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Assessment of Stormflow and Water Quality from Undisturbed and Site Prepared Forest Land in East Texas, Final Report

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ASSESSMENT OF STORMFLOW AND WATER QUALITY FROM UNDISTURBED AND SITE PREPARED FOREST LAND IN EAST TEXAS

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ABSTRACT

In 1979, nine small forested watersheds were instrumented in East Texas to determine the effect of intensive forest management practices on water quantity and quality. Three replications of three treatments were used: 1) clearcutting - followed by shearing and windrowing, 2) clearcutting - followed by roller chopping and 3) undisturbed control. Following treatment, the sheared and windrowed sites exposed 57% of the surface soil compared to 16% for the chopped watersheds. During 1981, the first year after treatment, stormflow volumes increased with the intensity of the site disturbance. Sites sheared produced the greatest amount of stormflow (5.76 inches), followed by chopped (3.26 inches) and the undisturbed watersheds (1.03 inches). Stormflow volumes decreased 66% and 57% on the sheared and chopped watersheds the second year following treatment. Sediment losses were significantly higher on the sheared watersheds (2,620 lb/acre) than the chopped (22 lb/acre), during 1981. By the fall of 1982, the exposure of mineral soil on the sheared sites dropped to 20% and to 4% on the chopped sites. For this reason and the lower volume of runoff, sediment loss for 1982 dropped to 71.3, 4.9 and 4.5 lb/acre for the sheared, chopped and undisturbed watersheds, respectively.

Nitrate concentrations were significantly different between treatments during 1981: Sheared - 205 ppb, chopped - 96 ppb and control - 10 ppb. During 1982, although nitrate concentrations were lower, the

sheared watershed still had a significantly higher concentration. Total nitrogen concentration on the sheared sites was 2,155 ppb, which was significantly higher than the chopped (999 ppb) or the control sites (996 ppb) for 1981. The first year total nitrogen export from the sheared sites (2.79 lb/acre) was 3.5 times greater than the chopped loss (0.76 lb/acre) and 12 times greater than the loss on the control sites (0.24 lb/acre). The second year following treatment, total nitrogen concentrations were not significantly different and total nitrogen loss on the sheared areas was less than half of the loss recorded from the control sites during 1981. Total phosphorus concentrations for 1981 were 221, 85 and 54 ppb for the sheared, chopped and control watersheds, respectively. Total phosphorus loss for this period was only 0.297 lb/acre from the sheared treatments, but was significantly higher than the chopped or undisturbed treatments. A drop in sediment concentrations and runoff in 1982 reduced phosphorus losses on the sheared watersheds by over 90%. Calcium, potassium and sodium concentrations during 1981, were highest for the chopped treatments, while magnesium concentrations were highest on the sheared treatments. Export of these elements was greatest from the sheared sites, except for calcium, which was lost in greater quantities on the chopped sites. During 1982 there was no significant difference between treatments for Ca, Mg, K and Na concentrations.

The rapid revegetation and reduction in exposed mineral soil that occurred on both sheared and chopped treatments during 1982, resulted in a decrease in runoff and sediment and nutrient losses. As the stabilization of sites continues, treatment differences should diminish.

Limiting shearing and windrowing activities to the more gentle slopes will reduce first year erosion and prevent increases in sediment and nutrient losses. Roller chopping on the other hand, appears to cause only minor changes to water yield and quality on slopes of up to 25%.

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INTRODUCTION

This study is spurred by the concern over the potential decline in forest productivity and the possible environmental effects of sediment and nutrient losses resulting from harvesting and site preparation activities. The scope of this project is to examine the influence of intensive forestry practices on water quality and yield, along with soil and vegetation parameters. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) make non-point pollution from forest practices increasingly more important, however, the effect of these practices on water quality in East Texas is not known.

This study is part of a regional program, with similar investigations being conducted in Arkansas. The regional collection of data is essential for characterizing the effects of forestry practices on water quality over a broad physiographic range. Extrapolation of water quality data between sites may not be feasible due to the variability in soil-physiographic-geologic conditions within the regions. However, an accurate accumulation of comparable information can be effectively generated for developing and evaluating sound predictive techniques with regional applications. Such predictive models will aid land managers in selecting practices that are environmentally sound as well as productive.

The treatments to be evaluated are the two most widely used methods of site preparing harvested forests in East Texas: 1) shearing and windrowing and 2) roller chopping. Nine six and one-half acre watersheds are being used to compare differences between these site preparation treatments. Six of these experimental watersheds were harvested during the summer of 1980. Three of these six were then sheared with a V-blade, windrowed and the windrows burned. The remaining three harvested watersheds were roller chopped and then broadcast burned. Site preparation treatments were applied during November of 1980. All treatments were applied using the best state-of-the-art techniques. Three watersheds were left undisturbed as controls.

This report attempts to familiarize the reader with the forest practices currently being used in East Texas, and the accompanying water quality problems. Results of the first three years of pre- and post-treatment soil, vegetation, precipitation, water yield and water quality data are included.

STATE-OF-THE-ART HARVESTING AND SITE PREPARATION PRACTICES IN EAST TEXAS

The majority of forest land in East Texas is managed primarily for pine sawtimber and/or pulpwood. Clearcutting and planting is the predominant regeneration system. Approximately 353,000 acres of trees are harvested in East Texas each year (Blackburn et al. 1978) (Table

1). Of these acres, 192,768 are clearcut, 127,413 are selectively harvested and 32,919 are harvested by the seed tree and shelterwood systems. Harvesting activities are carried out through most of the year, with about 66 percent occurring between March and August.

Of the forest land receiving a final harvest cut each year , about 142,800 acres receive some form of site preparation prior to re-establishment of a new forest (Blackburn et al. 1978) (Table 2). Mechanical means alone, or in combination with prescribed burning are the most frequently used methods.

Table 1. Estimated acreage of sawtimber and pulpwood sized material annually receiving a final harvest cut on forest land in East Texas, by regeneration system (Blackburn et al. 1978).

Regeneration System	Sawtimber	Pulpwood	Total	Percentage of Total
Clearcut	134,254	58,714	192,768	55
Selection*	74,941	52,872	127,413	36
Seed Tree	14,410	3,293	17,703	5
Shelterwood	12,090	3,126	15,216	4
Total	235,495	118,005	353,500	

*The figure reported for the selection regeneration system largely reflects intermediate harvest cuttings.

The following site preparation activities are employed on East Texas managed forests: 1) shearing, 2) windrowing, 3) roller chopping, 4) disking, 5) bedding, 6) burning windrows, 7) broadcast burning and 8) herbicide treatment. These activities may be employed singly or in various combinations. Shearing and windrowing are the most commonly used site preparation techniques with roller chopping ranking second.

Table 2. Estimated acres of East Texas forest land receiving a site preparation treatment annually (Blackburn et al. 1978).

Site Preparation Technique	Forestland
Mechanical	100,428
Prescribed Burning	33,163
Herbicide	9,229
Total	142,820*

*Actual area treated is less due to overlapping activities.

The windrows are usually burned following shearing and windrowing and the roller chopped areas are normally broadcast burned after chopping. Bedding and disking are only used on the poorly drained soils of southeast Texas. Herbicide spraying or injection is usually used in combination with one of the mechanical site preparation methods.

