year	*	0.78	4.424 x + 0.2588 (a)	23	0	N
12 Hr - both years (a)	*	0.49	3.310 x + 1.910 (a)	49	1	N
1st year (b)	*	0.67	6.392 x - 0.8970 (b)	26	0	N
2nd year (a)	*	0.81	2.566 x + 0.0539 (a)	23	0	N
6 Hr - both years (c,d)	*	0.49	2.341 x + 0.7884 (a,b)	49	1	N
1st year (c)	*	0.63	4.078 x - 2.134 (a)	26	0	N
2nd year (d)	*	0.74	1.764 x - 0.3872 (b)	23	0	N
2 Hr - both years	*	0.51	1.300 x - 0.7940 (a)	49	0	N
1st year	*	0.64	1.805 x - 2.554 (a)	26	0	N
2nd year	*	0.52	0.8893 x - 0.3510 (a)	23	0	N
1 Hr	*	0.48	0.8028 x - 0.2420	49	0	N
30 Min	*	0.41	0.4802 x - 0.8510	49	0	N
15 Min	*	0.28	0.2898 x + 0.1.560	49	0	N
Mean Int.	0.592	-	CI for slope included	49	1	Y
Duration (hrs)	0.094	-	CI for slope included	49	1	Y
Prior Rainfall (cum mm)						
30 Day	0.010	0.13	0.0005 x + 0.0312	52	0	?
10 Day	0.695	-	CI for slope included	54	0	Y
5 Day	0.174	-	CI for slope included	55	1	?
SCS Curve # Runoff Depth (in)			Unusable	55		Y
SCS Curve # with no threshold (in)	*	0.30	16.12 x + 4.831	55	0	Y

* P-value less than 0.001.

[1]Slopes of multiple equations for the same independent variable with the same letter are statistically equivalent at alpha= 0.05.

Table 3.6. Investigations of surface runoff frequency(%) as explained by precipitation metrics, at Watson Springs site,Greene County, in Georgia Piedmont, all storms tallied.

Independent Variable	P-value	r^2	Best Fit Equation	No.of Storms	Res. Outliers	Res. Bias
Storm Depth (mm)	*	0.46	0.2507 x - 1.224	27	1	N
RUSLE "R" (English)	*	0.75	0.4478 x - 1.226	24	0	N
Intensities (mm/hr)	*			24		
24 Hr	*	0.47	6.172 x - 1.205		1	N
12 Hr	*	0.50	3.459 x - 1.532		1	N
6 Hr	*	0.59	2.347 x - 3.621		1	N
2 Hr	*	0.58	1.186 x - 5.911		0	N
1 Hr	*	0.50	0.6636 x - 5.506		0	N
30 Min	*	0.42	0.3516 x - 3.930		0	N
15 Min	*	0.49	0.2555 x - 4.324		0	N
Mean Int.	0.552			24	0	Y
Duration (hrs)	0.888			24	0	Y
Prior Rainfall (cum mm)						
30 Day	0.075		CI for slope included 0	27	0	N
10 Day	0.256			27	0	N
5 Day	0.843			27	0	Y
SCS Curve # Runoff Depth (in)	-	-	Unusable	27	-	Y
SCS Curve # with no threshold (in)	*	0.39	20.64 x + 3.094	27	1	?

* P-value less than 0.001.

Table 3.7 . Comparison of cover and litter depth over time between surface runoff study sites, Greene County, in Georgia Piedmont

	Lewis[1]	Vanir[1]	Combined Plantations	Reference[2]
	----------End of first growing season (year 1)----------			
Cover Category (%)				
Bare	31	27	29	
Gravel	5	6	5	
Litter	31	35	33	
Plant	21	22	21	
Wood	12	11	11	
Standard Error Bare	4	5	3	
Litter Layer (mm)	2	2	2	
	-------End of second growing season (year 2)--------			
Cover (%)				
Bare	27	11	22	29
Gravel	0	1	1	0
Litter	26	53	34	64
Plant	39	26	35	3
Wood	7	8	8	3
Standard Error	3	3	2	5
Litter Layer (mm)	4	5	4	5

[1] Plantations were clearcut, herbicided, spot piled, ripped/bedded, and hand planted prior to study.

[2]Ca. 70 year old pine-hardwood reference stand was partly burned prior to second growing season.

See figure3.23 for graphic illustration.

Table 3.8. Summary of active[1] concentrated flow tracks for combined Lewis and Watson Springs sites, Greene County, in Georgia Piedmont[2,3]

	----------Type Breakthrough[4]---------			Infiltration[5]
	Sand	Silt	Clay	
Number	19	0	2	5
Old Ag Gullies	15.5		1	4.5
Topographic CFTs	3.5		1	0.5
Length (m)	29		71	44
Depth (m)	0.9		0.5	0.6
Land Slope (%) near CFT	13		14	14
Land Slope (%) of Hyd. Cont. Area (CA)	14		8	10
Bare Ground (BG) Nearby (%)	15		12	24
Bare Ground Sidewalls of CFT (%)	58		59	34
Bare Ground Bottom of CFT (%)	39		63	42
SMZ incursion (m)	12.3		10.2	5.6
CFT Area above SMZ (m^2)	15		55	22
Hydrologic Contributing Area (ha)	0.4		0.8	0.2
BG*CA (ha)	3		7	6
BG*CA*Slope (ha)	36		57	63
BG*CA (ac)	8		12	16
BG*CA*Slope (ac)	89		96	157

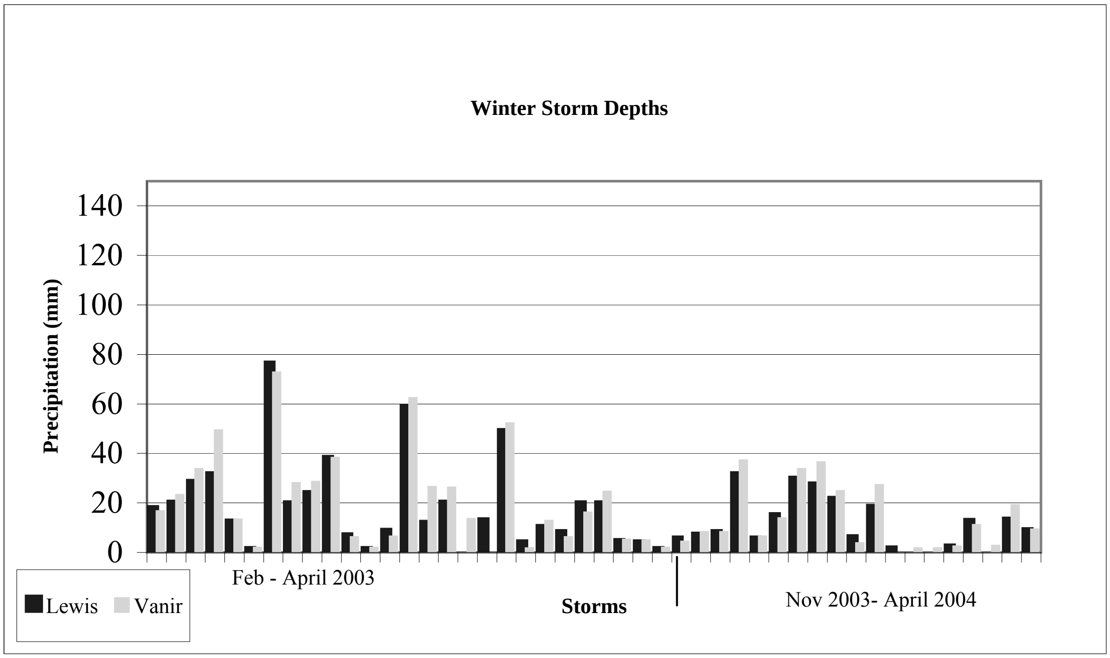
[1]Active tracks had a scour which intruded into the Streamside Management Zone.

[2]All data are medians, except counts.

[3]Data from Lewis was two growing seasons after planting and Watson Springs one growing season after burn.

[4] Breakthroughs had active scours fully penetrating the SMZ.

[5] Scour disappeared in the SMZ before reaching the stream.



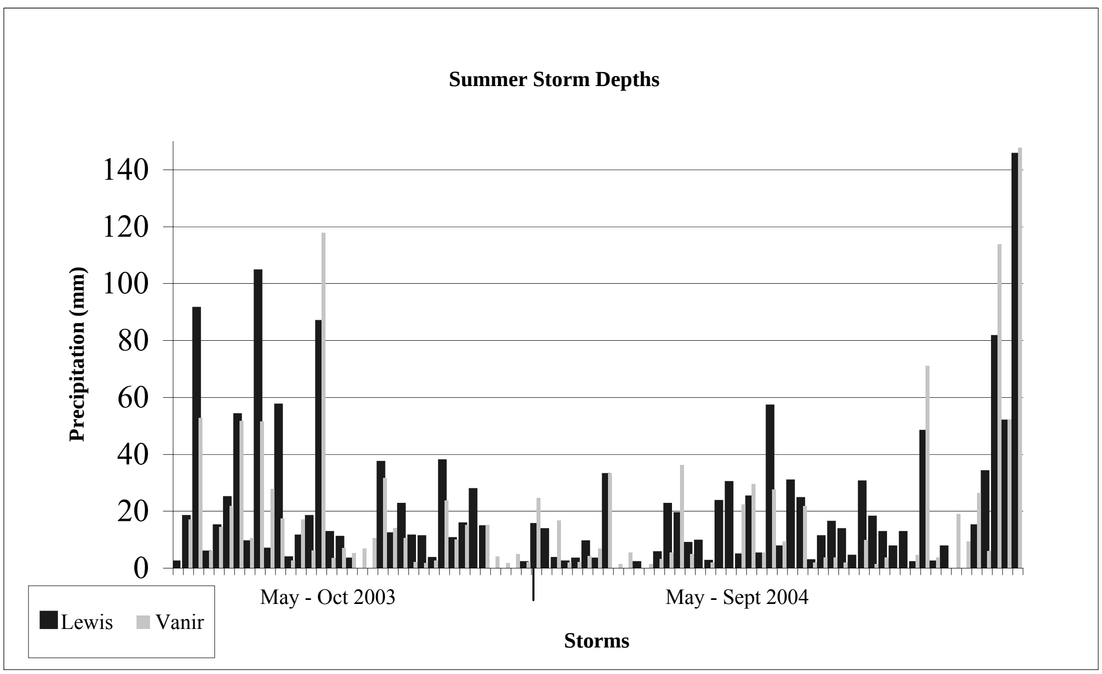


Figure 3.1. Comparison of variation in storm depths between plantations[1] and storms by seasons, Greene County, in Georgia Piedmont.

[1] The plantations are only 13 km (eight miles) apart.

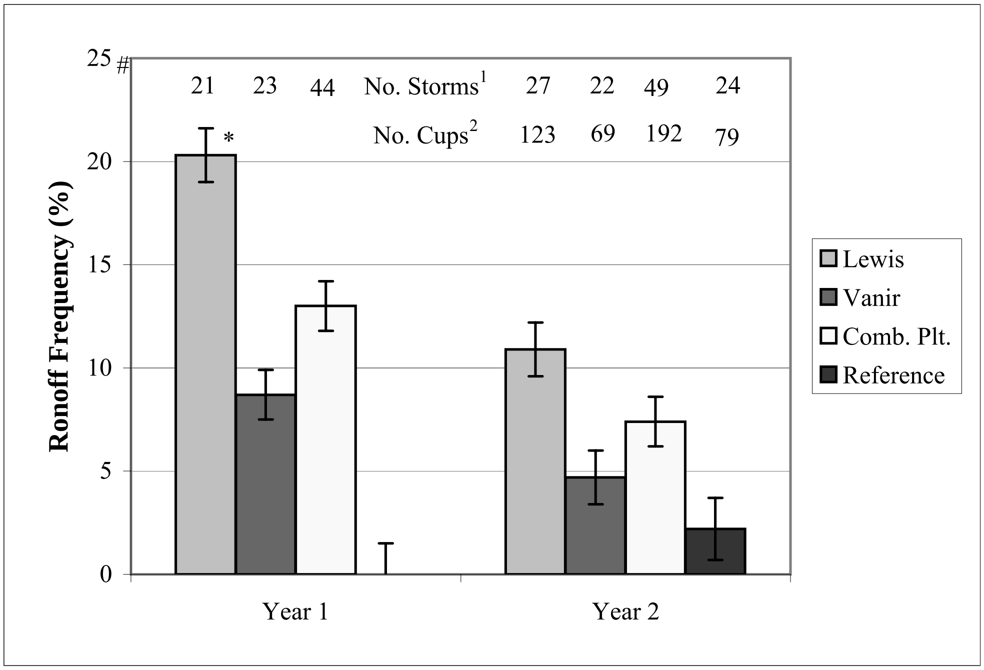


Figure 3.2. Mean response cups in plantations by years, for storms above 13 mm threshold, in Greene County, Ga. Piedmont surface runoff study

[1]Top row is number of storms > 13 mm threshold for site below.

[2]Second row is number of cups per site.

*Whiskers are standard error

#Frequencies were log transformed for statistics

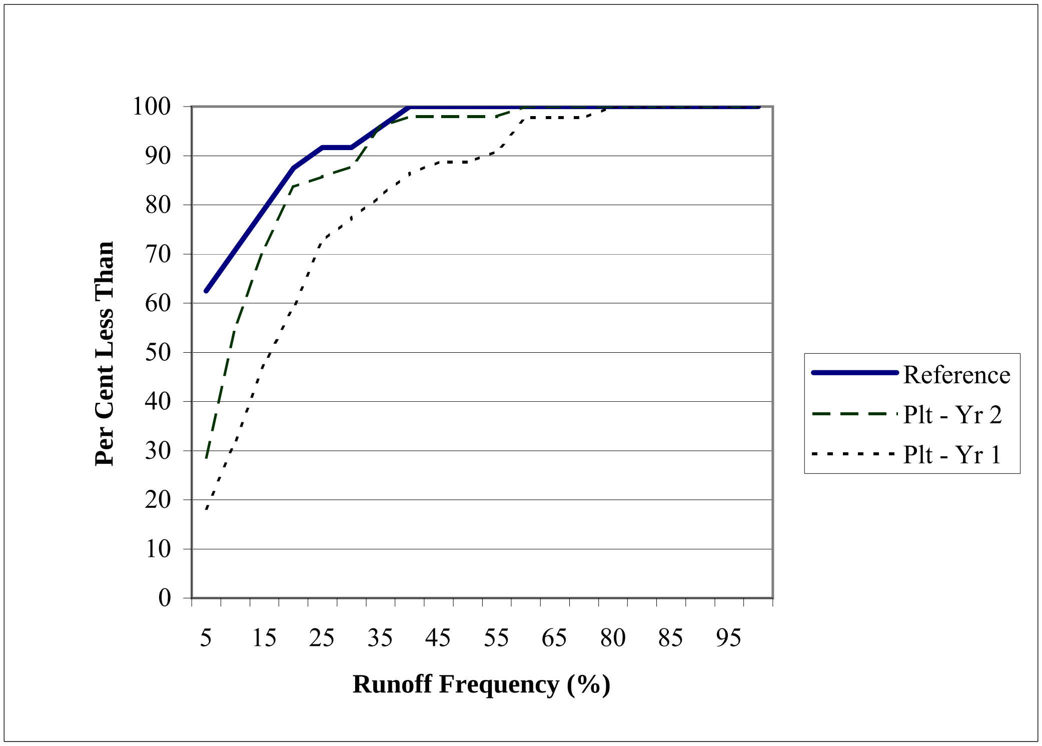


Figure 3.3. Cumulative distribution of surface runoff frequency for storms >13 mm combined plantations[1] plus reference site[2], Greene County in Georgia Piedmont.

[1]Year one was the period for nine months post-planting. Year two was the following 11 months.

[2] The reference site data were for most of year two.

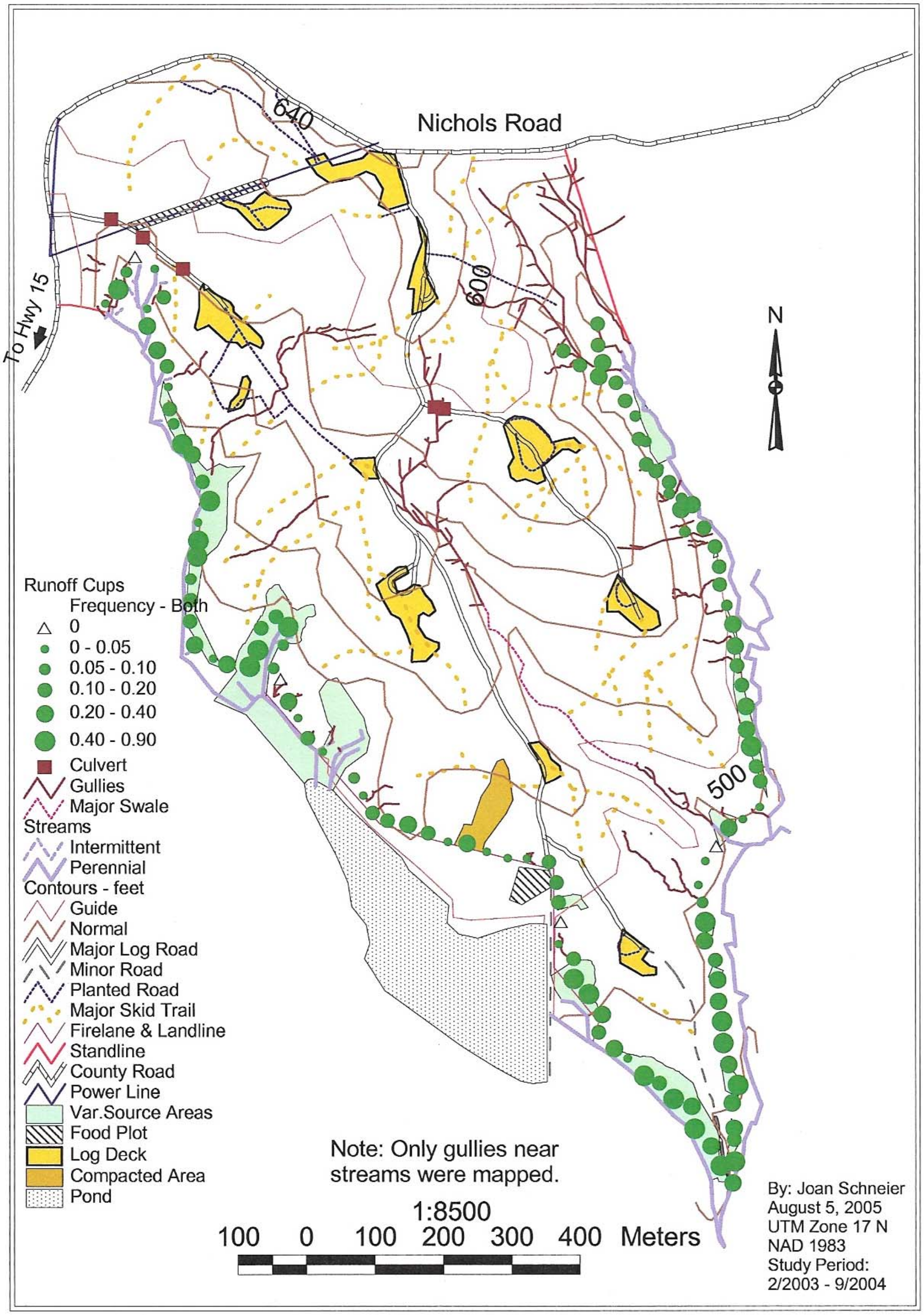


Figure 3.4. Surface runoff frequency for entire study period[1] by cups, Lewis tract, Greene County, in Georgia Piedmont.