LITERATURE REVIEW

Water Yield

Water yield from undisturbed forests is regulated by the vegetation, soils, topography and climate. Precipitation in the form of rain is the most common input for the humid region of the southeastern United States. Of the precipitation falling on a mature forested watershed, from 10 to 30 percent is intercepted by the forest canopy and lost as evaporation (Rogerson 1967). In most cases, the rain reaching the forest floor filters through the litter covered surface and infiltrates into the soil. Under certain circumstances of prolonged rainfall, the soil becomes saturated and the infiltration rate is reduced and overland flow occurs. Pierce (1967) found evidence of overland flow occurring over accumulated leaf debris and laterally at the interface of humus and/or litter layers and the mineral surface. Nonetheless, contribution to streamflow is primarily the result of subsurface flow (Hursh 1944; Whipkey 1967). Hewlett and Nutter (1970) explain streamflow as resulting from the expanding source area of subsurface flow near the stream channel. Evidence has also been presented to show the contribution of subsurface flow from upper slopes to the stream channel (Beasley 1976).

Forest management activities will significantly influence the timing and quantity of water yield. It has been well documented that harvesting the forest vegetation will increase streamflow (Douglass and Swank 1972; Hornbeck 1975; and Hewlett 1979). When the vegetative cover is removed, evapotranspiration is reduced and soil moisture is increased (Troendle 1970). The result is an increase in the water available for streamflow. The intensive forest practices of harvesting, site preparation and machine planting may also disturb the forest floor enough to cause overland flow. The impact of overland flow on the storm hydrograph will be a rapid response time, an increased volume of runoff and a higher peak discharge rate. Ursic (1979) found storm peak flows from small catchments, a sensitive index to changes in the components of stormflow and sediment production due to forestry activities. However, significant increases in peak flow are usually limited to a few large events. Although these events may produce a large percentage of the annual water and sediment yield, they do not persist with forest regeneration.

Water yield increases following clearcutting, is the rule rather than the exception. On the Fernow Experimental Forest in West Virginia, Reinhart (1962) found that stream discharge was increased in proportion to the amount of timber cut. In this study, the annual discharge increased up to 5 area-inches the first year following clearcutting. Another study (Aubertin and Patric 1974) on the Fernow Experimental Forest found that clearcutting increased streamflow 8 area-inches during the first year following cutting. Rapid revegetation reduced the increase in streamflow to 2.5 area-inches by the second year.

Clearcutting followed by roller chopping, in the Georgia Piedmont, resulted in a first year water yield increase of 10 area-inches (Hewlett 1979). This represented an increase of 27 percent above pretreatment stormflow. The cumulative effects of forest operations more than doubled small stormflows and peaks, but were proportionally less influential in large flood producing flows. Beasley (1979) studied the effect of three different site preparation treatments on stormflow in northern Mississippi. The first year following chopping, shearing, and windrowing, bedding and no treatment, stormflows were 20, 18, 20 and 3 area-inches, respectively. Stormflow as a percentage of rainfall decreased the second year following treatment.

The initial increase in water yield and peak flow following forest disturbance, appears to be short-lived for most of the eastern and southern United States. The rapid revegetation in these areas, quickly stabilizes the site and increases evapotranspiration. Douglass and

Swank (1972) conclude that water yield increases decline rapidly with regeneration of the forest and seldom persists beyond the fifth year.

Water Quality

Sediment

Sediment is often regarded as the primary pollutant from silvicultural activities . Generally, three types of erosion on forested watersheds are recognized: 1) surface erosion - the detachment and removal of individual soil particles or small aggregates from the land surface. It results in sheet erosion, rills and gullies, and is caused by the action of raindrops, then film flow, or concentrated surface runoff; 2) channel cutting - the detachment and moving of material from a stream channel, and; 3) mass movement - such as landslides and slumps, which are an important form of erosion in mountainous regions; but are not considered a significant source of erosion in East Texas.

The process of erosion involves three phases: 1) detachment, 2) transport and 3) deposition. Factors affecting the erosion process include: soil characteristics - texture, mineralogy, aggregate stability, organic matter, percolation and infiltration rates; topography, rainfall and most importantly, vegetative and litter cover. Erosion does not necessarily mean sedimentation, as sediment may be deposited in places other than a stream (Satterlund 1972).

Erosion from the undisturbed forest is seldom a water quality problem. The mature forest intercepts rainfall either in the canopy or at at the litter layer of the forest floor and prevents the destructive effects of rainfall impact. Rainfall then infiltrates into the soil and travels to the stream channel via subsurface flow. High infiltration rates for the undisturbed forest, prevent surface runoff in most circumstances, and hence, surface erosion from undisturbed forests.

The natural rate of sedimentation from undisturbed forests, varies with location, geology, vegetation, watershed size and season. Inference from studies in the southeast demonstrate that the natural erosion rate is very low from forested lands. A review of the literature (Yoho 1980) on sediment production from undisturbed forests in the South, revealed a range of sediment yields from trace levels to .32 tons/acre/year.

Ursic (1977) has suggested 60 ppm as the average annual sediment concentraton in stormflows from small, undisturbed southern pine catchments. However, concentrations for individual events, due to natural variation, may be higher by a factor of ten or more. Periodic flushing of sediments collected in the stream channel result in these occasionally higher values.

A study in northern Mississippi of five undisturbed forested watersheds, yielded sediment concentrations of 54, 47, 269, 143 and 120 ppm for the year (Duffy et al. 1978). This is an indication of the variability that often occurs even between similar watersheds. After reviewing erosion from eastern forests, Patric (1976) concluded that erosion from undisturbed, as well as carefully managed forest land, is from 0.05 to 0.10 tons/acre/year.

Logging and site preparation increase the potential for sediment production by disturbing the soil and the protective forest floor. Compaction and destruction of surface soil structure and macropore space cause an increase in surface runoff, thus increasing the sediment production potential (Dixon 1975; Lull 1959; Moehring and Rawls 1970). Disturbing the protective vegetation and litter, bares the soil to raindrop impact, which breaks soil aggregates into smaller particles. These smaller particles are more easily detached and may leave the site in runoff water and/or clog larger soil pores. Thus, infiltration is reduced and the possibility of surface runoff is increased (Edwards and Larson 1964). Removal of vegetation and litter also reduces resistance to overland flow and increases velocity, which in turn increases the carrying power of runoff (Douglass 1975).

Ursic (1974) has stated that intensive site preparation of hilly areas in the South, presents the most serious erosion problem. Shearing and windrowing is generally recognized as causing more site disturbance than roller chopping. Shearing and windrowing increase susceptibility to erosion by removing the protective surface cover and exposing the mineral soil. The shearing process tends to scalp the soil and then raking often carries this surface soil into the windrow. This results in a relocation of the nutrient rich surface horizon and a loss of available nutrients to a portion of the watershed. Soil-site equations indicate a reduction in site index and productivity as a result of such top soil loss (Switzer et al. 1978). Also, increased compacton caused by heavy shear-and-pile tractors reduce infiltration and thereby, increase surface runoff potential (McClurkin and Moehring 1978).

Roller chopping causes less disturbance and exposure of mineral soil and leaves more debris on the surface than shearing and windrowing. The blade of the roller chopper has a tillage effect which usually improves aeration, detention storage and soil density. Organic matter is incorporated into the soil and the slits left by the chopping blade help to reduce surface flow and minimize sediment movement. Maximum benefit is derived when the blade runs parallel to contour lines so that water collection in the blade slits will not start rill or gully erosion (Switzer et al. 1978).

Beasley (1979) studied the impact of three intensive site preparation treatments on four small (1.7-2.5 acre) watersheds in northern Mississippi. These watersheds have slopes ranging from 30 to 50 percent and prior to logging were occupied by a mixture of shortleaf pine and hardwoods. The treatments studied were: 1) roller chopping and burning; 2) shearing, windrowing into the stream channel and burning; 3) bedding on the contour, following shearing; 4) and a control with no logging, site preparation or other disturbance. After site preparation, the treated sites were fertilized, sown with subterranean clover, and planted with loblolly pine seedlings.

Exposed mineral soil following site preparation was 69%, 53% and 37% for the bedded, sheared and windrowed and chopped watersheds, respectively. The first year following treatment, stormflow was similar for the three treated watersheds (17.8 to 20 area-inches) (Table 3). In the second year, the chopped watershed had the highest stormflow (13.6 area-inches) and the bedded watershed the lowest treatment stormflow (9.3 area-inches).

Discharge weighted sediment yields for the first year, were similar among all four watersheds (.24 to .32 tons/acre-inch of stormflow). Channel scouring attributable to the increased stormflow produced by vegetation removal, was a significant source of sediment. A single storm accounted for 90% of the annual sediment loss from the control watershed. By April of the second year, soil was exposed on only 1, 4 and 6 percent of the chopped, sheared and bedded sites, respectively, and sediment losses dropped accordingly. Second year sediment losses ranged from 0.05 tons/acre-inch of stormflow on the control watershed to 0.26 tons/acre-inch of stormflow on the bedded treatment. The relatively high sediment yield on the bedded watershed was due to the formation of a gully above the flume site.

Douglass and Goodwin (1980) evaluated intensive site preparation practices, in the North Carolina Piedmont, using four replications of three treatments: 1)shearing; 2) shearing and disking and ; 3) shearing, disking, fertilizing and grass seeding. All treatments except the control were windrowed, burned and planted with loblolly pine seedlings. One year after treatment, the shearing and shearing and disking treatment produced the largest sediment yield (0.32 and 0.29 tons/acre-inch of stormflow, respectively) (Table 4). The higher

Table 3. Stormflow and sediment yield following site preparation in northern Mississippi (Beasley 1979).

Treatment	Storm Flow (area-inches)	Sediment Yield (tons/acre)	Discharge Weighted Sediment Yield (tons/acre-inches of stormflow)
		First Year	
Control	1.1	0.28	0.24
Chop and Burn	20.0	5.59	0.28
Shear, Windrow and Burn	17.8	5.71	0.32
Shear, Windrow Burn and Bed	20.0	6.36	0.32
		Second Year	
Control	1.1	0.05	0.05
Chop and Burn	13.6	1.03	0.08
Shear, Windrow and Burn	11.0	0.99	0.09
Shear, Windrow, Burn and Bed	9.3	2.47	0.26

value for the shearing treatment reflects the result of windrowing in the channels on two of the sheared watersheds. The sheared, disked, fertilized and seeded treatments reduced sediment yield by one-third (0.09 tons/acre-inch of stormflow) but produced five times more sediment than the control (0.02 tons/acre-inch of stormflow).

A paired watershed experiment in the Piedmont forest of Georgia, has shown relatively low levels of sediment loss following clearcutting and double roller chopping (Hewlett 1979). Harvesting increased sediment production by 16 lb/acre-inch of stormflow over the control watershed; whereas, roller chopping increased sediment production by 94 lb/acre-inch of stormflow. Modeling for the thirty year cutting

Table 4. First year sediment yields following site preparation in the North Carolina Piedmont (Douglass and Goodwin 1980).

Treatment	Sediment Yield (tons/acre)	Discharge Weighted Sediment Yield (tons/acre-inch of stormflow)
Control	0.04	0.02
Shear, Windrow and Burn	2.24	0.32
Shear, Windrow, Burn and Disk	1.06	0.29
Shear, Windrow, Burn, Disk, Fertilize and Seed	0.26	0.09

cycle, predicted the average annual sediment delivery to the channel under silvicultural practices, to be 157 lb/acre/year. This included the normal (geologic erosion) export rate of 82 lb/acre/year, but did not include sediment produced from road and channel damage (725 lb/acre/year). Ninety percent of all mass export from the basin during the thirty year rotation was attributed to roads and channel damage.

Nutrients

Undisturbed forested watersheds are a primary source of high quality water (Satterlund 1972). Mineral and organic nutrients enter the forest soil from rock and mineral decomposition, atmospheric input, and biological sources. Nutrient cycling within the forest is a continuous process of nutrient uptake from the soil by vegetation-temporary storage-decomposition and nutrient release. Loss of nutrients from the forest ecosystem results from erosion, leaching and volatilization. The amount of nutrients leaving a watershed fluctuates constantly in response to natural stress; but is subject to additional losses resulting from timber harvesting and residue removal or treatment (Moore and Norris 1974).

The quantity of nutrients lost following harvesting and site preparation is a function of soils, geomorphology, vegetation and climate characteristics, as well as the degree of disturbance. The removal of trees will trigger a number of significant reactions directly affecting the soil solution and rates of leaching. For example: 1) the forest will no longer be actively removing ions from the soil solution; 2) there will be an increase in soil surface temperature and moisture content, which influences the processes of decomposition, mineralization and carbon dioxide production and; 3) there will be a greater quantity of water passing through the soil because of decreased evapotranspiration and interception (Cole et al. 1975). If the increased amount of water available does not infiltrate the soil, then surface runoff and erosion are likely to occur. This runoff water may deliver an increased quantity of soluble nutrients to the stream along with any sediment associated nutrients. Recovery depends on revegetation, which re-establishes nutrient and soil water uptake and provides protection against surface runoff and erosion.

Schreiber et al. (1976) conducted a study to determine dissolved nutrient losses from forested watersheds in northern Mississippi. A replication of five watersheds (3.7 to 6.9 acres) were used on land previously eroded by agriculture and now stabilized with 32-year-old loblolly and slash pine. Nutrient concentrations in runoff exceeded rainfall concentrations for all nutrients except NO3-N (Table 5). However, a look at the annual import and export (lb/acre) of nutrients, shows a net gain for all nutrients except Mg. Generally, nutrient concentrations were not significantly correlated with storm runoff volumes, but nutrient losses were.

Table 5. The average dissolved nutrient concentrations for rainfall and runoff from five undisturbed watersheds in northern Mississippi for 1973 (Schreiber et al 1976).

Nutrient	Rainfall (74.44 inches)		Runoff (15.26 inches)	
	ppm	lb/acre	ppm	lb/acre
NO3-N	0.170	2.78	0.08	0.28
NH4-N	0.300	5.10	0.84	2.98
PO4P	0.004	0.06	0.01	0.04
Ca	0.410	6.92	1.62	5.57
Mg	0.160	2.72	0.80	2.74
K	0.260	4.47	0.86	2.97

In a companion study (Duffy et al. 1978) on the same watersheds, the following year (1973), aqueous and sediment-phase phosphorus yeilds were analyzed. The mean concentration of total P for the year was 0.027 ppm; of this, 0.006 ppm were organic-P, 0.012 ppm hydrolyzable-P and 0.009 ppm ortho-P. Sediment P concentrations varied significantly between the five watersheds. Sediment total P concentrations ranged from 0.0002 to 0.008 oz/oz for inorganic-P and 0.0001 to 0.003 oz/oz for organic-P. These levels were 2 to 8.9 times as high as found in the watershed soils. This was attributed to selective erosion of fine sediments and/or deposition of coarse sediments in transport. For the year, 70 percent of the total P transported in stormflow was associated with the sediment. Thus suggesting significant increases in P yields if forest management activities increase sediment losses.