[1]Post-planting through most of second growing season.

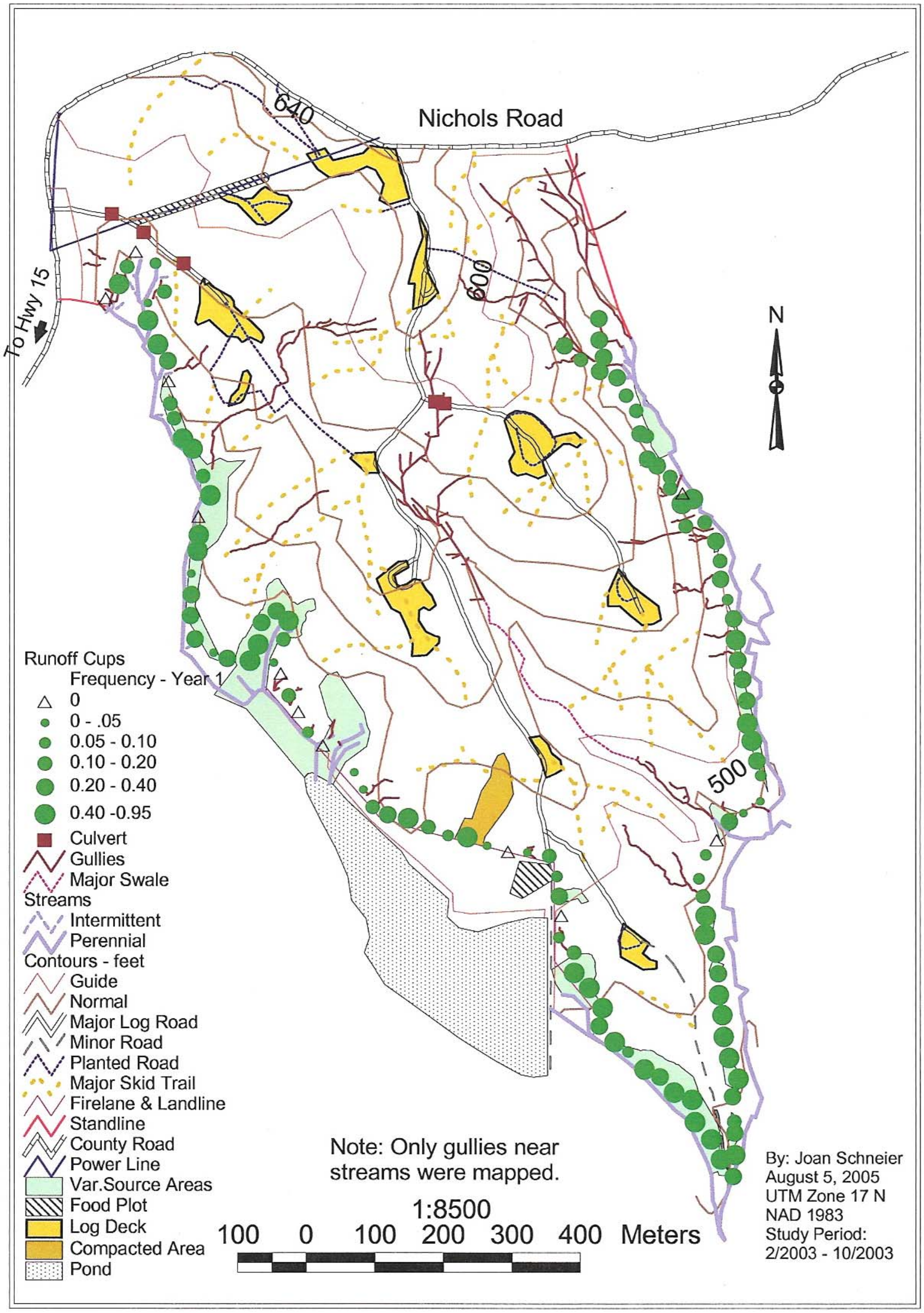


Figure 3.5. Surface runoff frequency for "year one"[1] by cups, Lewis tract, in Greene County, Georgia Piedmont.

[1] Post-planting through end of first growing season.

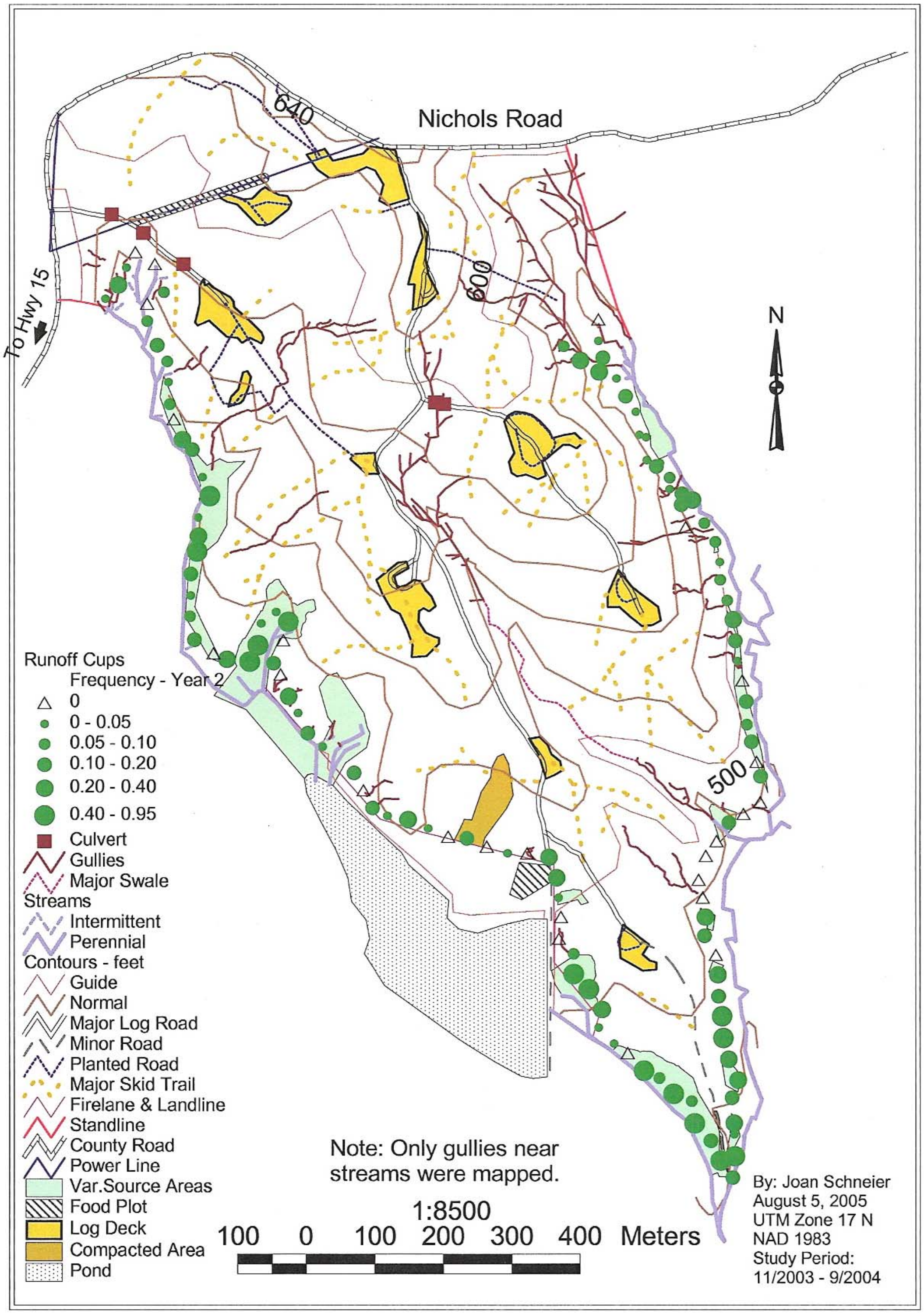


Figure 3.6. Surface runoff frequency for "year two"[1] by cups, Lewis tract, Greene County, in Georgia Piedmont.

[1] End of first growing season through most of second growing season.

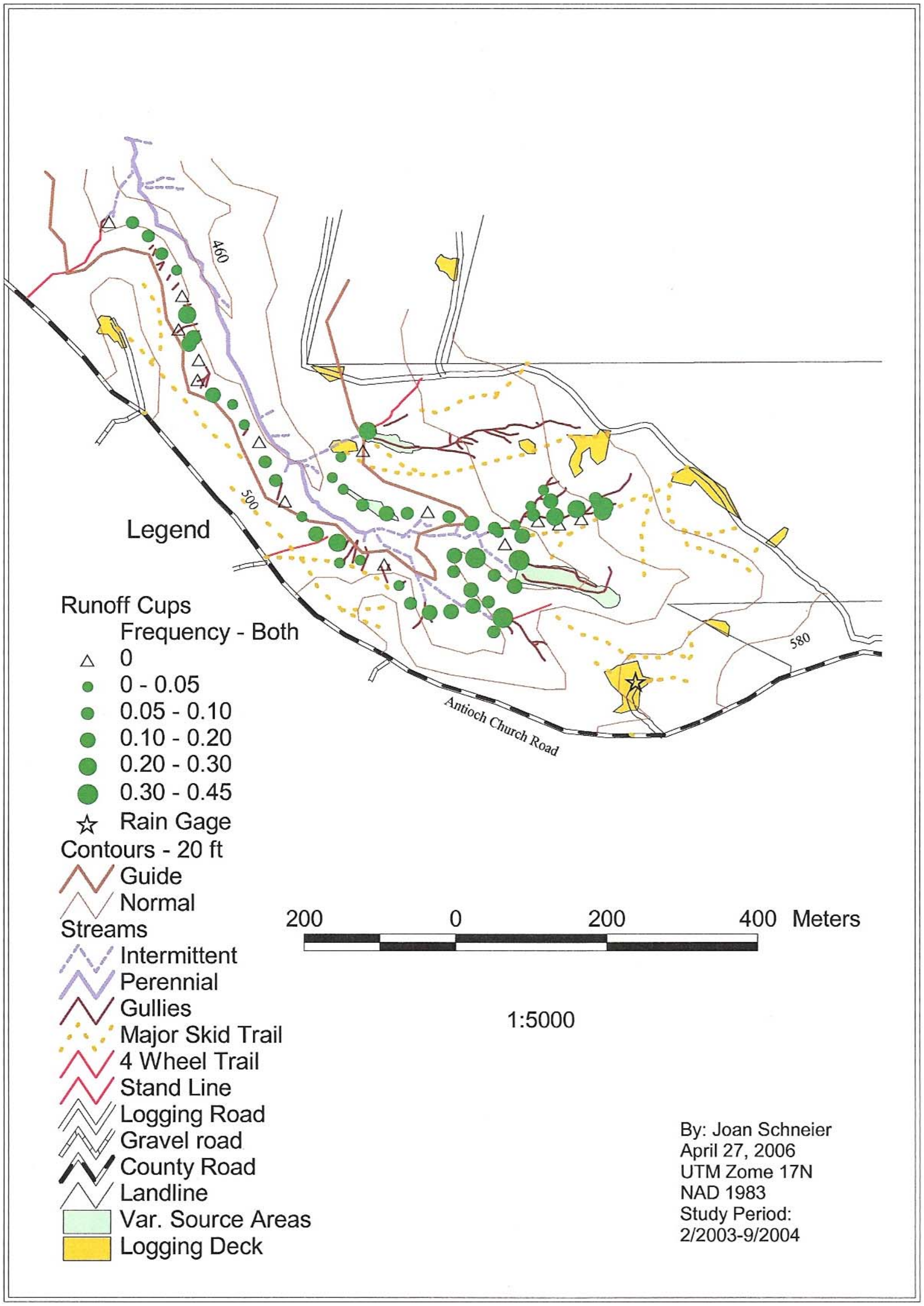


Figure 3.7. Surface runoff frequency for entire study period[1] by cups, Vanir tract, Greene County, in Georgia Piedmont.

[1]Post-planting through most of second growing season.

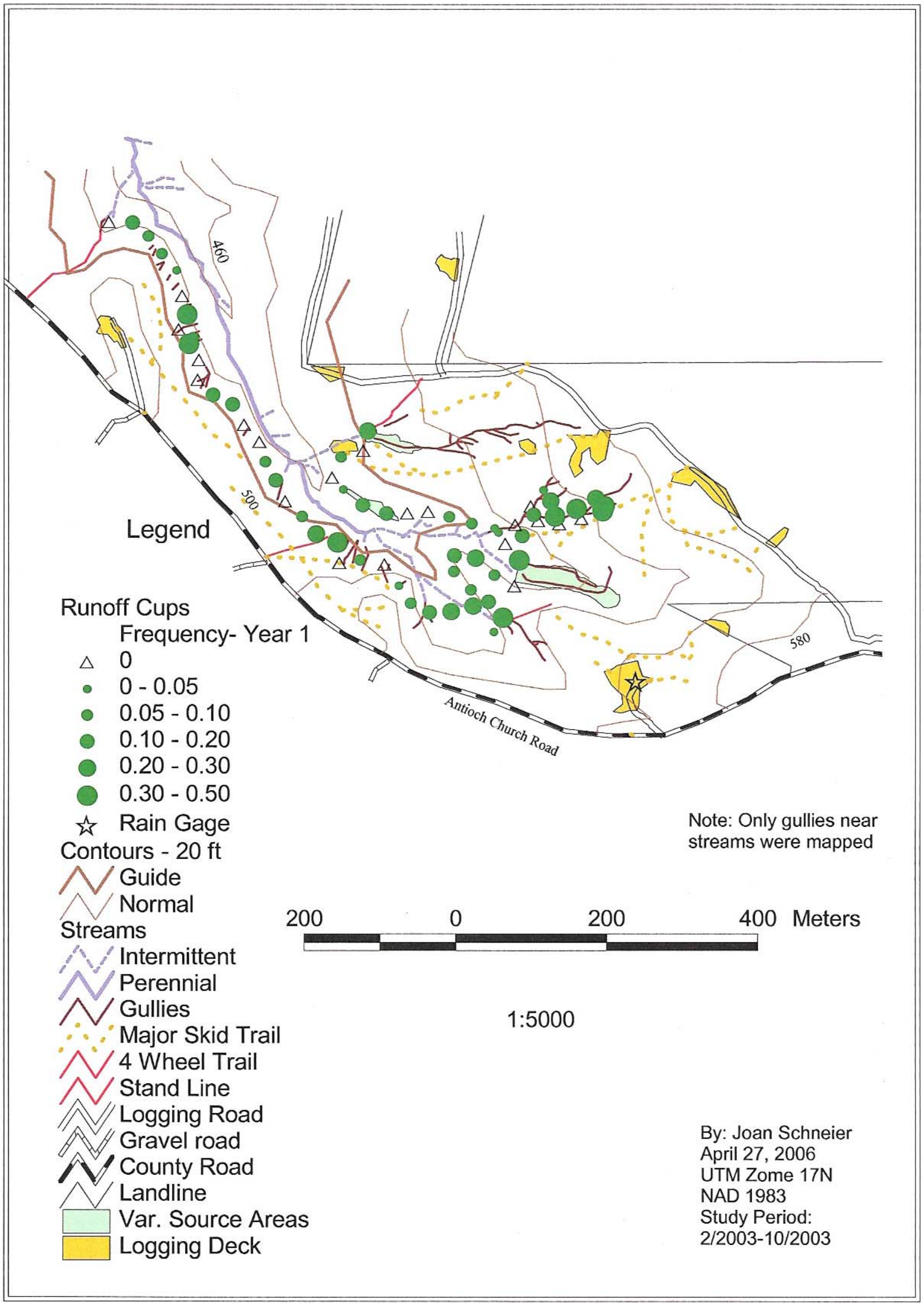


Figure 3.8. Surface runoff frequency for "year one"[1] by cups, Vanir tract, Greene County, in Georgia Piedmont.

[1]Post-planting through end of first growing season.

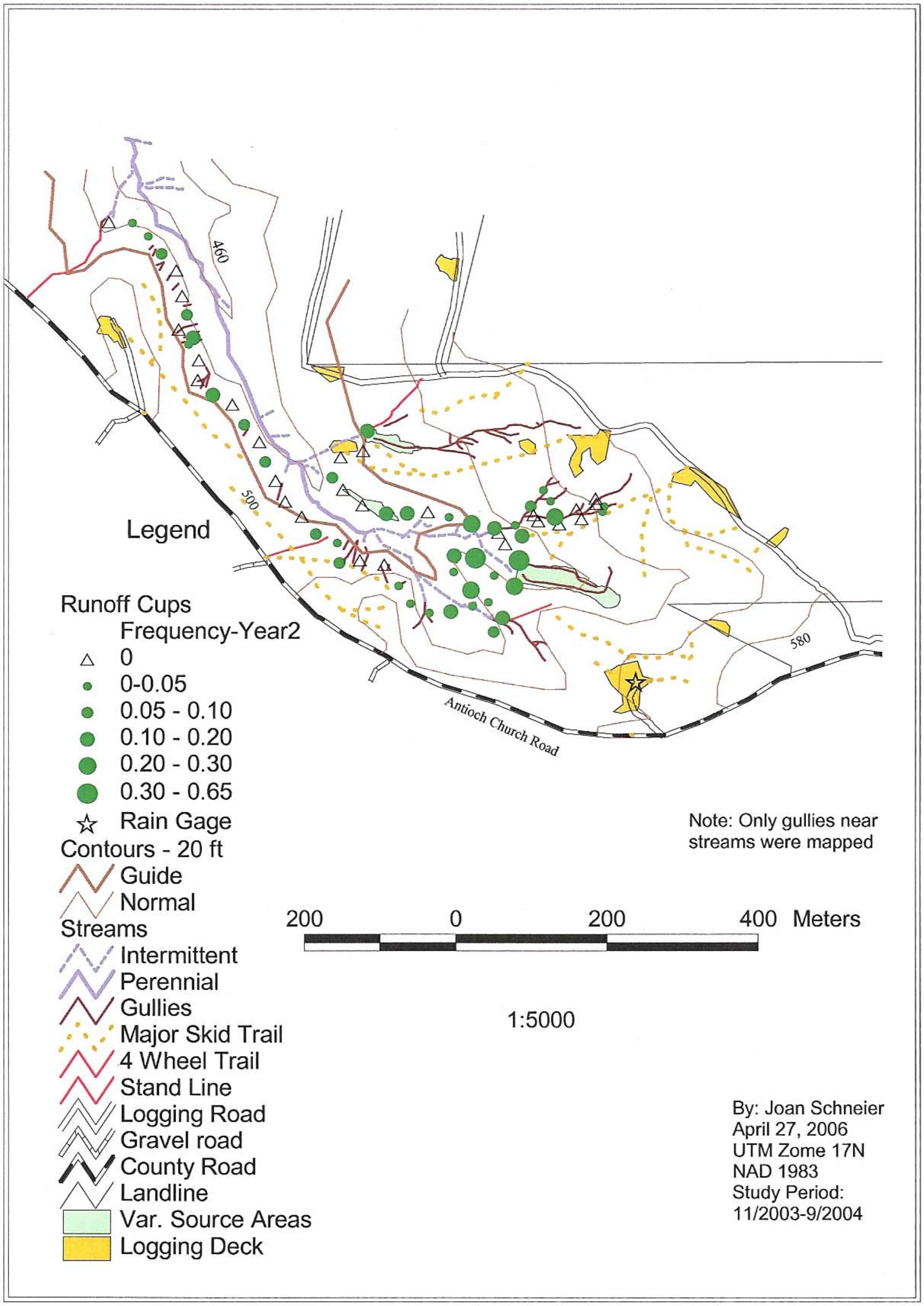


Figure 3.9. Surface runoff frequency for "year two"[1] by cups, Vanir tract, Greene County, in Georgia Piedmont.

[1]Beginning of second dormant season through most of second growing season.

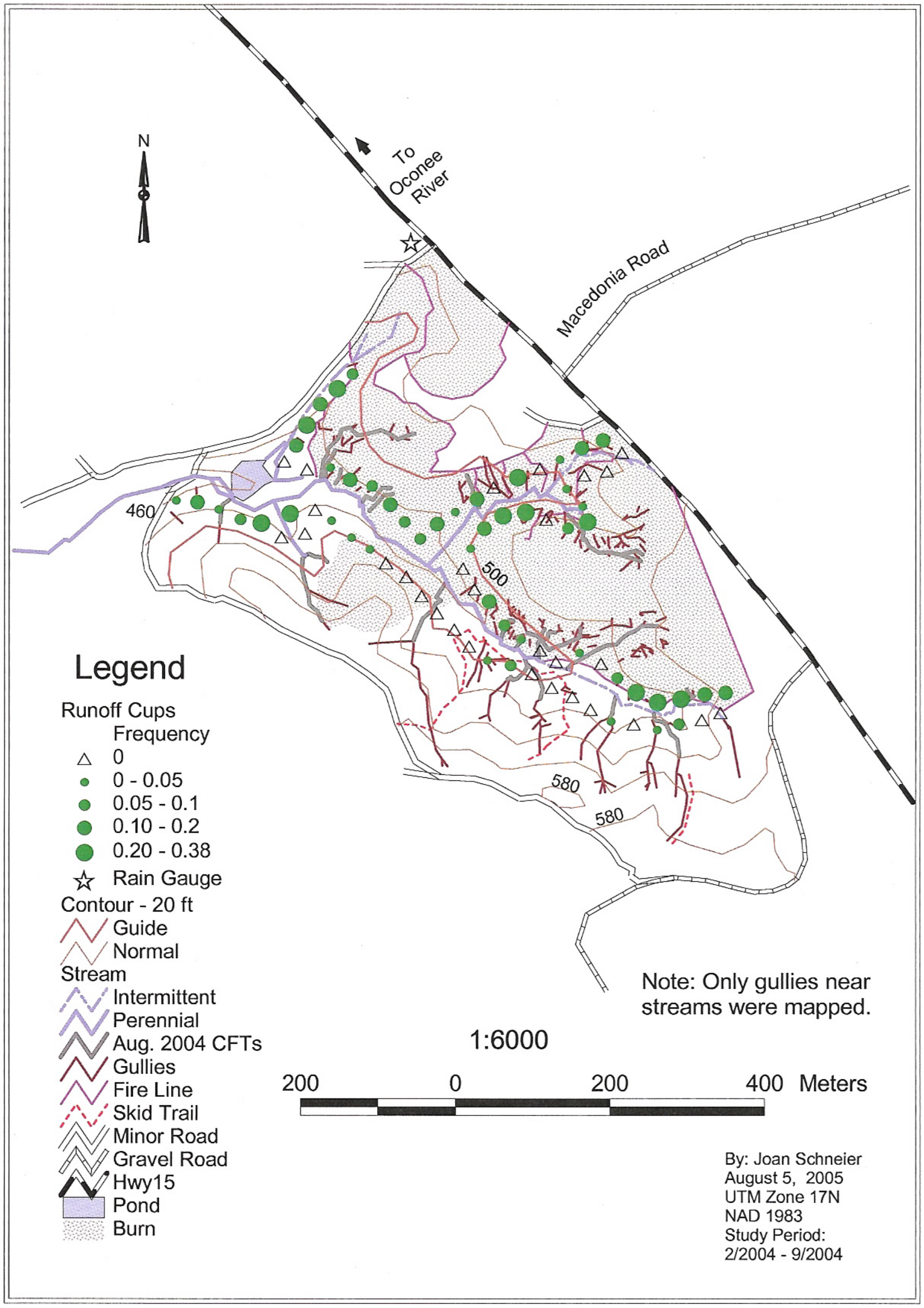


Figure 3.10. Surface runoff frequency for "year two"[1] by cups, Watson Springs (reference) tract, Greene County, in Georgia Piedmont.

[1]Part of study second dormant season through most of study second growing season, in mature timber.

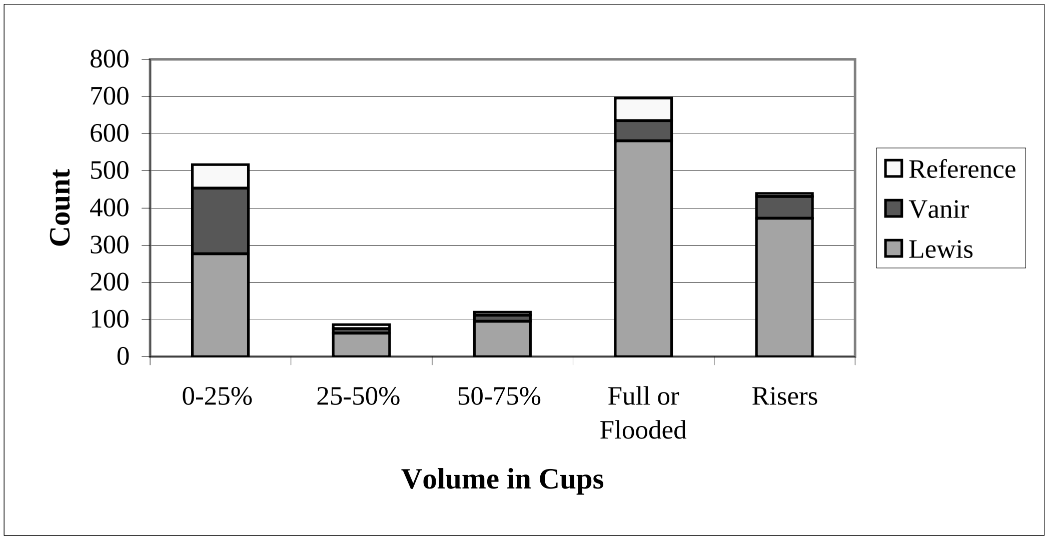


Figure 3.11. Distribution of runoff cup volumes for all three study sites combined, if surface runoff occurred, Greene County, in Georgia Piedmont.

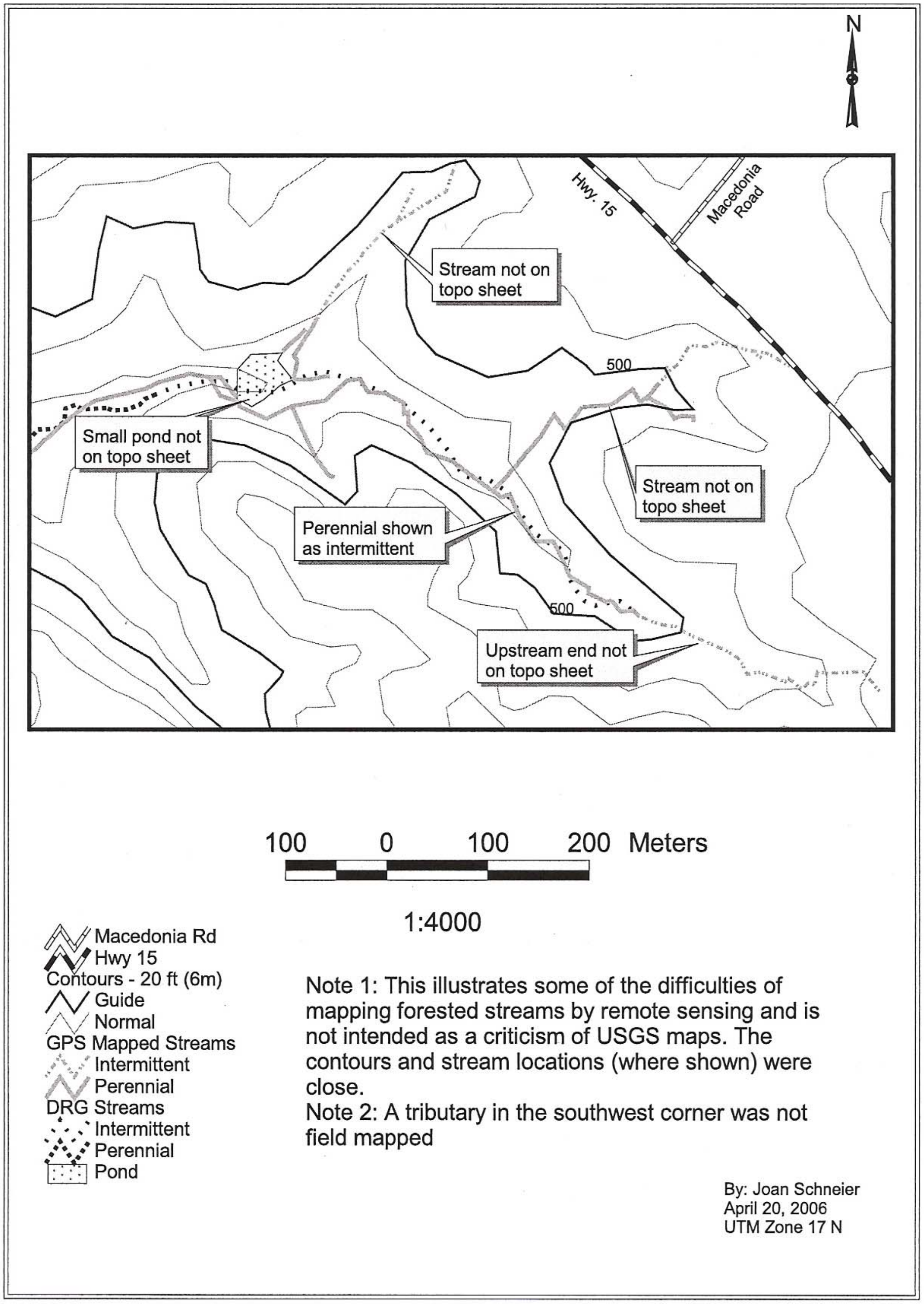


Figure 3.12. Comparison of field mapped water features to USGS topographic map features at Watson Springs tract, Greene County, Georgia, Greshamville 7.5' Quadrangle.

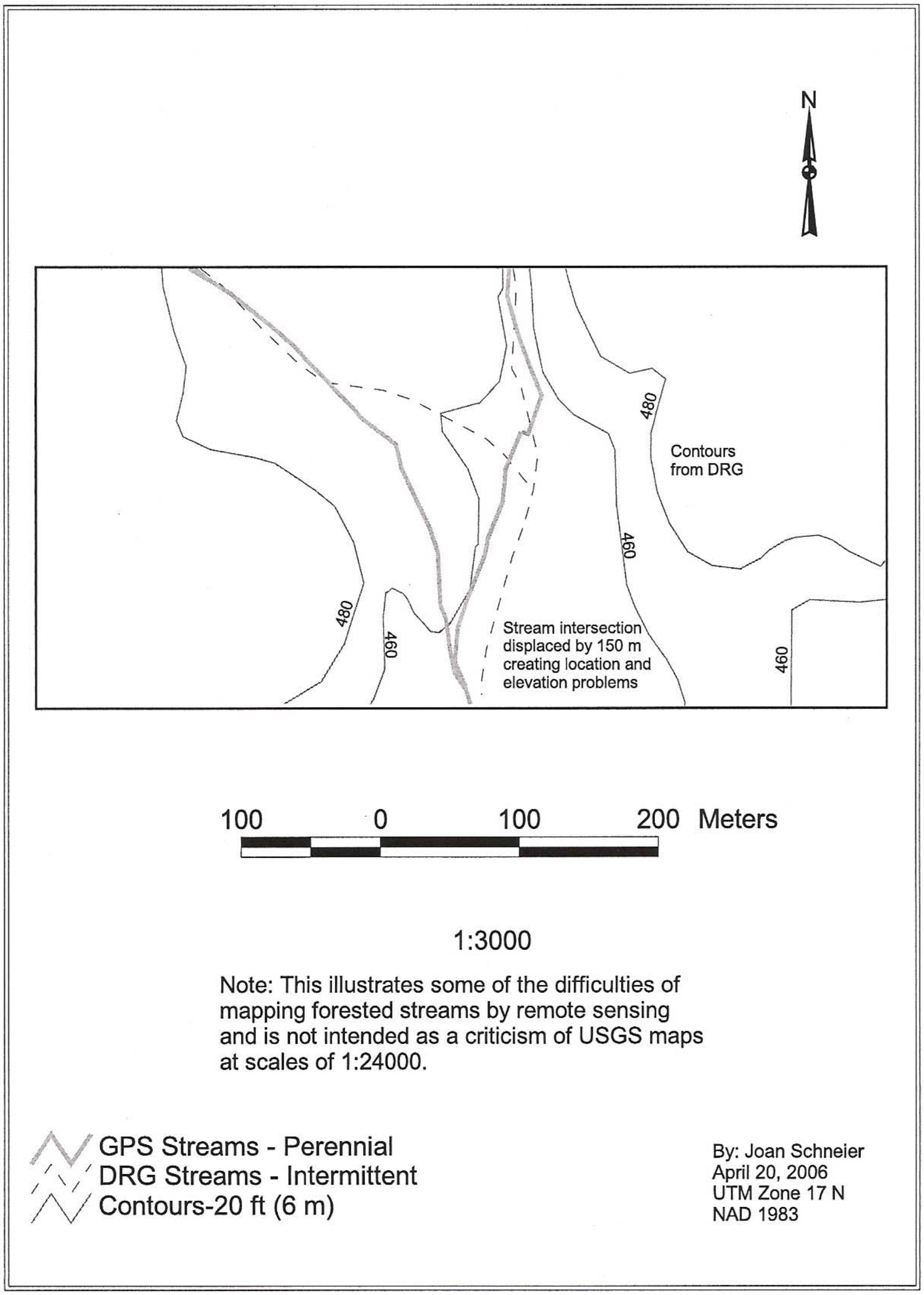


Figure 3.13. Comparison of field mapped water features to USGS topographic map features at Lewis tract, Greene County, Georgia, Greshamville 7.5' Quadrangle.

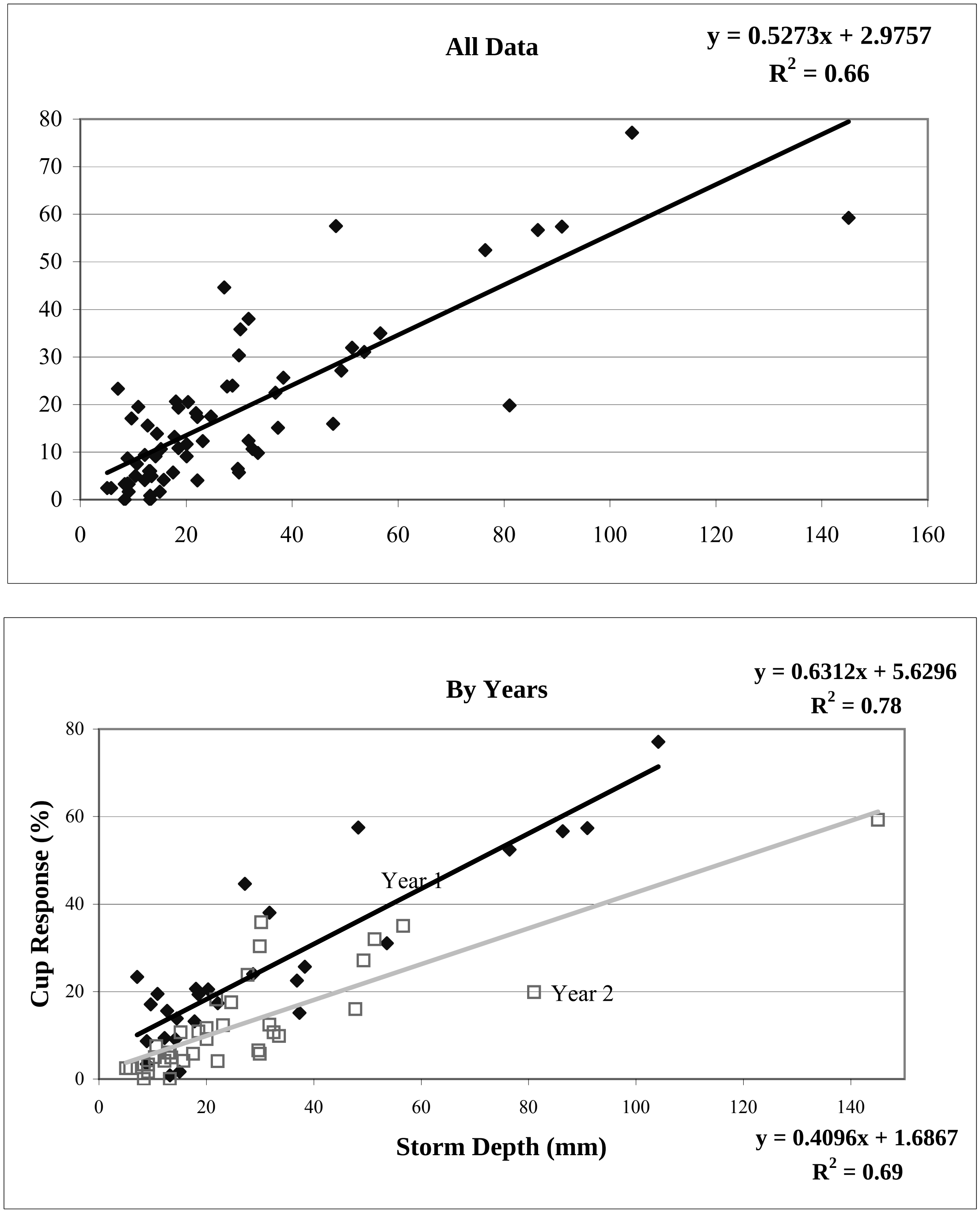
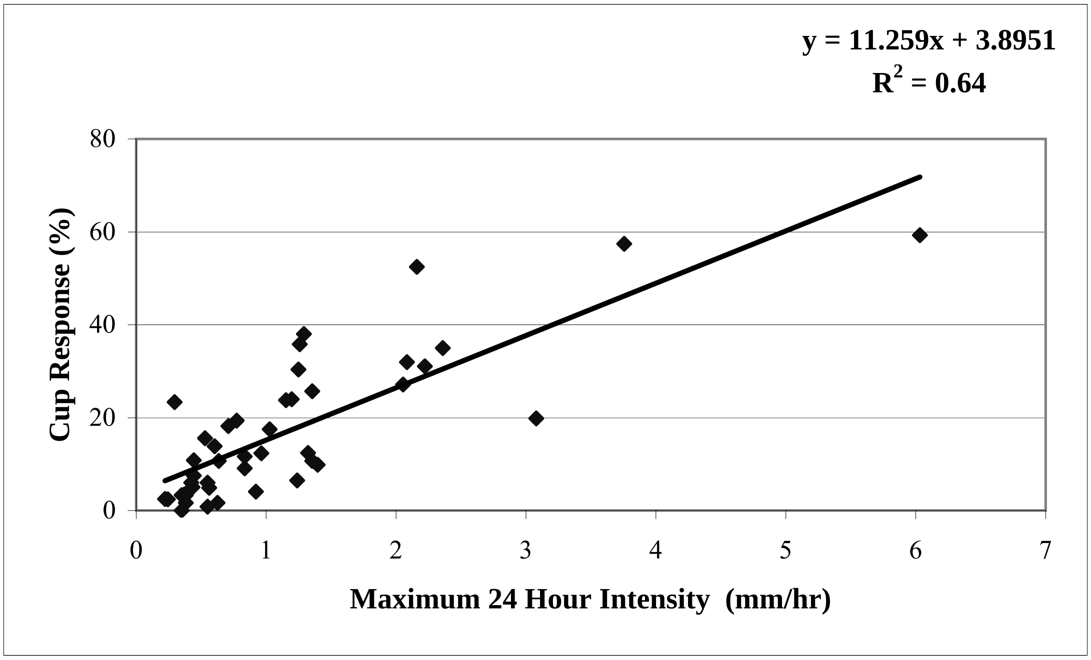


Figure 3.14. Storm depth versus surface runoff frequency at Lewis tract in Georgia Piedmont, all tallied storms included a) All data b) Data separated by year[1,2].