A paired watershed study in West Virginia (Abertin and Patric 1974) compared the effects of clearcutting with an undisturbed forest. In the first year following the clearcut of the hardwood forest, nutrient losses were higher than on the undisturbed forest (Table 6). The higher loss of NO3-N from the clearcut watershed (2.59 lb/acre) compared to the control (0.53 lb/acre), is probably due to the flushing of nitrates from the soil during dormant season high flows. During the dormant season, decomposition of slash occurs at a greater rate than can be taken up by the existing vegetation. The maximum NO3-N concentration reached on the clearcut watershed was 1.32 ppm, during a 2.5 inch rainfall event. Total P loss increased from 0.13 to 0.28 lb/acre following cutting. The authors conclude that both nitrogen and phosphorus concentrations increased irregularly and temporarily after clearcutting and that nutrient outflow decreased as vegetative regrowth occurred.

Table 6. First year nutrient losses from a clearcut and undisturbed forest in West Virginia (lb/acre) (Aubertin and Patric 1974).

Treatment	NO3-N	NH4-N	Total P	Ca	Mg	K
Clearcut	2.59	1.34	0.28	5.48	3.00	4.44
Undisturbed	0.53	0.75	0.03	3.90	2.17	2.79

Changes in nutrient concentrations following clearcutting and roller chopping in the Georgia Piedmont were studied by Hewlett (1979). Analysis of stormflow shows NO3-N levels increased only slightly following harvesting (0.06 to 0.08 ppm) and roller chopping (0.12 to 0.14 ppm) (Table 7). Total phosphorus did not show an increase until after site preparation. Values for K, Ca and Mg were all higher following roller chopping.

Table 7. Mean concentration (ppm) of stormflow waters following harvesting and roller chopping in Georgia (Hewlett 1979).

Treatment	NO3-N	Total P	K	Ca	Mg
Harvest					
Control	.06	.30	1.00	2.68	1.71
Treated	.08	.79	0.94	3.50	1.44
Roller Chopped					
Control	.12	.93	1.62	6.58	2.41
Treated	.14	.69	2.06	12.07	5.92

Weekly samples of base flow from the control watershed had higher concentrations of NO3-N, total P, K ,Ca and Mg than on the site prepared treatment. This was apparently due to natural variation between the watersheds. Total N averaged 3.0 ppm on both watersheds and showed no difference after treatment, by season or between base flow and stormflow. Comparison of the nutrient losses in base flow during calibration and after roller chopping, showed only minimal differences.

Following planting, all elements except phosphorus, were similar to pre-treatment levels, despite continued increases in water yield. Apparently, regrowing vegetation was effective in tying up mobile ions.

STUDY SITE

Before the actual selection process of the nine proposed watersheds began, certain criteria were established (Beasley et al. 1978) for each study site: 1) it is critical that each of the watersheds be located on soils with similar characteristics and ideally, all of the same soil series; 2) each of the proposed sites should have similar geomorphology, with slopes ranging from 8 to 20 percent. Slopes on the upper end of forestry conditions in Texas were chosen so that near maximum results could be monitored; 3) the size of each watershed should rage from 5 to 10 acres. A size of greater than 5 acres is needed to allow normal harvesting and site preparation activities. Ten acres was set as a maximum size so that streamflow would not exceed the capacity of 3-foot H-flumes to be used in measuring water flow; 4) each site should be as near undisturbed as possible to permit pre-harvest monitoring of conditions. It is important that results are not biased by any previous, poorly conducted harvesting activities; 5) vegetation of the nine sites should be of similar composition, as this will affect both pre- and post-treatment results; 6) it is also necesssary that the sites be located as near one another as possible. This reduces instrumentation, such as rain gauging equipment and increases the likelihood that each drainage would be affected by the same storm event; 7) ease of access to each of the flume locations is also important, both for flume construction and servicing the watersheds. No attempt was made to locate the study sites with similar aspects, due to the difficulty of locating nine, otherwise suitable watersheds all oriented in the same direction. This is not expected to significantly influence the results of the study.

The area selected is located approximately 10 miles west of Alto (Fig. 1). The nine watersheds are part of an 8,000-acre tract of Temple-Eastex land just east of the Neches River in southern Cherokee County. The nine ephemeral watersheds range in size from 6.37 to 6.78 acres and average 6.58 acres (Table 8, Appendix B).

Table 8. Acreage for each watershed.

Watershed Number	Acres
1	6.46
2	6.37
3	6.52
4	6.58
5	6.70
6	6.58
7	6.78
8	6.46
9	6.76
Mean	6.58

The area is characterized by rolling topography intersected with numerous drainages. Slopes range from 4% on the hilltops to as much as 25% for short distances on some of the side slopes near the stream channel. Vegetation is predominately the shortleaf pine-hardwood type (SAF forest cover type #80). The area has been managed under a selective cutting system with the last harvest occurring in 1972 for watersheds 1 and 6, and in 1971 for the others.

An attempt was made when selecting the watersheds to locate each on the same soil series. However, the extreme variability of soils in East Texas, particularly in the marine deposited upland areas, has made that requirement difficult to achieve. Seven different soil series are found among the nine watersheds (Table 9).

Table 9. Percent of watershed area occupied by soil series.

Watershed Number	Briley	Cuthbert	Darco	Kirvin	Lilbert	Rentzel	Tenaha
1	-	41.5	0.9	8.2	36.5	1.9	10.8
2	-	77.1	-	13.3	-	1.3	-
3	5.7	47.4	-	2.6	14.4	0.5	29.4
4	-	74.6	-	5.2	2.0	0.9	17.2
5	-	63.9	-	11.7	12.7	2.8	8.7
6	-	88.7	-	4.0	4.6	0.7	1.9
7	-	47.6	-	17.9	30.4	3.7	0.4
8	-	65.7	-	6.5	18.9	3.2	5.5
9	-	73.9	-	5.5	1.5	0.6	18.5
Avg.	0.7	68.8	0.1	8.9	10.1	1.8	9.7

The Cuthbert series is predominant and covers approximately 70% of the nine watersheds. This series has as a fine sandy loam A horizon, with a depth up to 10 inches, overlaying a red clay B horizon to 40 inches. The C horizon is composed of stratified red sandstone and grey shale to 55 inches. These soils are well drained and are located on sloping to steep sides, with slopes usually greater than 8%.

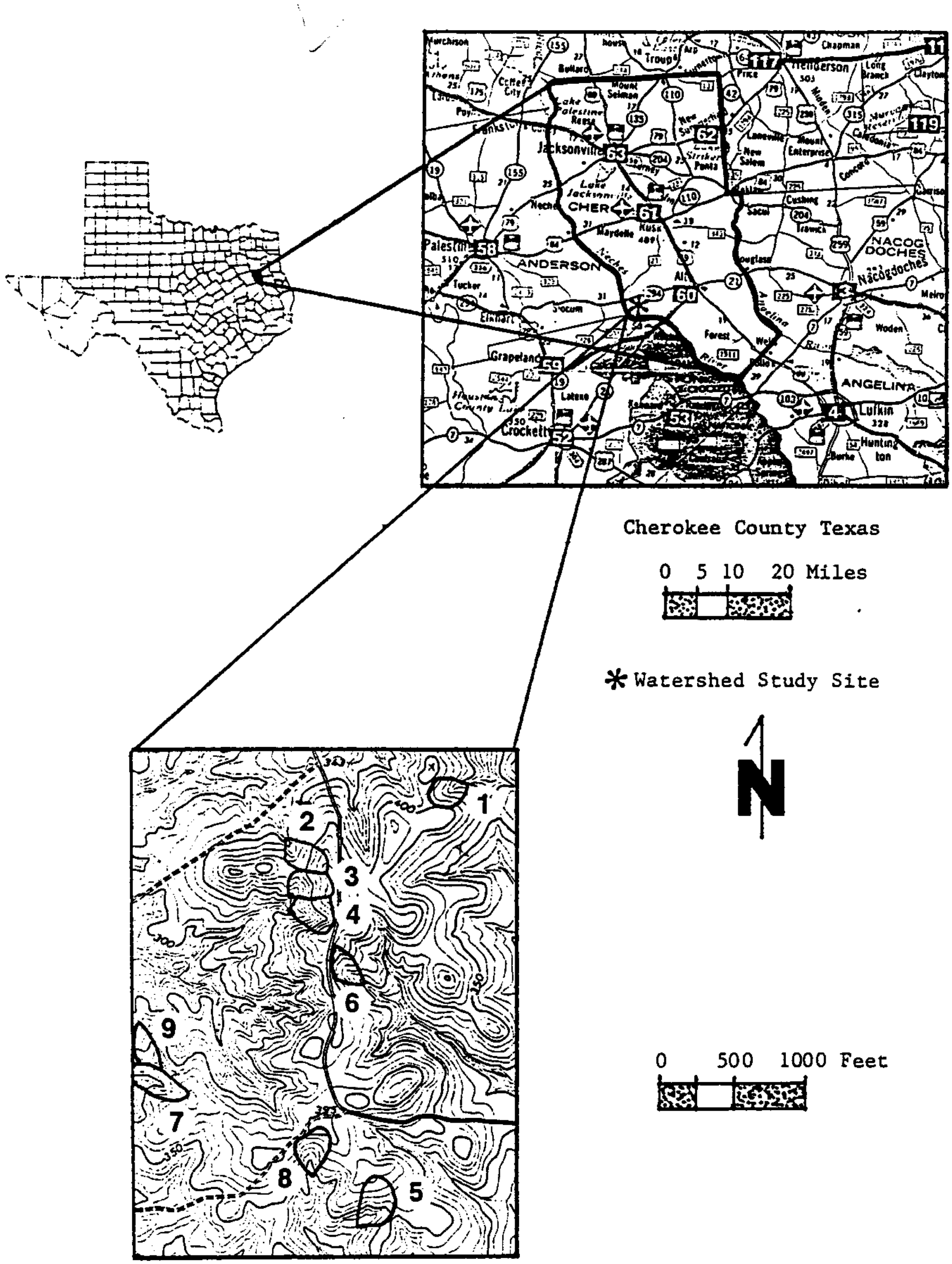

Figure 1. Study site location.

The competing series to Cuthbert is the Kirvin series. Whereas, the solum thickness for Cuthbert ranges from 20 to 40 inches thick, the Kirvin series ranges from 40 to 60 inches and occurs on ridges with slopes of less than 8%.

Soils of the Lilbert series, are deep loamy fine sands with a yellowish sandy clay loam B horizon from 28 to 80 inches. It is located on ridge tops with slopes from 2 to 6%.

Similar to the Lilbert series, is the Briley series. It is also a loamy fine sand A horizon, but the sandy clay loam B horizon is located at 23 inches and is reddish in color. This series occurs on convex ridges with 2 to 5% slope.

The Tenaha series is one of the competing series to Lilbert and Briley. It has a deep, loamy fine sand A horizon up to 40 inches thick. The B horizon is a reddish sandy clay loam overlaying a soft red sandstone. This series is located on the steeper (3-15%) side slopes.

The Rentzel series is a deep loamy fine sand to 33 inches; overlaying a mottled brown and grey sandy clay loam B horizon to 80 inches. This soil is located along drainage ways, parallel to stream channels. The Darco series has a very deep loamy fine sand A horizon up to 52 inches thick. The B horizon is a yellowish-red sandy clay loam to 80 inches. This series is found along the ridge tops.

In summary, the Cuthbert and Kirvin series are similar in development, both having a shallow sandy loam surface horizon and a clayey B horizon. Kirvin dominates the upper slopes and Cuthbert the side slopes. The Lilbert, Briley and Darco series occur on the ridges, while Tenaha is found on the side slopes. All four of these series are deep loamy fine sands, with the clayey B horizon found much deeper than in Cuthbert and Kirvin. The loamy fine sand Rentzel series occurs along the stream channel.

All of these soil types are extensive throughout Texas and much of the Southern Coastal Plain. For this reason, results should have wide applicability for much of the forested areas of Texas and the South. A complete description of the soils is found in the Soil Survey prepared by the Soil Conservaton Service (1980).

EXPERIMENTAL DESIGN

A replicated watershed approach, in randomized blocks, is being used to measure the effects of silvicultural practices on the quantity and quality of receiving waters. Three replications of three treatments (including the control) are used. Blocking of the watersheds into groups of three was based on several factors. Geomorphological considerations, such as shape, slope and stream density were compared for similarities. Soil characteristcs also played an important role in determining which watersheds to block.

Several formulas are available (Chow 1964) for numerical comparison of geomorphological characteristics (Table 10). Drainage density is used to measure the amount of stream channels per unit area. The larger the drainage density, the closer the stream channel spacing will be and possibly the greater susceptibility to erosion. The circularity ratio is a measure of shape, which expresses the departure from circularity of a watershed; a ratio of 1 indicates a circular basin. Long, narrow watersheds have high sediment yield, but low runoff; whereas, circular watersheds have high runoff and low sediment yield. Stream slope measures the amount of fall in elevation in relation to the length of the stream channel. The relief ratio is a measure of the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on the slopes of the basin. Variation among these geomorphic measures proved to be relatively small. However, an attempt was made to group the watersheds according to similar traits.

Soil factors were also considered in the blocking process. Although Cuthbert was the dominant series among all watersheds, sites with similar soil types were grouped together. Soil factors received weighted consideration over geomorphic factors when watershed blocking was determined. Although the nine watersheds are quite similar to one another, blocking should allow more comparable responses.

Random selection was used to determine watershed treatment for each block (Table 11). Prior to treatment, storm events were monitored on the nine watersheds for six months. This was to assess both the natural variability in water yield and water quality among the watersheds, and to collect pre-treatment information on the undisturbed forest.

Table 10. Geomorphic variables considered in blocking the experimental watersheds (Chow 1964).

Watershed Number	Drainage Density (Dd)1	Circularity Ratio (Rc)2	Stream Slope (Ss)3	Relief Ratio (Rr)4
1	8.35	0.89	783	0.110
2	8.56	0.74	1126	0.174
3	15.77	0.85	1185	0.131
4	11.14	0.82	846	0.134
5	10.41	0.81	894	0.123
6	9.49	0.78	841	0.103
7	10.55	0.72	582	0.077
8	11.54	0.88	945	0.108
9	10.31	0.88	725	0.126
Mean (x)	10.68	0.82	881	0.121
Std. dev. (S)	2.19	0.16	188	0.027

1 Drainage density, (Dd) = L/A

2 Circularity ratio, (Rc) = $A/(P/2 \text{ (square root of pi)})^2$

3 Stream slope, (Ss) = R/SL

4 Relief ratio, (Rr) = R/SL1

L = length of all storm segments (mi)
A = area of watershed (sq mi)
P = perimeter of watershed (mi)
SL = stream length, main channel (mi)
SL1 = straight line, main channel stream length, mouth to divide (ft)
R = total fall (ft)

Table 11. Watersheds by treatment and blocks.