[1]Year one is first dormant and growing season post-planting

[2] Year two is second dormant and most of second growing season post-planting.



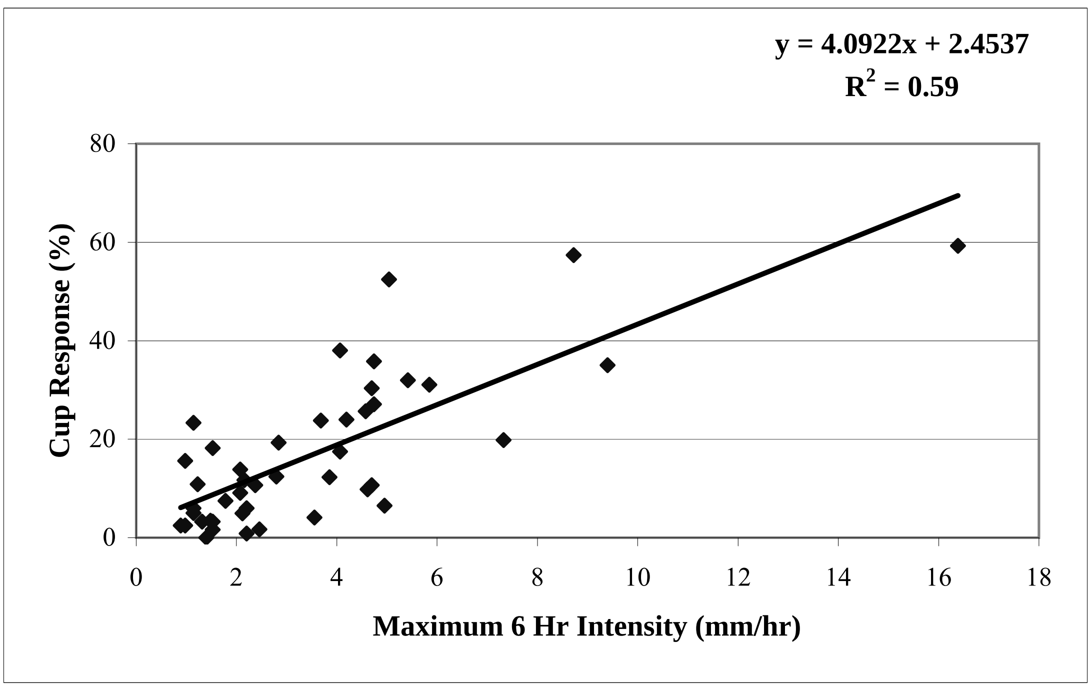
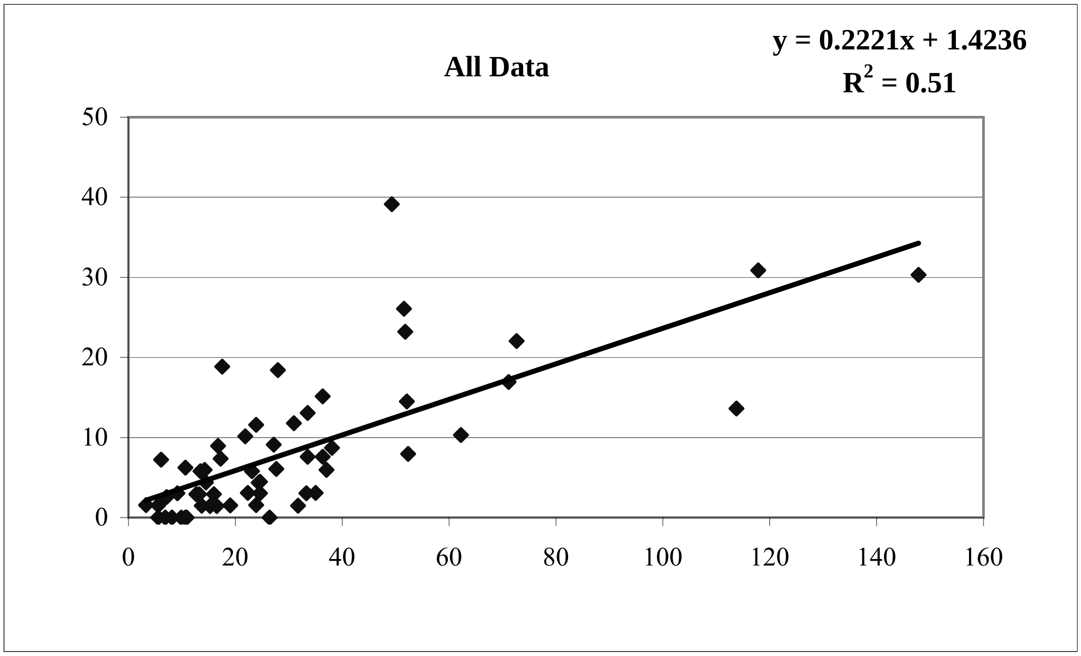


Figure 3.15. Maximum rain intensities versus surface runoff frequency at Lewis tract in Georgia Piedmont, all tallied storms included a) 24 hour and b) 6 Hour



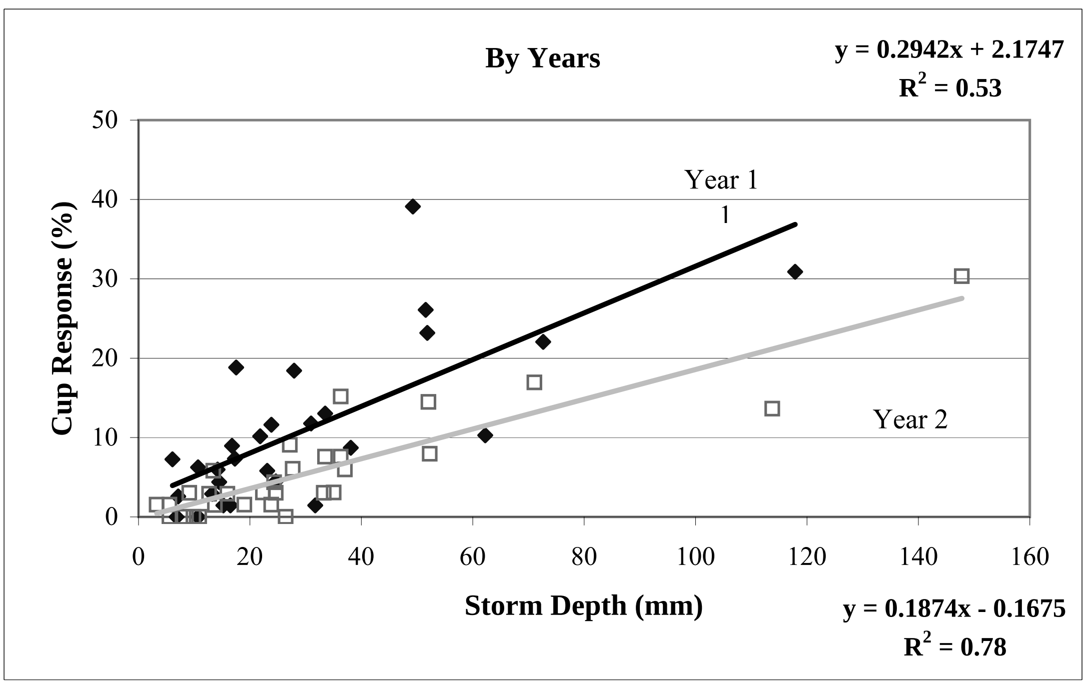
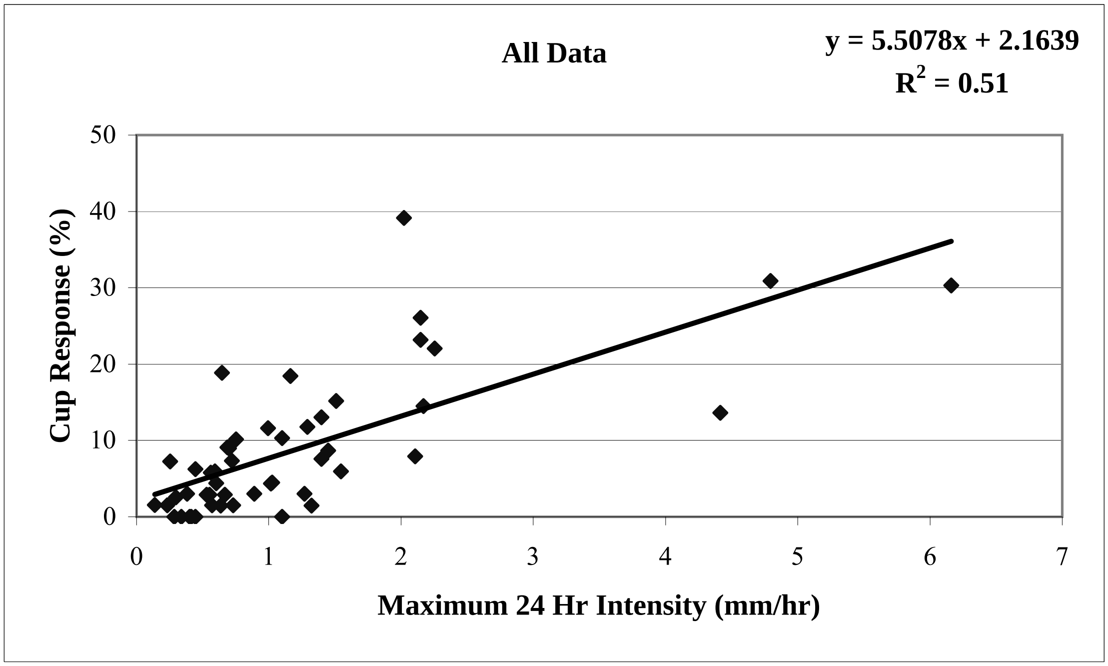


Figure 3.16. Storm depth versus surface runoff frequency at Vanir tract in Georgia Piedmont, all tallied storms included a) All data b) Data separated by year[1,2].

[1]Year one is first dormant and growing season post-planting

[2] Year two is second dormant and most of second growing season post-planting.



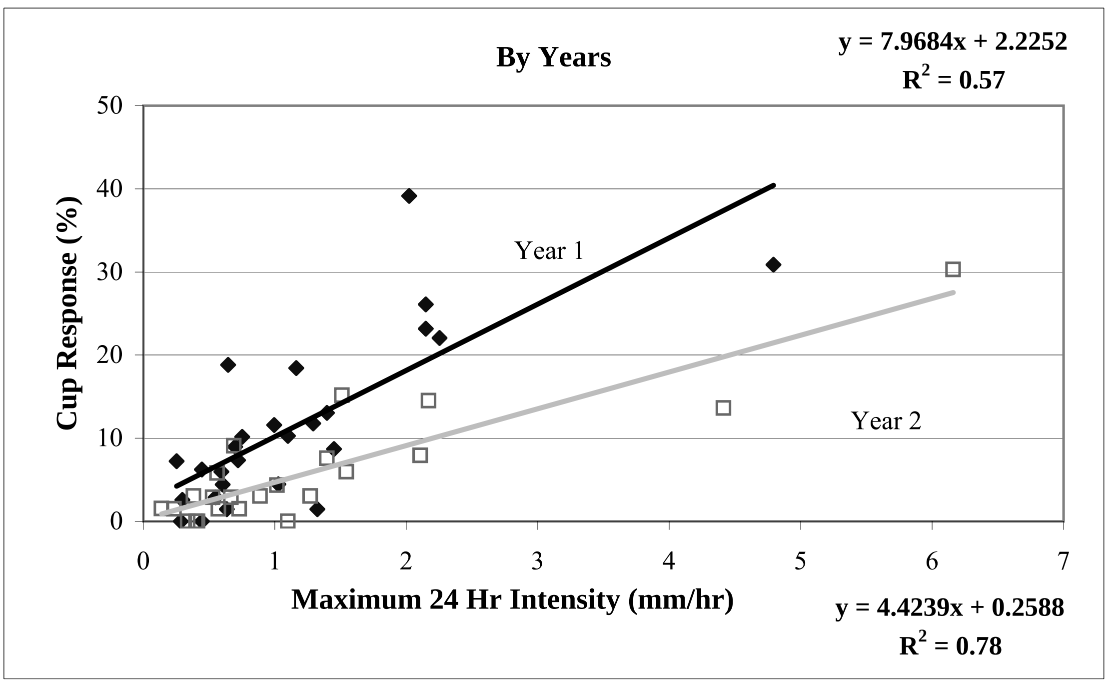


Figure 3.17. Maximum 24 hour intensity versus surface runoff frequency at Vanir tract in Ga. Piedmont, all tallied storms included a) All data b) Data separated by year[1,2].

[1]Year one is first dormant and growing season post-planting

[2] Year two is second dormant and most of second growing season post-planting.

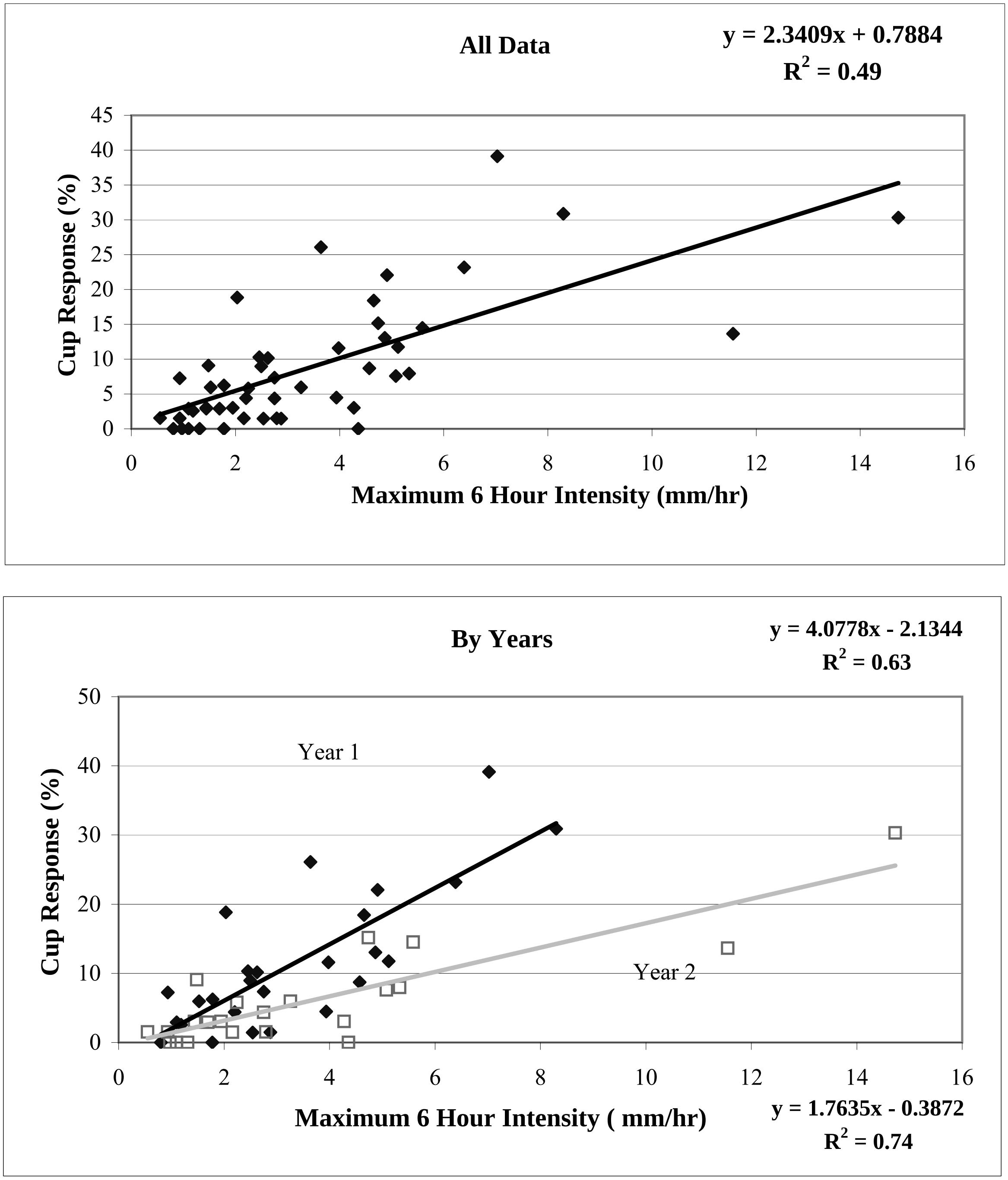


Figure 3.18. Maximum 6 hour intensity versus surface runoff frequency at Vanir tract in Georgia Piedmont, all tallied storms included a) All data b) Data separated by year[1,2].

[1]Year one is first dormant and growing season post-planting

[2] Year two is second dormant and most of second growing season post-planting.