Treatment	Block 1	Block 2	Block 3
Control	4	8	6
Shear/Windrow	3	1	2
Chop	7	5	9

Statistical analysis was performed using the Statistical Analysis System (SAS) developed by the SAS Institute (Helwig and Council 1979). All analysis was run on the Texas A&M University Amdahl 470/V6/V8 computer. Analysis of variance for randomized blocks was used to compare differences between treatments. Duncan's new multiple range test at the 5% level of probability was used to separate treatment means (Steele and Torrie 1960). All significant differences reported are at the 5% level of probabilty.

TREATMENTS

Harvest

Clearcut harvesting of the six watersheds began in June 1980. All merchantable pine sawlogs and pulpwood were removed in tree lengths. Normal hand felling techniques were used. Where possible, trees were felled parallel to the skidding direction, with log butts toward the landing. Care was taken not to fell trees into or across stream channels. All trees were limbed in place before skidding.

Skidding was performed by a single rubber-tired skidder. Skid trails were located along contours, where possible, to minimize steep gradients and to keep soil displacement to a minimum. The watersheds' drainage characteristics allowed each side of the main stream channel to be logged separately, so that the skidder would not have to cross the stream channel.

Trees were skidded to landings located outside the watershed boundary. The influence of a landing on such a small watershed would mask results obtained from harvesting and site preparation activities. Logs were then loaded on a truck and removed. No logging haul roads were located within the watershed boundary.

A buffer strip of undisturbed vegetation was left along all major stream channels, with only merchantable pines removed from these areas. Hardwood trees, shrubs and herbaceous vegetation within this zone, were left to protect the integrity of the stream channel. All heavy equipment was kept out of the buffer strip. The width of the buffer strip varied from 20 to 60 feet, depending on slope and channel size.

Merchantable trees unsuitable for tree length removal (generally low grade hardwoods and small pines) were removed by several pulpwood trucks. All six watersheds received essentially the same treatment during harvesting, which was completed in October 1980.

Site Preparation

Variation in treatment began with site preparation, in November 1980. Three of the designated watersheds were treated by shearing all remaining vegetation with a D-8 dozer equipped with a V-blade. Slash and debris were than raked into windrows with D-6 and D-8 dozers using a brush rake. Windrows were located along the contours to help bar excessive erosion along the slopes. Windrows were later burned in January 1981. The remaining three treatment watersheds were roller chopped following clearcutting, with a D-8 dozer pulling a single drum chopper. A broadcast burn was used to reduce slash in February 1981. All sites were handplanted in February 1981 with 1-0 improved loblolly pine seedlings.

MEASUREMENT AND ANALYSIS

Water

Precipitation

Precipitation amounts are measured in Forest Service type raingauges located in a network on each site to provide a minimum of two gauges for every watershed. Timing and intensity is obtained from two recording raingauges (Belfort weighing bucket type).

Water Yield

Timing, rates, and volumes of runoff are measured with 3-foot H-flumes equipped with FW-1 type water level recorders. Approach sections to the flume are 12-feet long. Output will include runoff volumes in area inches and peak discharge rates.

Water Sample and Bedload Collection

Suspended sediment and water quality samples are collected at each flume with a Coshocton wheel sampler coupled to a splitter. The wheel samplers are set below the lips of the flumes so as to just miss the small prolonged flows that often occur on small watersheds during the wet season or after large storms. Such flows are usually low in sediment; their inclusion would only dilute the sample and bias the results. Low flows are manually sampled periodically and their sediment and nutrient concentrations measured to see if results are biased by disregarding low flows. Water collected by the wheel sampler (about 0.5% of total flow) is further divided by 10 as it flows through the splitter constructed from 4-inch PVC pipe. The sample is collected in a chemically inert container, which is collected for laboratory analysis the day following the runoff event.

Single stage non-proportional samplers are installed in the side walls of the flumes (at 6, 12, 18 and 24 inches) to provide data on stage-concentration relationships for sediment and nutrients. The devices, which sample the rising limb, serve as an insurance against malfunctions in the wheel samplers and splitters.

Watersheds 2, 6 and 9 are equipped with Isco water pump samplers. Water samples are automatically collected at a predetermined time sequence by a floating intake nozzle in the approach section of the flume. This provides data on sediment and nutrient concentrations at discrete time intervals throughout the storm hydrograph.

Bedload is collected in a 32 inch x 68 inch x 9 inch concrete drop box located at the front of the approach section to the flume. The volume of bedload deposited is determined after each

Sediment

Suspended sediment is determined by vacuum filtering a liter sample of water through 0.45 micron Millipore filters, oven drying and weighing. Sediment is expressed in parts per million (ppm) and pounds per acre (lb/acre).

Bedload samples are dried and weighed to determine the bedload loss. Analysis is also made to determine the aggregate stability, texture, and nutrient content.

Turbidity

Turbidity of each sample is measured with a Hach Model No. 2424 Nephelometer. Turbidity measurements are important because many state water quality standards applicable to non-point source pollution are specified in terms of turbidity. Altough efforts to correlate turbidity with sediment concentrations have generally been unsuccessful, an attempt will be made to develop local relationships between the two parameters.

Water Chemistry

Water samples were analyzed for nitrates,. ammonia, total nitrogen, ortho and total phosphorus using a Technicon Auto Analyzer II. Total nitrogen, nitrate and ammonia water samples were filtered through 0.45u Millipore filters prior to analysis for nitrogen. Samples were also analyzed for unfiltered total nitrogen. Nitrates were analyzed by reducing to nitrites using the cadmium reduction method (APHA et al. 1976). Total nitrogen, which includes organic nitrogen and ammonia was measured using the ammonia/salicylate complex method after digestion with a salt/acid catalyst mixture (APHA et al. 1976). The ammonia concentration was determined using the same method as for total nitrogen without the digestion.

Ortho-phosphate and total phosphate were both analyzed unfiltered because of their association with sediments. Ortho-phosphate was determined using the ascorbic acid reduction method (APHA et al. 1976). Ortho-P, molybdate ion and antimony ion combine and are reduced by ascorbic acid to form a blue dye read colorimetrically at 660nm (Murphy and Riley 1962). Total phosphate includes ortho-P, condensed phosphates and organic phosphates. Samples were first digested using the persulfate digestion method, with the total P concentrations then determined by the ascorbic acid reduction method (APHA et al. 1976).

Calcium, magnesium, potassium and sodium concentrations were determined following filtering through 0.45u Millipore filters, using an Instrumentation Laboratory 457 Atomic Absorption Spectrophotometer. Samples were analyzed using the standard procedures for atomic absorption spectrophotometry (Sotera and Stux 1979).

Vegetation and Surface Condition

The following methodologies are used to sample vegetation and surface cover.

Overstory and Intermediate Vegetation

A minimum 10% inventory was made of the dominant and codominant trees and woody stems greater than 1 inch dbh, by using one-tenth acre circular plots. Data recorded includes species height and dbh from which stand volume and density is computed.

Understory

Permanent milacre plots have been established to measure pre-treatment understory vegetation and to evaluate the development of woody plants after treatment. Species and heights of the dominant understory plants are measured. Total area of sample plots is approximately one percent of the watershed area.

Ground Surface Condition

Surface cover or condition is measured by point sampling at 6.6 inch intervals on 66 foot transects. Sampling intensities were adjusted to provide standard errors of no more than 20% for the major cover criteria. The surface condition is sampled for vegetation, litter, slash, rock and mineral soil. The presence of erosion is recorded as sheet, rill or deposition. This survey was made prior to treatment, after site preparation and planting and then each fall thereafter.