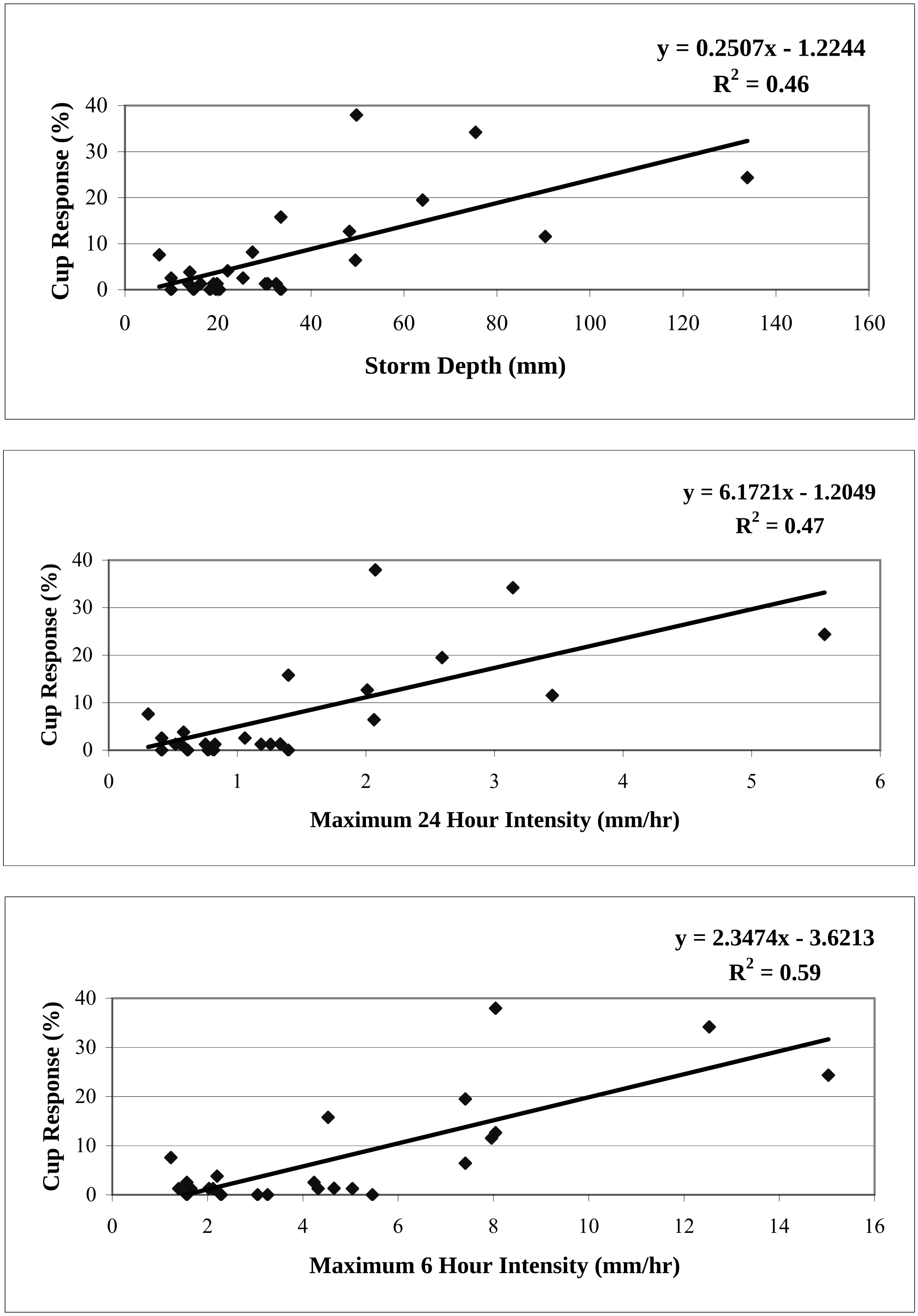


Figure 3.19. Rain factors versus surface runoff at reference site in Georgia Piedmont, all storms tallied, a) Storm depth b) 24 hour maximum intensity c) 6 hour maximum intensity, for 8 of 11 months of year two of study.

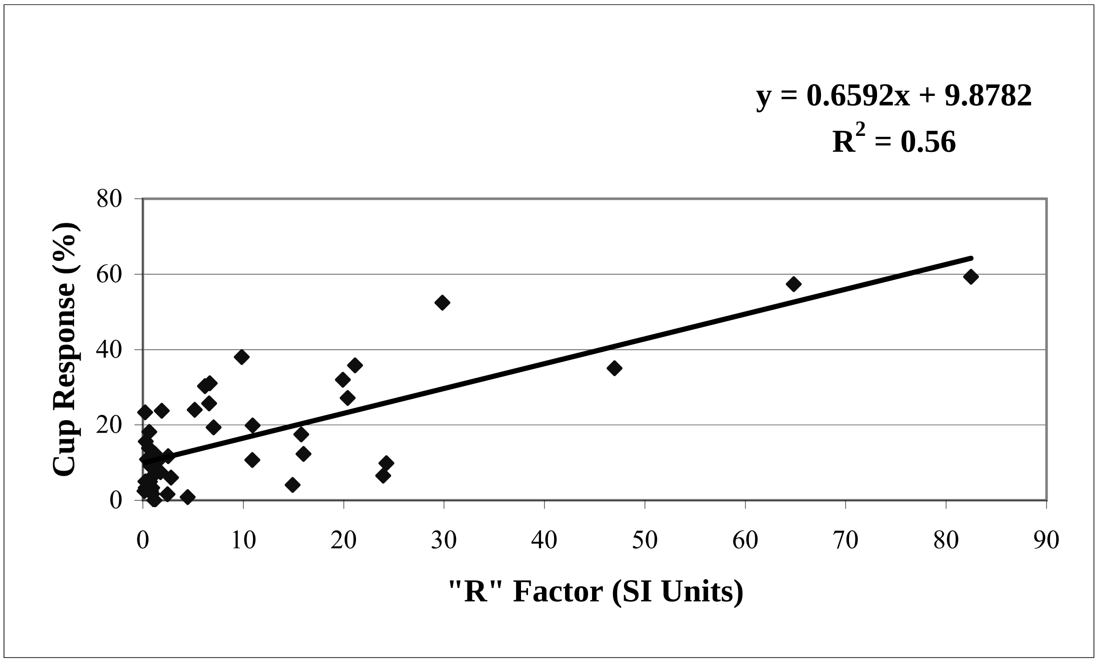
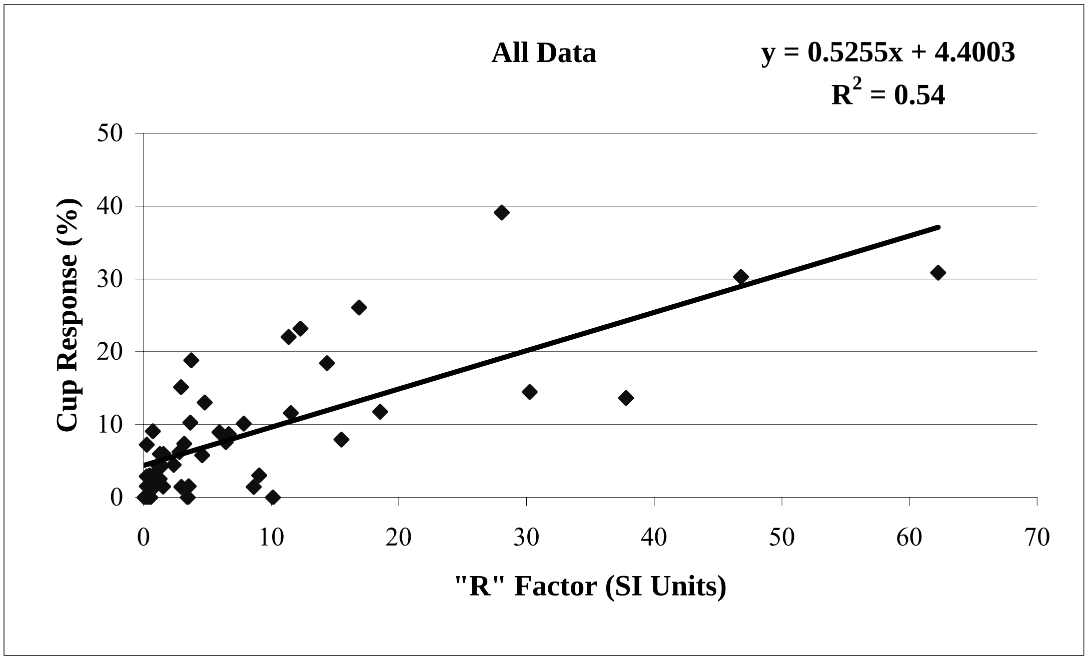


Figure 3.20. RUSLE "R"[1] versus surface runoff frequency at Lewis tract in Georgia Piedmont, all tallied storms included

[1]Storms were separated by 24 hour gaps in the winter and 12 hour gaps in the summer, not by RUSLE standard of 6 hour gaps.



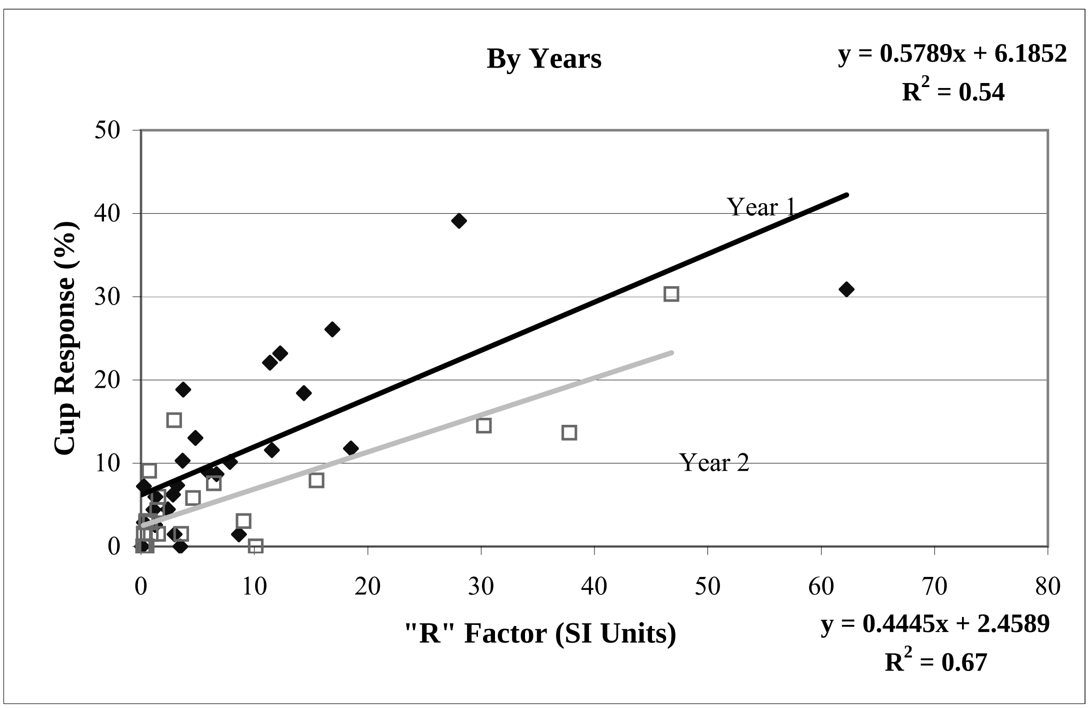


Figure 3.21. RUSLE "R"[1] versus surface runoff frequency at Vanir tract in Georgia Piedmont, all tallied storms included a) All data b) Data separated by years[2.3]

[1]Storms were separated by 24 hour gaps in the winter and 12 hour gaps in the summer, not by RUSLE standard of 6 hour gaps.

[2]Year one is first dormant and growing season post-planting

[3] Year two is second dormant and most of second growing season post-planting.

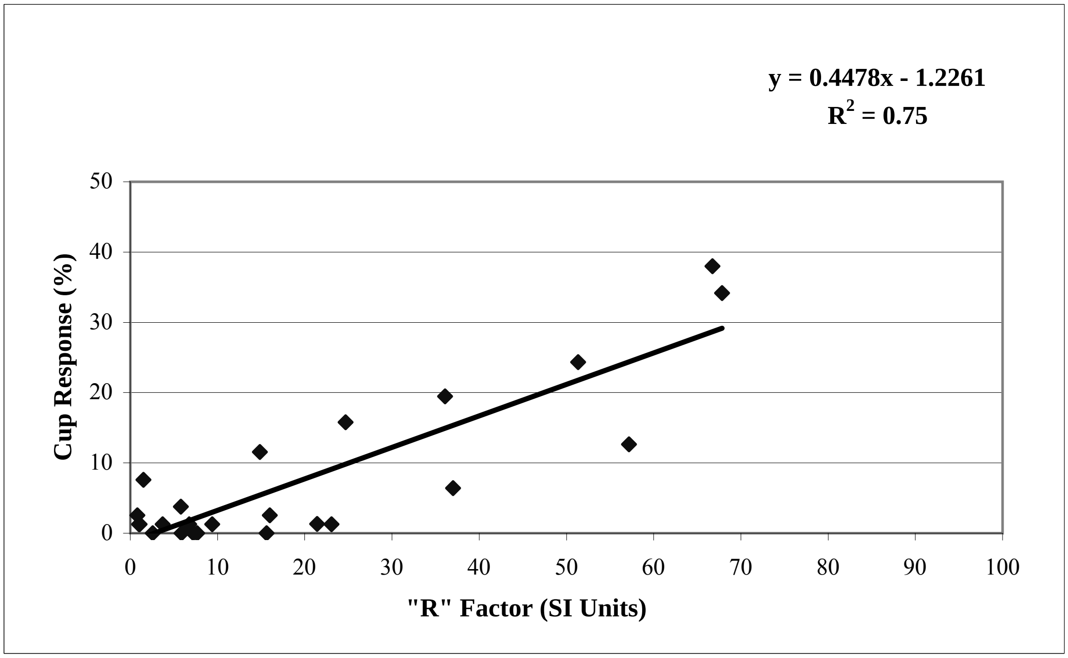


Figure 3.22. RUSLE "R"[1] versus surface runoff frequency at reference site in Georgia Piedmont, all tallied storms included, for 8 of 11 months of year two of study.

[1]Storms were separated by 24 hour gaps in the winter and 12 hour gaps in the summer, not by RUSLE standard of 6 hour gaps.

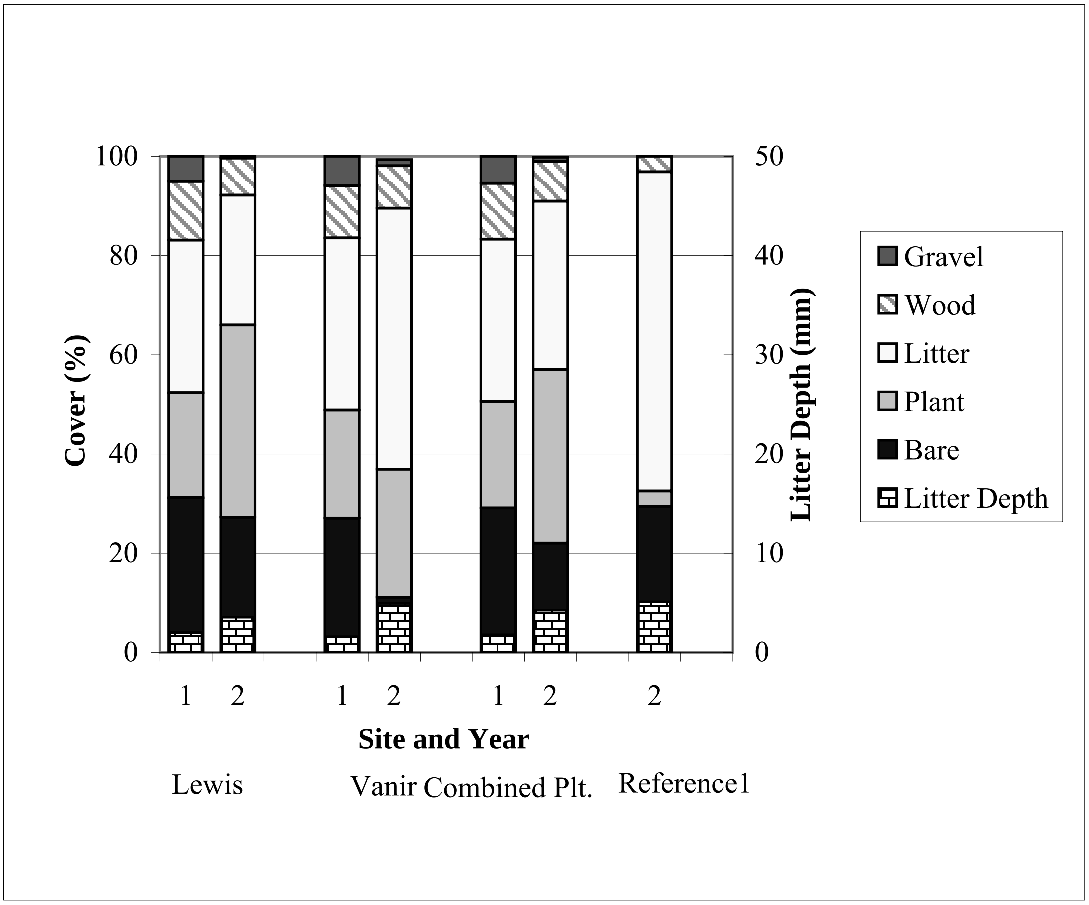


Figure 3.23. Cover and litter depth by sites and years[2], Greene County, in Georgia Piedmont.

[1]Reference site is one growing season post-burn.
Litter depth is on secondary axis with different scale.

[2]Graph represents data in table 3.7

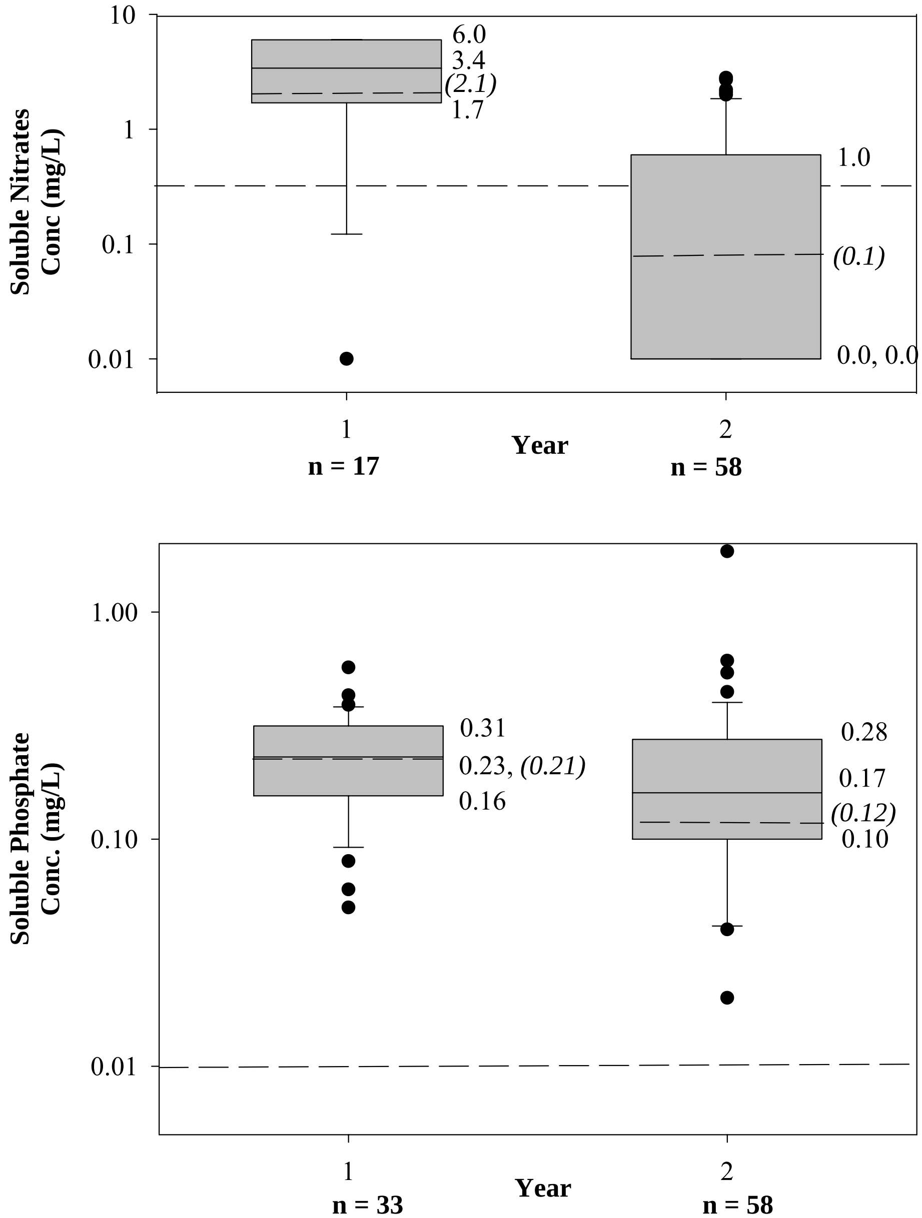


Figure 3.24. Boxplots of combined concentrations of dissolved a) Nitrates[1] and b) Phosphates grab sampled during large storms at pine plantation concentrated flow tracks, Greene County, in Georgia Piedmont[2].