Litter

Litter weight and depth are determined from samples collected in 2.69 square foot plots located a pre-determined distance from the permanent milacre plots. Sampling intensity is such as to provide for a precision of 10% of litter dry weight.

Soil Properties

Soil Bulk Density, Texture, Moisture and Organic Matter

Bulk density determinations of the 0 to 3 inch depth zone using a core sampler were made at approximately 20 locations in each watershed prior to treatment. Sampling of each watershed is repeated in the spring (the season when soil moisture conditions are conducive to sampling) of each year, beginning the spring after logging and site preparation. The samples are taken to the lab and oven-dried at 220 degrees F for dry weight determinations. An additional sample from the 0 to 3 inch depth is collected for texture analysis by the hydrometer method and organic matter determination by the Walkley Black (1934) method.

Soil moisture in the primary rooting zone is an important factor for many streamflow models. Bi-monthly measurements are made on each of the watersheds by the use of a neutron soil probe. Six to eight neutron probe access tubes are located on each watershed, with soil moisture readings taken at 6, 16, 28, 39 and 51 inches.

RESULTS AND DISCUSSION

Watershed Condition

Pre-treatment 1980

An inventory of the vegetation prior to treatment was conducted in June 1980, according to the procedures outlined in the section on Measurement and Analysis. Pine volumes on the nine watersheds ranged from 2,061 to 4,573 bd.-ft./acre for sawlogs and from 17 to 43 cords/acre for pulpwood (Table 12). Hardwood sawlogs and pulpwood were relatively sparse and volumes averaged only 300 bd.-ft./acre and 14 cords/acre on the watersheds. The number of stems in the 1 to 5 inch dbh category, were uniform among the watersheds and averaged 289 stems/acre.

Woody stems less than one inch in diameter are listed in Table 13. The number of pine seedlings varied from 1,410 stems/acre on WS 3 to 20,440 stems/acre on WS 5. There was no appreciable difference in the number of hardwoods, shrubs or vines among the watersheds.

Litter, humus and slash covered an average of 94.5% of the nine watersheds (Table 14). Average vegetative cover of the watershed surface was 1.6%. Thus, 96.1% of the watersheds' surface were covered with a protective layer of vegetation or litter.

Mineral soil was exposed on 3.3% of the watersheds. Rill and sheet erosion were evident on only 0.21% of the mineral soil, hence, the remaining mineral soil was in a stable condition.

Herbaceous biomass was very low on all watersheds because of the dense canopy cover (Table 15). Above ground plant production ranged from 10 lb/acre on WS 7 to 151 lb/acre on WS 5. Litter accumulation on the watersheds averaged 9,367 lb/acre with an average depth of 1.7 inches.

Soil samples were collected from each of the watersheds at the same time as the vegetation inventory. Results of the textural analysis support the soil series classification made by the USDA Soil Conservation Service (1980). The Cuthbert and Kirvin series both have sandy loam surface horizons and the Lilbert, Tenaha and Rentzel series have loamy sand surface horizons (Table 16). No samples were collected from the Briley and Darco series because of the small area involved. Organic matter in the surface horizon ranged from 3.3 to 3.9%. Bulk density at a 0-3 in depth, averaged 1.10 g/cc for all soil series.

Table 12. Tree volumes and stems/acre, for the Alto watersheds, June 1980.

Watershed No.	Pine		Hardwood		Stems (dbh 1"-5")/Acre					
	Sawlogs bd.ft./acre	Pulpwood cords/acre	Sawlogs bd.ft./acre	Pulpwood cords/acre	Pine	Oaks	Hickory	Sweetgum	Others	Total
1	4,494	23	341	13	122	121	24	54	58	330
2	4,573	43	107	7	76	123	17	68	49	333
3	4,092	28	232	13	70	165	34	35	45	349
4	2,789	26	80	13	36	119	37	14	16	222
5	2,673	19	137	12	29	51	21	25	24	100
6	2,061	17	596	19	94	84	23	59	57	317
7	4,386	41	789	17	91	177	10	29	57	364
8	3,373	37	-0-	7	79	141	26	31	21	298
9	4,208	40	421	19	89	88	25	35	52	289
Average	3,628	30	300	14	76	119	24	39	42	289

Table 13. Pre-treatment understory vegetation (stems <1" dbh/acre), for the Alto watersheds, June 1980.

	Watershed No.									
	1	2	3	4	5	6	7	8	9	Avg.
Pine										
Loblolly & Shortleaf	8,260	4,110	1,410	2,960	20,440	1,460	7,180	7,980	9,480	7,031
Hardwoods										
Oak	4,470	3,870	2,910	5,700	3,240	2,830	2,790	4,820	2,390	3,172
Elm	1,200	360	130	130	710	1,250	60	80	430	483
Dogwood	1,040	90	680	1,110	170	710	1,060	640	1,140	738
Sweetgum	260	730	780	1,770	1,460	1,480	1,590	1,320	630	1,113
Other	2,490	1,400	1,850	2,050	1,590	1,520	2,740	1,900	1,430	1,886
TOTAL	9,460	6,450	6,350	10,760	7,170	7,790	8,240	8,760	6,020	7,392
Shrubs										
American Beautyberry	1,230	2,980	1,740	1,520	1,980	1,310	2,040	1,500	700	1,667
Blackberry	1,720	2,250	2,310	3,000	1,070	3,040	790	1,820	1,380	1,931
South Waxmyrtle	300	160	2,240	2,050	620	420	2,130	1,540	860	1,147
Other	1,860	480	700	440	1,160	850	470	220	1,160	816
TOTAL	5,110	5,870	6,990	7,010	4,830	5,620	5,430	5,080	4,100	5,561
Vines										
Virginia Creeper	3,320	1,200	4,040	2,680	2,140	1,300	4,530	1,760	2,300	2,586
Greenbriar	3,140	2,850	1,350	1,610	2,540	3,420	2,660	4,040	1,340	2,550
Poison Ivy	1,420	2,980	1,220	1,380	2,860	440	1,530	8,440	2,110	2,487
Other	3,680	5,600	1,220	3,710	3,730	1,850	2,340	1,600	2,070	2,867
TOTAL	11,560	12,630	7,830	9,380	11,270	7,010	11,060	15,840	7,820	10,490

Table 14. Pre-treatment ground surface condition (%), for the Alto watersheds, June 1980.

	Watershed No.									
	1	2	3	4	5	6	7	8	9	Avg.
Surface Condition										
Litter	88.6	89.5	88.9	89.8	83.6	91.7	90.2	87.8	86.4	88.5
Slash	6.7	4.3	6.3	5.6	5.8	3.3	6.8	7.2	8.4	6.0
Rock	0.4	0.0	0.1	0.0	3.1	0.1	0.3	0.3	0.4	0.5
Mineral Soil	2.9	3.9	3.4	2.6	5.8	3.4	1.5	3.7	2.3	3.3
Erosion										
Rill	0.0	1.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2
Sheet	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	<0.1
Deposition	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tree	0.5	0.4	0.5	0.8	0.5	0.3	0.4	0.4	0.8	0.5
Shrub	0.1	0.5	0.1	0.3	0.1	0.2	0.2	0.2	0.4	0.2
Grass	0.7	0.8	0.7	0.7	1.1	0.8	0.3	0.3	1.0	0.7
Forb	0.0	0.4	0.0	0.2	0.0	0.2	0.0	0.1	0.2	0.1
Moss	0.1	0.2	0.0	0.0	0.0	0.1	0.3	0.0	0.1	0.1

Table 15. Pre-treatment herbaceous biomass and litter accumulation (lb/acre), for Alto watersheds, June 1980.