[1] First year nitrates capped at 6.0 mg/L due to test limitations.

[2] Year one is within first year post-planting, year two is within second year post -planting.

Note log scale on y-axis. Boxes are 25 percentile and 75 percentiles.
Whiskers are 10 and 90 percentiles.
Solid lines are medians and dashed lines within box are *(means)*.
The long dashed line is EPA baseflow standard for Southern Piedmont perennials (US EPA 2000) .

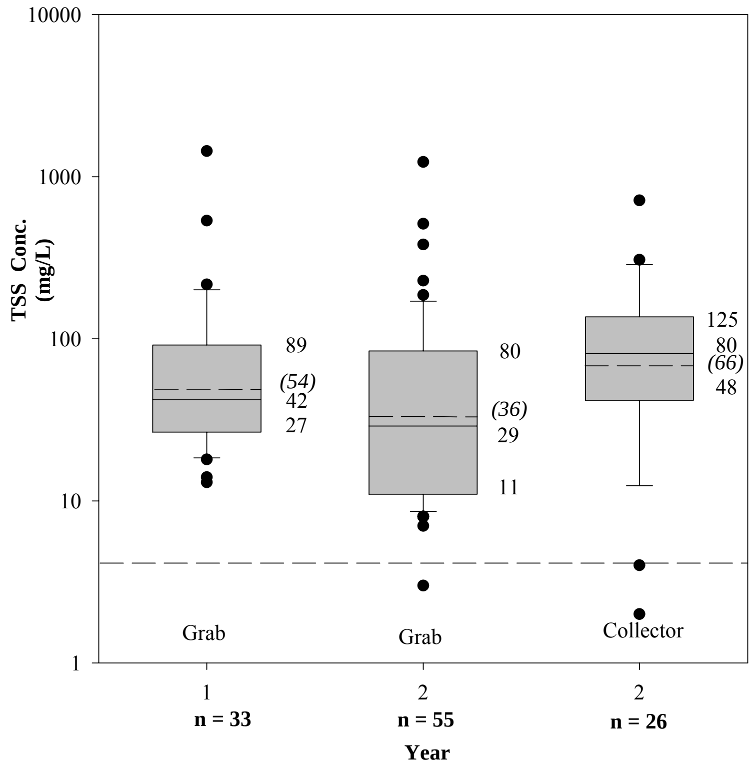
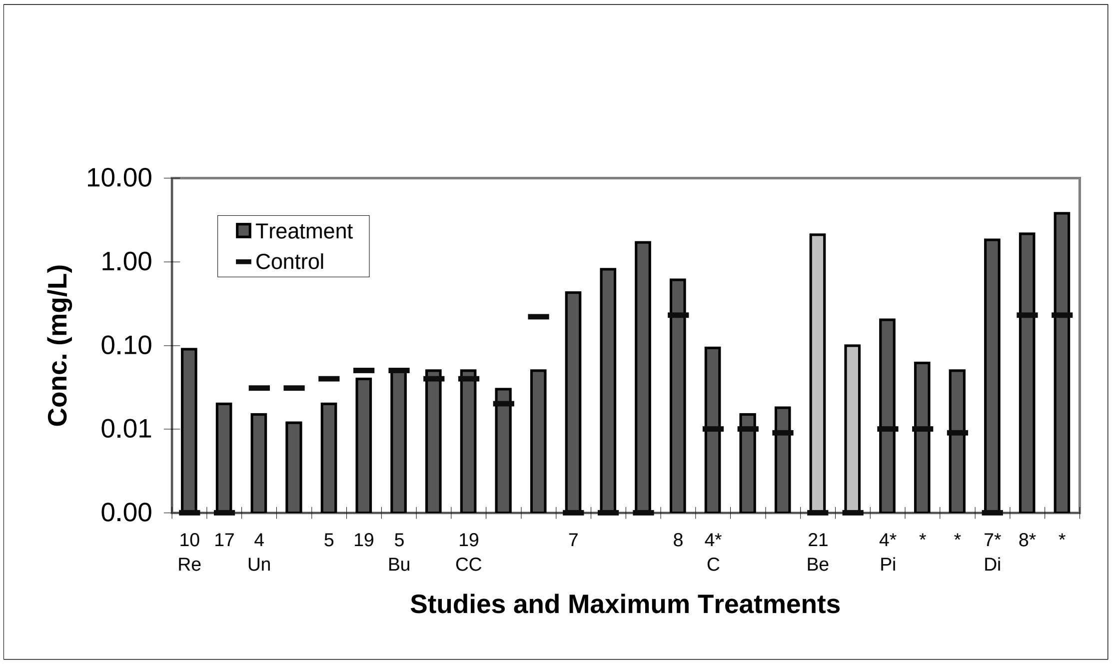


Figure 3.25. Boxplots of concentrations of Total Suspended Solids (TSS) sampled during storms at two pine plantations, Greene County, in Georgia Piedmont[1].

[1] Year one is within first year post-planting, year two is within second year post-planting.
The two left boxes are data from grab samples in concentrated flow tracks at the Lewis and Vanir sites.
The right box is data from overland flow collectors at the Vanir site.
Note log scale on y-axis.
Boxes are 25 percentile and 75 percentiles.
Whiskers are 10 and 90 percentiles.
Solid lines are medians and dashed lines within box are *(means)*.
The long dashed line is the EPA baseflow standard for Southern Piedmont perennials (US EPA 2000).



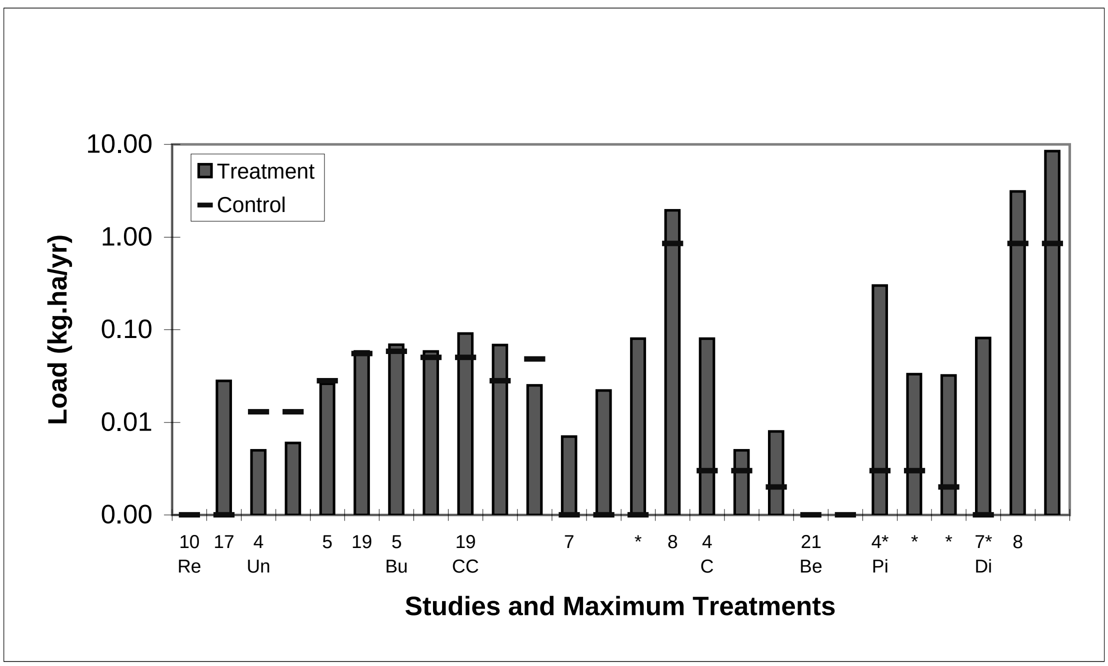
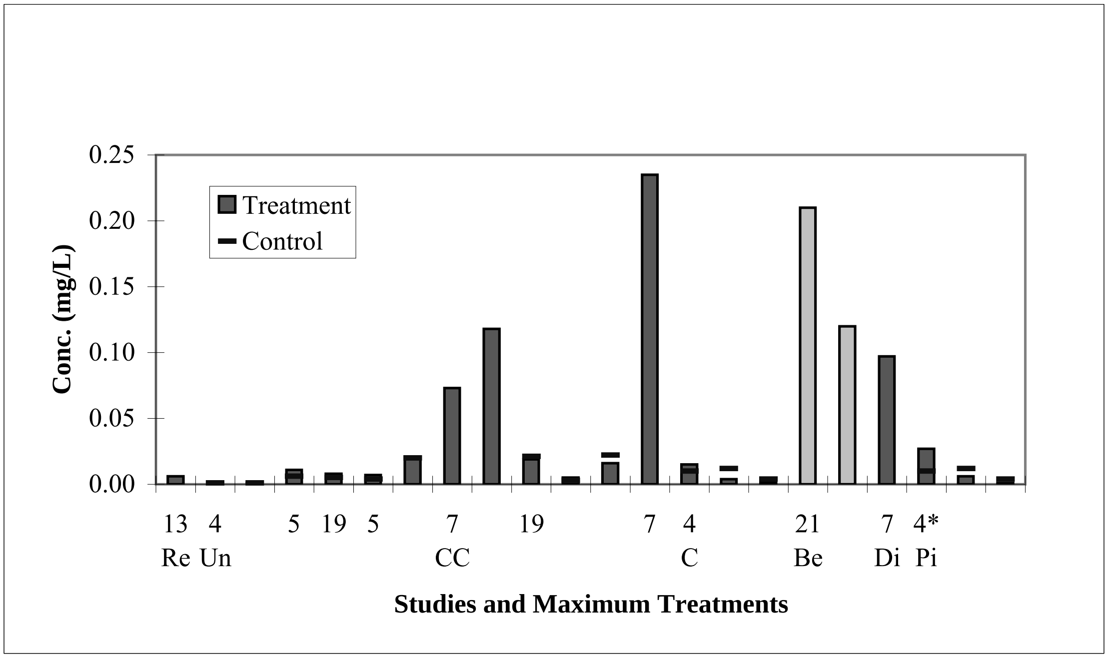


Figure 3.26. Mean NO_3 stormflow a) Concentrations and b) Loads in southeastern US forested ephemeral streams or runoff plots, from calibration through second year post-treatment

Blank spaces are successive years or a different site in the previous study number.
* = Significant difference between treatment and control for that year.
No data shown as 0.001. Note log scale on y-axis. 21 = current study. See Table 1.3 for citations.
Labels show most site disturbing but not every treatment. Re= Reference for Eastern perennials; Un=Uncut calibrations; B= Burn; CC= Clearcut; C = Chop; Be = Bed; Pi= Pile; Di = Disc



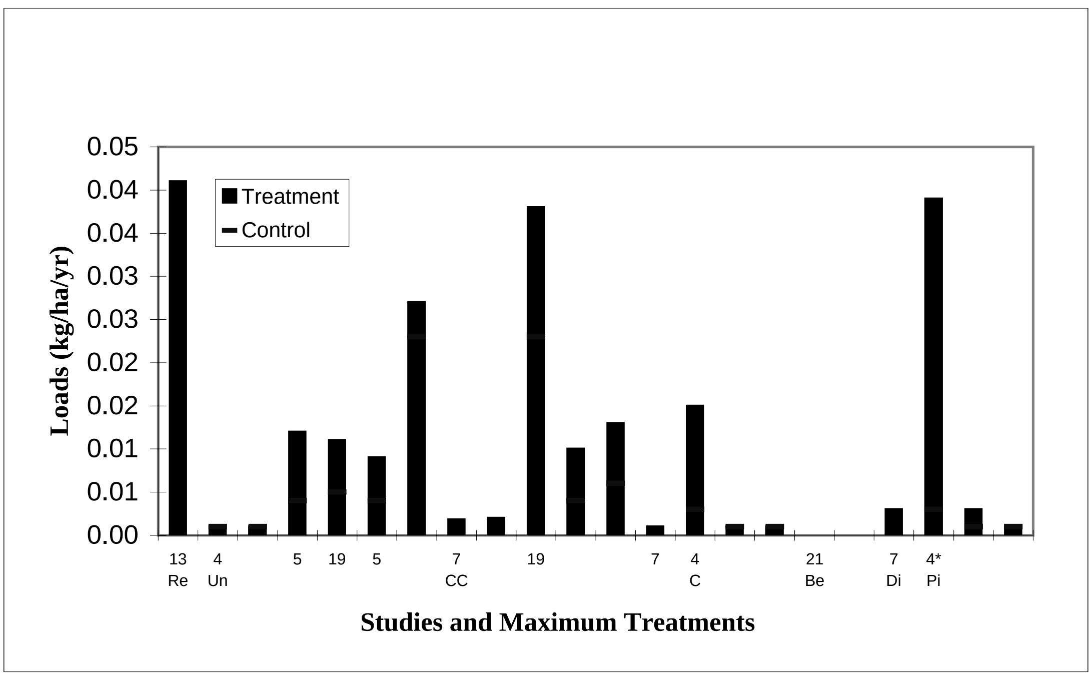


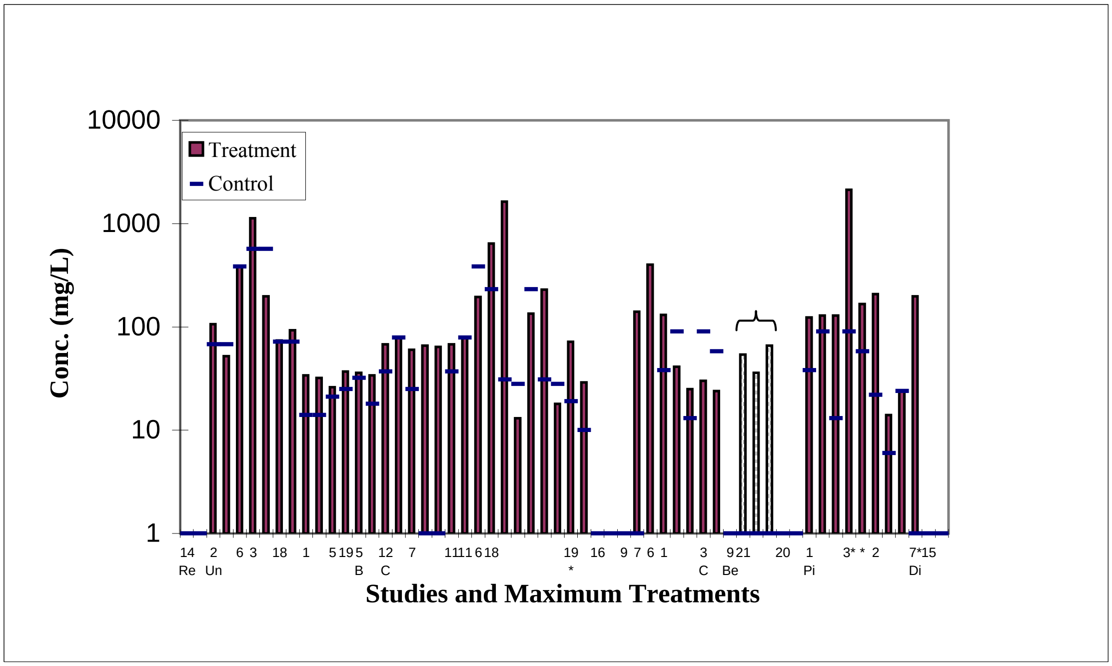
Figure 3.27. Mean PO_4 stormflow a) Concentrations and b) Loads in southeastern US forested ephemeral streams or runoff plots, from calibration through second year post-treatment

Blank spaces are successive years or a different site in the previous study number.

* = Significant difference between treatment and control for that year.

No data shown as 0.001. Note log scale on y-axis. 21 = current study. See Table 1.3 for citations.

Labels show most site disturbing but not every treatment. Re= Reference for Eastern perennials; Un=Uncut calibrations; B= Burn; CC= Clearcut; C = Chop; Be = Bed; Pi= Pile; Di = Disc



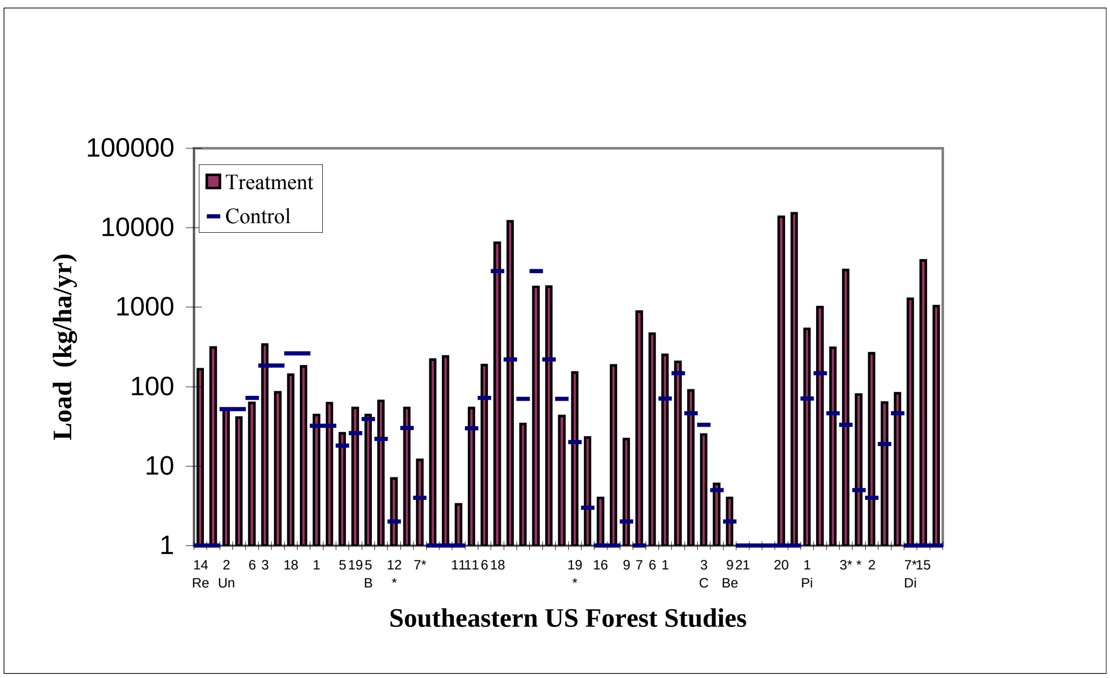


Figure 3.28. Mean sediment stormflow a) Concentrations and b) Loads in southeastern US forested ephemeral streams or runoff plots, from calibration through second year post-treatment

* = Significant difference between treatment and control for that year.

No data shown as 1. Note log scale on y-axis. See Table 1.3 for citations.

Labels show most site disturbing but not every treatment. Re= Reference for Eastern perennials; Un=Uncut calibrations; B= Burn; CC= Clearcut; C = Chop; Be = Bed; Pi= Pile; Di = Disc

21 Current study

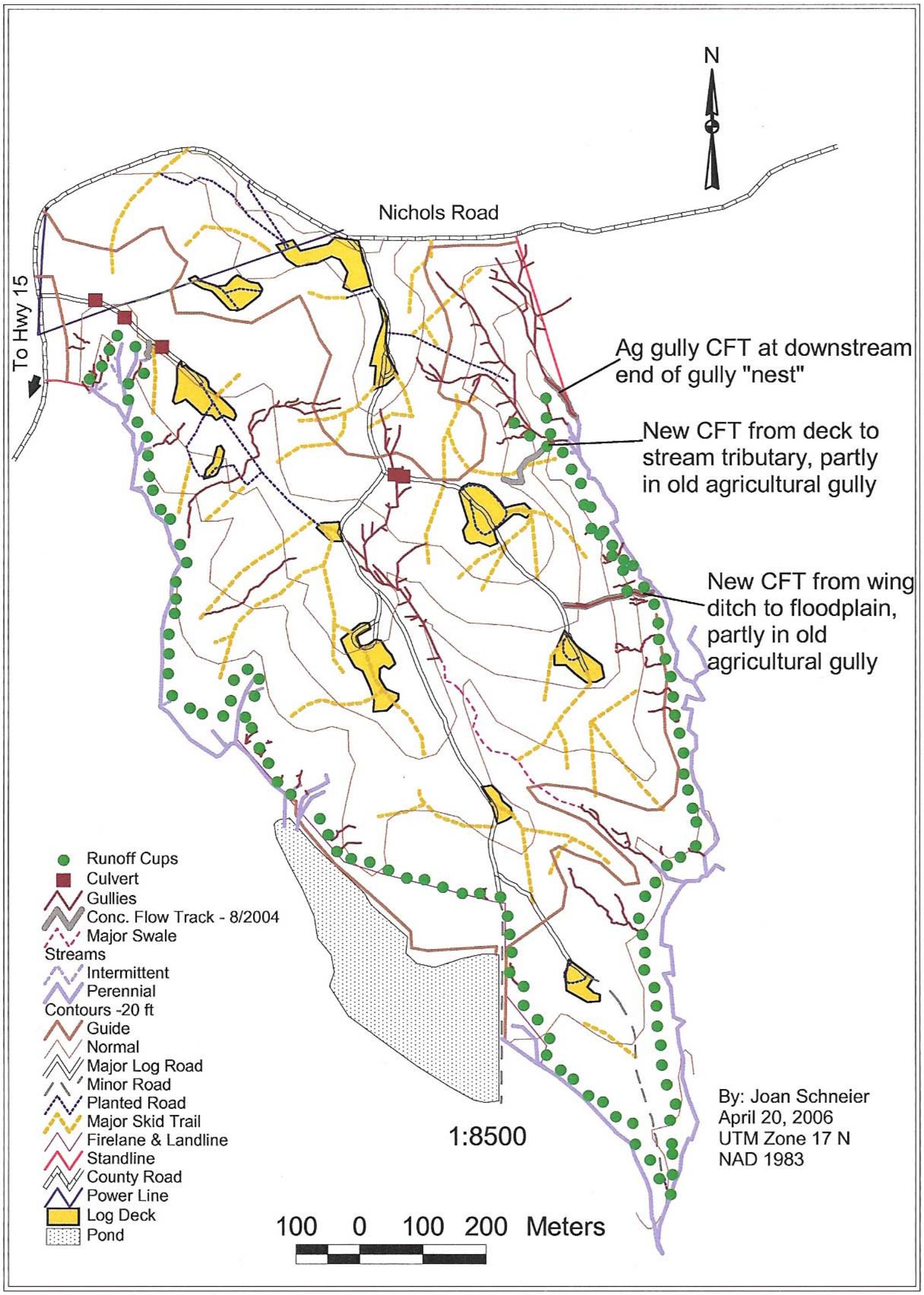


Figure 3.29. Map of active[1] concentrated flow tracks (CFTs) at end of second growing season at Lewis site, Greene County in Georgia Piedmont.

[1]Active CFTs are scoured at least part way into the Streamside Management Zone.

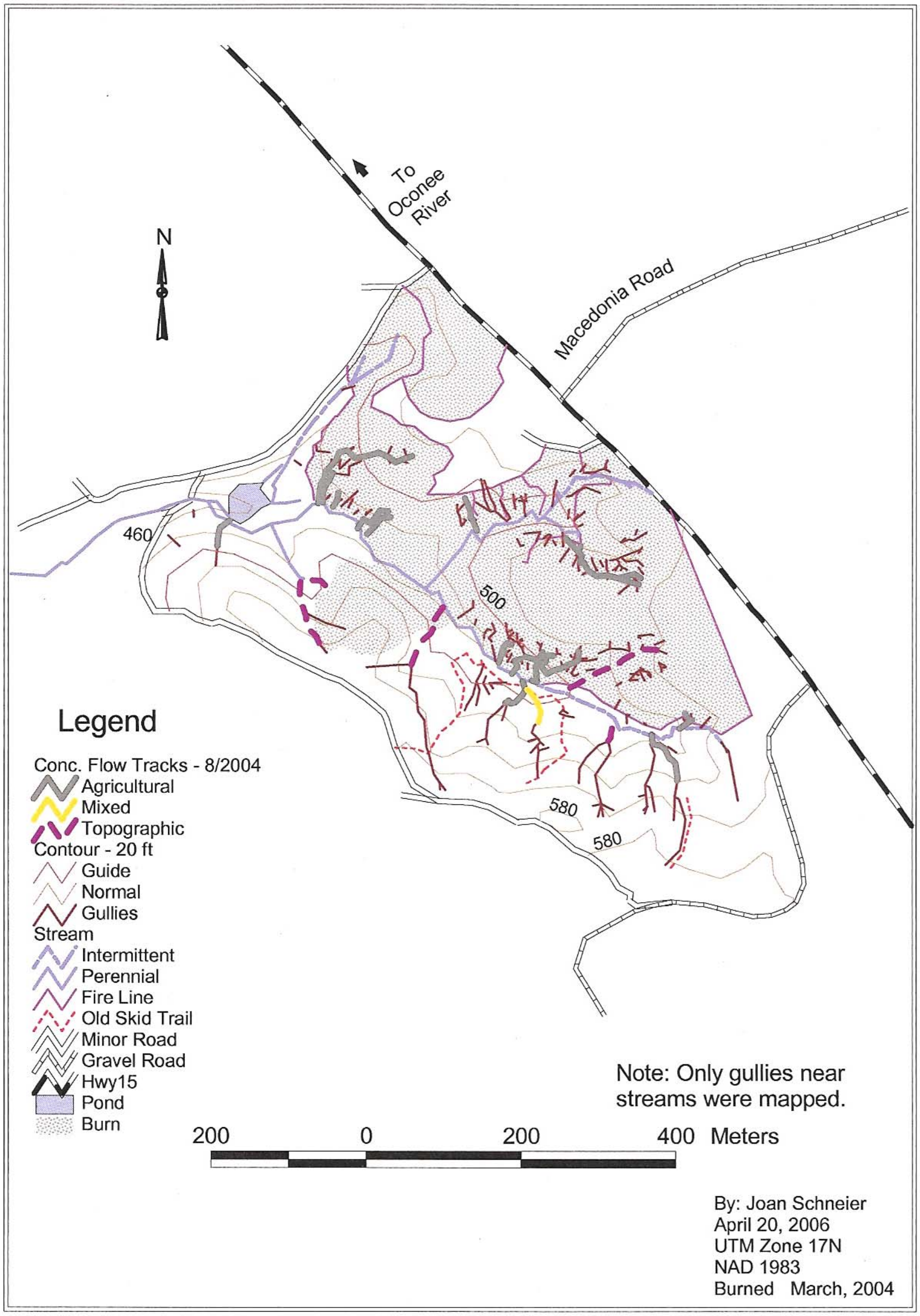


Figure 3.30. Map of active[1] concentrated flow tracks (CFTs) in a mature forest five months post-burn, at Watson Springs site, Greene County, in Georgia Piedmont.

[1]Active CFTs are scoured at least part way into the Streamside Management Zone.

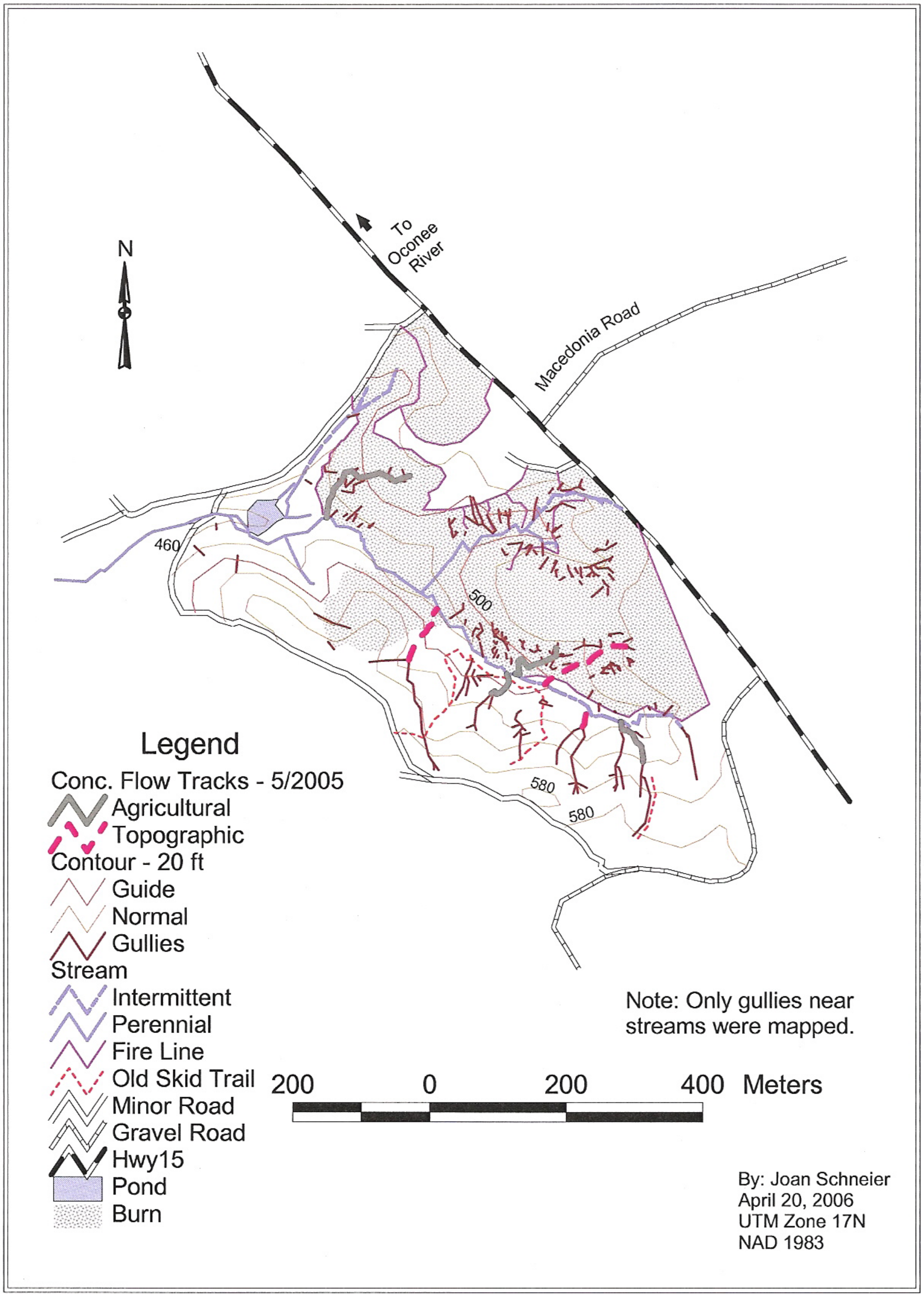


Figure 3.31. Map of active[1] concentrated flow tracks (CFTs) in a mature forest 14 months post-burn, at Watson Springs site, Greene County, in Georgia Piedmont.

[1]Active CFTs are scoured at least part way into the Streamside Management Zone.

CHAPTER 4

CONCLUSIONS

The runoff cup method described appeared to be a functional method of studying runoff frequency. Overland flow occurred on the two forest regeneration areas studied, reaching the upper edge of the Streamside Management Zone (SMZ). The mean frequency of overland flow for storms over 13 mm during the first nine months following planting was 20.3% at the Lewis site and 8.7% at the Vanir site. This decreased to 10.9% at Lewis and 4.7% at Vanir, over the next 11 months. The combined plantation mean runoff frequencies were 13.0% the first period and 7.4% the second period, for an average of 9.7% for the 20 month study period. The highest response rate for any single storm was 77.1% at Lewis during the first growing season. Overland flow occurred in at least one plantation cup in all storms over 13 mm in depth in the first period and 98.0% of these storms in the second period. It was also widespread spatially around the edge of the SMZ, occurring at least once in 83.3% of the cups in the first period, and 74.5% the second period. Mean runoff frequency at Lewis differed statistically from that at Vanir, for the combined dormant seasons and during the entire study period.

Overland flow also occurred on the mature forest reference site at 2.2% frequency, in 79.2% storms, and at least once in 64.6% of the cups. The highest cup response rate of any single storm was 38.0%. Mean runoff frequency at the reference site differed statistically from the Lewis plantation, for the combined dormant seasons, the combined growing seasons, and the entire study period. Mean runoff frequency at the reference site differed statistically from the combined plantations for only the entire study period. Mean runoff frequency at the reference site was statistically similar to the Vanir plantation.

The best rainfall predictors of frequency of overland flow were: the “R” factor of the Revised Universal Soil Loss Equation (RUSLE), storm depth, and maximum 24-hour and 6-hour intensities, with linear regression r^2 values between 0.46 and 0.75. Bare ground decreased from a first year value of 31% at Lewis, 27% at Vanir, and 29% for the combined pantations, to second year values of 27% at Lewis, 11% at Vanir, and 22% for the combined plantations. Litter depth increased from two mm after one growing season to four mm after the second growing season from the combined plantations. Bare ground was 29% and litter depth 5mm in the reference stand in the second period of the study.

Dissolved nitrate means were 2.1 the first year and 0.8 mg/L the second year from storm grab samples of combined plantations. Dissolved phosphate means were 0.23 the first year and 0.12 mg/L the second year. Total Suspended Solid (TSS) means were 54 the first year and 36 mg/L the second year from grab samples from combined plantations. The TSS mean from overland flow collectors was 66 mg/L the second growing season from only one plantation. The highest grab-sample values were >6.0 for nitrates, 1.85 for phosphates, and 1436 for TSS, all in mg/L.

Active concentrated flow tracks that penetrated the SMZ averaged 46 m (151 ft) long in the management area, 0.9 m (3. ft) deep, and had a hydrologic contributing area of 0.3 ha (0.7 ac). Active concentrated flow tracks that infiltrated in the SMZ averaged 44 m (144 ft) long in the management area, 0.6 m (2 ft) deep and had a hydrologic contributing area of 0.2 ha (0.5 ac). Most of these CFTs followed old agricultural gullies and were therefore deeper than new CFTs . Concentrated flow traveled up to 146 m (479 ft) in the management area and up to 26 m (85 ft) in the SMZ, in this study.

Timber managers interested in water quality should pay more attention to sensitive areas such as variable source areas, concentrated flow tracks, and old agricultural gullies. These could be factored into decisions about placements of roads, ditches, decks, site preparation, and streamside management zones and timing of management activities.

Further research should be done on surface runoff generation in forests in general. More specific questions during the regeneration window pertain to the roles of topography, microtopography, and compaction.

CITATIONS

Abu-Zreig, M., R.P. Rodra, and H.R. Whitely. 2001. Validation of a vegetated filter strip model (VFSMOD). *Hydrological Processes* **15**:729-742.

Agassi, M., I. Shainberg, and J. Morin. 1981. Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. *Soil Science Society of America Journal* **45**:848-851.

Allan, C.J., and N.T. Roulet. 1994. Runoff generation in zero-order precambrian shield catchments: The stormflow response of a heterogeneous landscape. *Hydrological Processes* **8: 369-388**

Amerman, C.R. 1965. The use of unit-source watershed data for runoff prediction. *Water Resources Research* **1**:499-507.

Atkinson, T.C. 1978. Techniques for measuring subsurface flow on hillslopes, p. 73-120, *In* M. J. Kirkby, ed. Hillslope Hydrology. John Wiley and Sons, Chichester, England.

Barling, R.D., and I.D. Moore. 1994. Role of buffer strips in management of waterway pollution - a review. *Environmental Management* **18**:543-558.

Barnes, K.H. 1998. The effects of sedimentation on Georgia's fish assemblages with emphasis on the Upper Etowah system. MS, University of Georgia, Athens, Ga.

Beasley, R.S. 1979. Intensive site preparation and sediment losses on steep watersheds in the Gulf coastal Plain. *Soil Science Society of America Journal* **43**:412-417.

Beasley, R.S., and A.B. Granillo. 1988. Sediment and water yields from managed forests on flat Coastal Plain sites. *Water Research Bulletin* **24**:361-366.

Beasley, R.S., A.B. Granillo, and V. Zillmer. 1986. Sediment losses from forest management: Mechanical vs. chemical site preparation. *Journal of Environmental Quality* **15**:413-416.

Betson, R.P. 1964. What is watershed runoff? *Journal of Geophysical Research* **69**:1541-1552.

Betson, R.P., and J.B. Marius. 1969. Source areas of storm runoff. *Water Resources Research* **5**:574-582.

Beven, K., M.J. Kirkby, N. Schofield, and A.F. Tagg. 1984. Testing a physically-based flood forescasting model (TOPMODEL) for three U.K. catchments. *Journal of Hydrology* **69**:119-143.

Blackburn, W., J.C. Wood, and M.G. DeHaven. 1986. Storm flow and sediment losses from site-prepared forest land in East Texas. *Water Resources Research* **22**:776-784.

Blackburn, W.H., and J.C. Wood. 1990. Nutrient export in stormflow following forest harvesting and site-preparation in East Texas. *Journal of Environmental Quality* **19**:402-408.

Blinn, C.R., and M.A. Kilgore. 2001. Riparian management practices - A summary of state guidelines. *Journal of Forestry* **99**:11-17.

Bonnell, M., and D.A. Gilmour. 1978. The development of overland flow in a tropical rainforest catchment. *Journal of Hydrology* **39**:365-382.

Brady, N.C., and R.R. Weil. 1999. The Nature and Property of Soils. 12 ed. Prentice-Hall Inc., Upper Saddle River, NJ. pp. 831

Burt, T.P. 1989. Storm runoff generation in small catchments in relation to the flood response of large basins, p. 11-35, *In* K. Beven and P. Carling, eds. Floods-Hydrological, sedimentological, and geomorphological implications. J. Wiley, New York.

Castillo, V.M., A. Gomez-Plaza, and M. Martinez-Mena. 2003. The role of antecedent soil water content in the runoff response of semi-arid catchments: a simulation approach. *Journal of Hydrology* **284**:114-130.

Cavalcanti, C.G., and B.G. Lockaby. 2005. Effects of sediment deposition on fine root dynamics in riparian forests. *Soil Science Society of America Journal* **69**:729-737.

de Pinho, A.P. 2003. Retancao de atrazina e picloram, provenientes de escoamento superficial, em zonas riparias. Ph.D. Dissertation, Universidada Federal de Vicosa, Minais Gerais, Brasil.

DeBano, L.F. 2000. The role of fire and soil heating on water repellancy in wildland environments: a review. *Journal of Hydrology* **231/232**:195-206.

Dietrich, W.E., D.M. Windsor, and T. Dunne. 1982. Geology, climate, and hydrology of Barro Colorado Island, p. 27-46, *In* E. G. J. Leigh, et al., eds. Seasonal Rhythms and the Ecology of a Tropical Forest: Seasonal Rhythms and Long-term Changes. Smithsonian Institution Press, Washington, D.C.

Douglass, J.E., and D.H. Van Lear. 1983. Prescribed burning and water quality at ephemeral streams in the piedmont of South Carolina. *Forest Science* **29**:181-189.

Dunne, T., and R.D. Black. 1970a. An experimental investigation of runoff production in permeable soils. *Water Resources Research* **6**:478-490.

Dunne, T., and R.D. Black. 1970b. Partial area contributions to storm runoff in a small New England watershed. *Water Resources Research* **6**:1296-1311.

Dunne, T., and L.B. Leopold. 1978. Water in Environmental Planning Will Freeman and Co., New York.

Dunne, T., T.R. Moore, and C.H. Taylor. 1975. Recognition and prediction of runoff-producing zones in humid regions. *Hydrological Sciences Bulletin* **20**:305-325.

Dykes, A.P. 1997. Rainfall interception from a lowland tropical forest in Brunei. *Journal of Hydrology* **200**:260-279.

Dykes, A.P., and J.B. Thornes. 2000. Hillslope hydrology in tropical rainforest steeplands in Brunei. *Hydrological Processes* **14**:215-235.

Eaton, A.D., L.N. Clesceri, A.E. Greenberg, and M.A.H. Franson, (eds.) 1995. Standard methods for the examination of water and wastewater, 19th ed. American Public Health Association, Washington, D.C.

Elsenbeer, H., and R.A. Vertessy. 2000. Stormflow generation and flowpath characteristics in an Amazonian rainforest catchment. *Hydrological Processes* **14**:2367-2381.

Ferreira, A.J.D., C.O.A. Coelho, R.P.D. Walsh, R.A. Shakesby, A. Ceballos, and S.H. Doerr. 2000. Hydrological implications of soil water-repellency in *Eucalyptus globulus* forests, north-central Portugal. *Journal of Hydrology* **231-232**:165-177.

Field, J.P., K.W. Farrish, and E.A. Carter. 2003. Soil and nutrient losses following site preparation burning in a harvested loblolly pine site. *Transactions of the ASAE* **46**:1697-1703.

Field, J.P., K.W. Farrish, B.P. Oswald, M.T. Ramig, and E.A. Carter. 2005. Forest site preparation effects on soil and nutrient losses in East Texas. *Transactions of the ASAE* **48**:861-869.

Findeling, A., S. Ruy, and E. Scopel. 2003. Modeling the effects of a partial residue mulch on runoff using a physically based approach. *Journal of Hydrology* **275**:49-66.

Fox, D.M., and R.B. Bryan. 2000. The relationship of soil loss by interrill erosion to slope gradient. *Catena* **38**:211-222.

Fox, T.R., J.A. Burger, and R.E. Kreh. 1986. Effects of site preparation on nitrogen dynamics in the Southern Piedmont. *Forest Ecology and Management* **15**:241-256.

Franklin, D.H., M.L. Cabrera, J.L. Steiner, D.M. Endale, and W.P. Miller. 2001. Evaluation of percent flow captured by a small infield runoff collector. *Transactions of the ASAE*. **44**:551-554.

Gabet, E.J., and T. Dunne. 2003. Sediment detachment by rain power. *Water Resources Research* **39**:1002, 1-12.

Georgia Environmental Protection Division, and Georgia Forestry Commission. 1999. Georgia's Best Management Practices for Forestry, Macon, GA. pp.66.

Georgia Forestry Commission. 2005. Georgia forest facts. [Online] www.gfc.state.ga.us (posted March 2005; Accessed 11/8/2005).

Georgia GIS Clearinghouse. [Online] http://gis1.state.ga.us Accessed Oct 2004.

Georgia State Climatology Office. 1997. Monthly precipitation: 30 year Averages [Online] http://climate.engr.uga.edu/plant_sciences/precip.html Accessed July 2004

Georgia State Climatology Office. 2002. Daily summaries. 1990-1999 [Online] http://climate.engr.uga.edu/plant_sciences/daily_90s.html Accessed July 2004

Georgia State Climatology Office. 2003. Daily summaries. 2000-2003 [Online] http://climate.engr.uga.edu/plant_sciences/daily_2000s.html Accessed July 2004

Germann, P.F. 1986. Rapid drainage response to precipitation. *Hydrological Processes* **1**:3-14.

Ghadiri, H., C.W. Rose, and W.L. Hogarth. 2001. The influence of grass and porous buffer strips on runoff hydrology and sediment transport. *Transactions of the ASAE* **44**:259-268.

Godsey, S., H. Elsenbeer, and R. Stallard. 2004. Overland flow generation in two lithologically distinct rainforest catchments. *Journal of Hydrology* **295**:276-290.

Grace, J.M.I. 2004. Soil erosion following forest operations in the southern Piedmont of central Alabama. *Journal of Soil and Water Conservation* **59**:160-166.

Han, J., J.S. Wu, and C. Allan. 2005. Suspended sediment removal by vegetative filter strips treating highway runoff. *Journal of Environmental Science and Health Part A- Toxic/Hazardous Substances and Environmental Engineering* **40**:1637-1649.

Hansen, W.F. 2001. Identifying stream types and management implications. *Forest Ecology and Management* **143**:39-46.

Heede, B.H. 1987. Overland flow and sediment delivery five years after timber harvest in a mixed conifer forest, Arizona, U.S.A. *Journal of Hydrology* **91**.

Herwitz, S.R. 1986. Infiltration-excess caused by stemflow in a cyclone-prone tropical rainforest. *Earth Surface Processes and Landforms* **11**:401-412.

Hewlett, J.D. 1978. Forest water quality: an experiment in harvesting and regenerating Piedmont Forest Land. School of Forest Resources, University of Georgia, Athens, GA.

Hewlett, J.D., and A.R. Hibbert. 1963. Moisture and energy conditions within a sloping soil mass during drainage. *Journal of Geophysical Research* **68**:1081-1087.

Hewlett, J.D., H.E. Post, and R. Doss. 1984. Effect of clearcut silviculture on dissolved ion export and water yield in the Piedmont. *Water Resources Research* **20**:1030-1038.

Hewlett, J.D., and A.R. Hibbert. 1967. Factors affecting the response of small watersheds to precipitation in humid areas, p. 275-290, *In* W. E. Sopper and H. W. Lull, eds. Forest Hydrology. Pergamon Press, New York.

Horton, R.E. 1933. The role of infiltration in the hydrologic cycle. *Transactions of the American Geophysical Union* **14**:446-460.

Horton, R.E. 1940. An approach towards a physical interpretation of infiltration-capacity. *Soil Science Society Proceedings* **5?**:399-417.

Hunzinger, H. 1997. Hydrology of montane forests in the Sierra de San Javier, Tucuman, Argentina. *Mountain Research and Development* **17**:299-308.

Ice, G.R., G.W. Stuart, J.B. Waide, L.C. Irland, and P.V. Ellefson. 1997. Twenty five years of the Clean Water Act: How clean are forest practices? *Journal of Forestry* **95**:9-13.

Jackson, C.R. In press. Wetland hydrology, *In* D. P. Batzer and R. Sharitz, eds. Ecology of Freshwater and Marine Wetlands. University of California Press.

Jayawardena, A.W., and R.R. Bhuiyan. 1999. Evaluation of an interrill soil erosion model using laboratory catchment data. *Hydrological Processes* **13**:89-100.

Johansen, M.P., T.E. Hakonson, and D.D. Breshears. 2001. Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. *Hydrological Processes* **15**:2953-2965.

Keim, R.F., and S. Schoenholtz. 1999. Functions and effectiveness of silvicultural streamside management zones in loessial bluff forests. *Forest Ecology and Management* **118**:197-209.

Kirkby, M.J., and R.J. Chorley. 1967. Throughflow, overland flow, and erosion. *International Association of Scientific Hydrology Bulletin* **12**:5-21.

Kothyari, B.P., P.K. Verma, B.K. Joshi, and U.C. Kothyari. 2004. Rainfall-runoff-soil and nutrient loss relationships for plot size areas of bhetagad watershed in Central Himalaya, India. *Journal of Hydrology* **293**:137-150.

Lacey, S.T. 2000. Runoff and sediment attenuation by undisturbed and lightly disturbed forest buffers. *Water, Air and Soil Pollution* **122**:121-138.

Lesack, L.F.W. 1993. Water-balance and hydrologic characteristics of a rain-forest catchment in the cetral Amazon basin. *Water Resources Reseach* **29**:759-773.

Liebenow, A.M., W.J. Elliot, J.M. Laflen, and K.D. Kohl. 1990. Interrill erodibility: Collection and analysis of data from cropland soils. *Transactions of the ASAE* **33**:1182-1888.

Malmer, A. 1996. Hydrological effects and nutrient losses of forest plantation establishment on tropical rainforest land in Sabah, Malaysia. *Journal of Hydrology* **174**:129-148.

Martinez-Mena, M., V.M. Castillo, and J. Albaladejo. 2001. Hydrological and erosional response to natural rainfall in a semi-arid area of south-east Spain. *Hydrological Processes* **15**:557-571.

Miller, W.P., R. Jackson, and T.C. Rasmussen. 1999. Readings in soils and hydrology. A text for CRSS/FORS 3060 University of Georgia, Athens, GA. pp. 170

McClurkin, D.C., P.D. Duffy, and N.S. Nelson. 1987. Changes in forest floor and water quality following thinning and clearcutting of 20-year old pine. *Journal of Environmental Quality* **16**:237-241.

McClurkin, D.C., P.D. Duffy, S.J. Ursic, and N.S. Nelson. 1985. Water quality effects of clearcutting upper Coastal Plain loblolly pine plantations. *Journal of Environmental Quality* **14**:329-332.

McDowell, T.R., and J.M. Omernik. 1977. Nonpoint source-stream nutrient level relationships: A nationwide study.Supplement 1: Nutrient map reliability EPA-600/3-77-105. US Environmental Protection Agency, Corvallis, OR.

McGregor, K.C., R.L. Bingner, A.J. Bowie, and G.R. Foster. 1995. Erosivity index values for northern Mississippi. *Transactions of the ASAE* **38**:1037-1047.

Meding, S.M., L.A. Morris, C.A. Hoover, W.L. Nutter, and M.L. Cabrera. 2001. Denitrification of a long-term forested land treatment system in the piedmont of Georgia. *Journal of Environmental Quality* **30**:1411-1420.

Miller, E.L. 1984. Sediment yield and storm flow response to clear-cut harvest and site preparation in the Ouachita Mountains. *Water Resources Research* **20**:471-475.

NCASI. 1994. Forests as Nonpoint Sources of Pollution, and Effectiveness of Best Management Practices Technical Bulletin 672. National Council of the Paper Industry for Air and Stream Improvement, Inc, New York.

Nutter, W.L. 1973. The role of soil water in the hydrologic behavior of upland basins, p. 181-193, *In* M. Stelly, ed. Field Soil Water Regime. Soil Science Society of America, Madison, WI.

Onset Computer Corporation. 2001. Data Logging Rain Gauge Manual RG2 and RG2-M Onset Computer Corporation, Bourne, MA.

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality* **9**:73-79.

Patric, J.H., J.O. Evans, and J.D. Helvey. 1984. Summary of sediment yield data from forested land in the United States. *Journal of Forestry* **82**:101-104.

Pearce, P.A., G.W. Frasier, M.J. Trlica, W.C. Leininger, J.D. Stednick, and J.L. Smith. 1998. Sediment filtration in a montane riparian zone under simulated rainfall. *Journal of Range Management* **51**:309-314.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. *Ecology* **65**:1466-1475.

Phillips, J.D. 1989. An evaluation of the factors determining the effectiveness of water quality II. Runoff processes. *Journal of Hydrology* **107**:133-145.

Pilgrim, D.H., D.D. Huff, and T.D. Steele. 1978. A field evaluation of subsurface and surface runoff. *Journal of Hydrology* **38**:319-341.

Ponce, V.M., and R.H. Hawkins. 1996. Runoff curve number: Has it reached maturity? *Journal of Hydrologic Engineering* **1**:11-19.

Pye, J.M., and P.M. Vitousek. 1985. Soil and nutrient removals by erosion and windrowing at a southeastern U.S. piedmont site. *Forest Ecology and Management* **11**:145-155.

Quansah, C. 1985. The effect of soil type, slope, flow rate and their interactions on detachment by overland flow with and without rain, p. 19-28, *In* P. D. Jungerius, ed. Soils and Geomorphology, Catena Supp. 6.

Ragan, R.M. 1967. An experimental investigation of partial area contributions, p. 241-251 Hydrological Aspects of the Utilization of Water, Vol. Publication 76. International Association of Scientific Hydrology (IAHS), Gentbrugge, Belgium.

Richter, D.D., and D. Markewitz. 2001. Understanding soil change. Soil sustainability over millenia, centuries, and decades Cambridge University Press, New York.pp. 255.

Rivenbark, B.L., and C.R. Jackson. 2004. Concentrated flow breakthroughs moving through silvicultural streamside management zones: Southeastern Piedmont, USA. *Journal of American Water Resources Association* **40**:1043-1052.

Robichaud, P.R., and T.A. Waldrop. 1994. A comparison of surface runoff and sediment yields from low-severity and high-severity site preparation burns. *Water Resources Bulletin* **30**:27-34.

Roper, D.M. 1996. Boyhood memories of Watson Springs resort. *North Georgia History* **Spring**:8-11.

Schmitt, T.J., M.G. Dosskey, and K.D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. *Journal of Environmental Quality* **28**:1479-1489.

Schreiber, J.D., P.D. Duffy, and D.C. McClurkin. 1980. Aqueous sediment-phase nitrogen yields from five southern pine watersheds. *Soil Science Society of America Journal* **44**:401-407.

Sheridan, J.M., R.R. Lowrance, and H.H. Henry. 1996. Surface flow sampler for riparian studies. *Applied Engineering in Agriculture* **12**:183-188.

Shainberg, I., A.I. Mamedov, and G.J. Levy. 2003. Role of wetting rate and rain energy in seal formation and erosion. *Soil Science* **168**:54-62.

Sharma, P.P., S.C. Gupta, and G.R. Foster. 1995. Raindrop-induced soil detachment and sediment transport from interrill areas. *Soil Science Society of America Journal* **59**:727-734.

Sidle, R.C., Y. Tsuboyama, S. Noguchi, I. Hosoda, M. Fujieda, and T. Shimizu. 2000. Stormflow generation in steep forested headwaters: A linked hydrogeomorphic paradigm. *Hydrological Processes* **14**:369-385.

Sinun, W., W.W. Meng, I. Douglas, and T. Spencer. 1992. Throughfall, stemflow, overland-flow and throughflow in the Ulu Segama rain forest, Sabah Malaysia. *Philosophical Transactions of the Royal Society of London Series B - Biological Sciences* **335**:389-395.

Srivastava, P., D.R. Edwards, T.C. Daniel, P.A.J. Moore, and T.A. Costello. 1996. Performance of vegatative filter strips with varying pollutant source and filter strip lengths. *Transactions of the ASAE* **39**:2231-2239.

Stomph, T.J., N. de Ridder, T.S. Steenhuis, and N.C. van de Giesen. 2002. Scale effects of Hortonian overland flow and rainfall-runoff dynamics laboratory validation of a process-based model. *Earth Surface Processes and Landforms* **27**:847-855.

Sutherland, A.B., J.L. Meyer, and E.P. Gardiner. 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. *Freshwater Biology* **47**:1791-1805.

Swift, L.W., Jr. 1986. Filter strip widths for forest roads in the southern Appalachians. *Southern Journal of Applied Forestry* **10**:27-34.

Teixera, P.C., and R.K. Misra. 1997. Erosion and sediment characteristics of cultivated forest soils as affected by the mechanical stability of aggregates. *Catena* **30**:119-134.

Tennessee Valley Authority. 1965. Area-stream factor correlation, a pilot study in the Elk River basin. *Bulletin of International Scientific Hydrology* **10**:22-37.

Thompson, M.T. 1998. Forest statistics for Georgia, 1997 [Online]. Available by USDA Forest Service, Southern Research Station http://www.srs.fs.usda.gov/pubs (verified 10/2002).

Trimble, S.W. 1974. Man-induced soil erosion on the Southern Piedmont 1700-1970 Soil Conservation Society of America, Ankenny, IA, pp.180.

Ursic, S.J. 1991. Hydrologic effects of two methods of harvesting mature southern pine. *Water Resources Bulletin* **27**:303-315.

US Environmental Protection Agency. 2000. Ambient water quality criteria recommendations. Information supporting the development of state and tribal nutrient criteria for rivers and streams in nutrient ecoregion IX [Online] http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_9.pdf (posted Dec 2000; verified 03/30/2006).

US Environmental Protection Agency. 2002. National water quality inventory report to Congress (305(b) report). 2002 National Assessment Database [Online] http://www.epa.gov/305b; verified 11/2005.

United States Geological Survey. Surface-water data for the nation. Gauge # 02218300 [Online] http://waterdata.usgs.gov/nwis/sw. Accessed 2005.

van de Giesen, N.C., T.J. Stomph, and N. de Ridder. 2000. Scale effects of Hortonian overland flow and rainfall- runoff dynamics in a West African catena landscape. *Hydrological Processes* **14**:165-175.

Van Lear, D.H., J.E. Douglass, S.K. Cox, and M.K. Augspurger. 1985. Sediment and nutrient export from burned and harvested pine watersheds in the South Carolina Piedmont. *Journal of Environmental Quality* **14**:169-174.

Waldron, L.J., and S. Dakessian. 1982. Effect of grass, legume, and tree roots on soil shearing resistance. *Soil Science Society of America Journal* **46**:894-899.

Wallach, R., and D. Zaslavsky. 1991. Lateral flow in a layered profile of an infinite uniform slope. *Water Resources Reseach* **27**:1809-1818.

Ward, J.M., and C.R. Jackson. 2004. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. *Journal of American Water Resources Association* **40**:1421-1431.

Weyman, D.R. 1970. Throughflow on hillslopes and its relation to the stream hydrograph. *Bulletin of International Association of Scientific Hydrology* **15**:25-33.

White, W.J. 2003. Retention of sediment and phosphorus in forested streamside management zones of the Georgia Piedmont under simulated overland flow conditions. MS, University of Georgia, Athens, GA.

Wigington, P.J., Jr., T.J. Moser, and D.R. Lindeman. 2005. Stream network expansion: A riparian water quality factor. *Hydrological Processes* **19**:1715-1721.

Wischmeier, W.H., and D.D. Smith. 1958. Rainfall energy and its relationship to soil loss. *Transactions of the American Geophysical Union* **39**:285-291.

Wohlgemuth, P.M., K.R. Hubbert, and P.R. Robichaud. 2001. The effects of log erosion barriers on post-fire hydrologic response and sediment yield in small forested watersheds, southern California. *Hydrological Processes* **15**:3053-3066.

Zhang, X.C., and M.A. Shao. 2003. Effects of vegetation coverage and management practices on soil nitrogen loss by erosion in a hilly region of the Loess plateau in China. *Acta Botanica Sinica* **45**:1195-1203.

Ziegler, A.D., T.W. Giambelluca, L.T. Tran, T.T. Vana, M.A. Nullet, J. Fox, T.D. Vien, J. Pinthong, J.F. Maxwell, and S. Evett. 2004. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: evidence of accelerated overland flow generation. *Journal of Hydrology* **287**:124-146.