	Watershed Number									
	1	2	3	4	5	6	7	8	9	Avg
Grass	49	41	47	100	114	42	10	89	23	57
Grasslike	0	0	0	0	0	0	0	0	30	3
Forb	12	13	2	20	37	8	0	6	5	11
Litter	9,081	10,633	10,702	8,159	6,198	6,487	13,903	10,524	8,614	9,367
Litter depth (in)	1.2	2.0	1.6	1.6	1.6	1.6	2.0	2.0	2.0	1.7

Table 16. Pre-treatment soil analysis, June 1980.

Soil Series	Sand %	Texture Silt %	Clay %	Class	Organic Matter %	Bulk Density gm/cc
Cuthbert	72	19	9	Sandy loam	3.9	1.09
Kirvin	72	18	10	Sandy loam	3.9	1.10
Lilbert	77	17	6	Loamy sand	3.3	1.10
Tenaha	81	12	7	Loamy sand	3.3	1.10
Rentzel	78	14	8	Loamy sand	3.8	1.10

Post-treatment June 1981

Immediately following harvesting and site preparation, Crawley (1982) made an in-depth study of site disturbance. He found clearcutting left 35% of the watersheds undisturbed, 17% in primary skid trails and 24% in secondary skid trails, with 23% covered in slash. Mineral soil was exposed on 34% of the primary skid trails and on 5% of the secondary skid trails. Bulk density was significantly different between primary trails (1.16 g/cc), secondary trails (1.06 g/cc) and the undisturbed forest (.99 g/cc).

During June 1981, the vegetation survey was repeated on the treated watersheds, using the same plots and transect lines. Understory vegetation was reduced on all watersheds from the preceeding year. The chopped watersheds contained a larger number of pine, hardwood and vine stems per acre than the sheared watersheds (Table 17). Pine seedling densities on chopped watersheds were 25% higher and hardwoods 65% higher than the sheared watersheds. The average number of shrub stems on the sheared watersheds (4,976/acre) were slightly higher than on the chopped watersheds (4,465/acre).

The ground surface condition following site preparation was significantly different between the two treatments. Slash and litter cover averaged 34% on the sheared watersheds and 79% on the chopped watersheds (Table 18). Mineral soil exposure was 3.5 times greater on the sheared watersheds (57% on the sheared and 16% on the chopped). Evidence of active erosion was found on 83% of the exposed mineral soil and 47% of the sheared watersheds. In comparison, 35% of the exposed mineral soil on the chopped watersheds showed evidence of erosion and only 5.6% of the watersheds were in some stage of erosion. Vegetative cover averaged about 4% for both treatments. The bulk density of the sheared watersheds (1.11 g/cc) were significantly higher than the roller chopped (.95 g/cc) or the undisturbed (.92 g/cc) watersheds.

Above ground herbaceous production for the treated watersheds did not differ substantially. Grass production was 181 and 166 lb/acre for the sheared and chopped watersheds, respectively (Table 19). The largest difference was in forb production; the sheared watersheds produced an average of 267 lb/acre and the chopped watersheds 167 lb/acre. Litter accumulation was over six times greater on the chopped watersheds (3,366 lb/acre) than on the sheared watersheds (501 lb/acre).

Table 17. Post-treatment understory vegetation (stems <1"dbh/acre), for the Alto watersheds, June 1981.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Pine								
Loblolly & Shortleaf	452	680	510	547	685	838	509	677
Hardwoods								
Oak	1,467	960	1,298	1,242	1,981	1,822	921	1,575
Elm	339	120	-0-	153	55	48	137	80
Dogwood	32	-0-	234	89	815	32	549	632
Sweetgum	516	300	170	329	296	210	274	260
Hickory	145	180	85	137	296	113	39	149
Other	2,290	1,860	1,553	1,901	1,944	8,177	2,020	4,047
TOTAL	4,789	3,420	3,340	3,850	5,387	10,902	3,940	6,743
Shrubs								
American Beautyberry	2,548	3,260	1,489	2,432	2,759	3,145	1,529	2,478
Blackberry	1,435	1,780	2,064	1,760	333	1,226	1,647	1,069
Southern Waxmyrtle	32	-0-	1,234	422	19	1,306	411	579
Other	613	260	213	362	667	177	176	340
TOTAL	4,628	5,300	5,000	4,976	3,778	5,854	3,763	4,465
Vines								
Virginia Creeper	97	620	1,702	806	1,055	1,822	1,706	1,528
Greenbriar	1,290	880	340	837	1,963	1,290	1,039	1,431
Poison Ivy	32	760	255	349	926	564	627	706
Other	1,339	900	532	924	1,222	1,919	1,725	1,622
TOTAL	2,758	3,160	2,829	2,916	5,166	5,595	5,097	5,286

Table 18. Post-treatment ground surface condition (%), for the Alto watersheds, June 1981.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Surface Condition								
Litter	21.3	26.4	29.3	25.7	60.4	56.4	53.7	56.8
Slash	6.3	7.5	9.3	8.7	15.5	21.1	30.8	22.5
Rock	0.5	1.7	0.7	2.0	5.9	1.1	0.0	2.3
Mineral Soil	65.3	59.7	48.5	56.8	15.2	17.3	14.5	15.7
Erosion								
Rill	0.0	1.0	1.5	0.8	0.0	0.1	0.1	<0.1
Sheet	15.1	25.8	19.6	20.2	2.4	0.9	0.8	1.4
Deposition	26.5	23.3	29.2	26.3	5.7	4.3	2.4	4.1
Tree	0.1	0.0	0.0	<0.1	0.1	0.3	0.2	0.2
Shrub	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1
Grass	2.9	1.7	1.5	2.0	1.2	2.1	3.0	2.1
Grasslike	0.9	0.1	0.5	0.5	0.1	0.3	0.4	0.3
Forb	1.7	1.3	2.2	1.7	1.1	0.8	2.4	1.4
Moss	0.0	0.0	0.0	0.0	0.0	0.1	0.0	<0.1

Table 19. Post-treatment herbaceous biomass and litter accumulation (lb/acre), for the Alto watersheds June 1981.

	Shear and Windrow				Roller Chop			
	Watershed No.							
	1	2	3	Avg.	5	7	9	Avg.
Grass	189	134	220	181	181	156	160	166
Grasslike	8	40	37	28	5	15	47	22
Forb	313	290	198	267	246	112	144	167
Litter	715	187	602	501	4017	2819	3262	3366

Post-treatment October 1981

A third vegetation inventory was conducted in October 1981 to determine changes in the site condition at the end of the first growing season. The density of understory pines and hardwoods was reduced on both sheared and chopped watersheds from the amounts found in June 1981 (Tables 17 and 19). Pine seedling densities, which includes planted and volunteer seedlings, were similar for sheared and chopped watersheds (Table 20). Chopped watersheds contained over 2.5 times the number of hardwood stems per acre (5,970) found on the sheared watersheds (2,249). The number of shrubs and vines found on the chopped areas is also more than double the sprouts found on the sheared areas. This is an indication of the effectiveness of shearing in reducing site competition. Whether or not this competition will effect pine development on the chopped areas will have to be determined in the future.

Ground surface condition in October indicates revegetation to be progressing on the treated watersheds. Exposed mineral soil is still high on the sheared sites (60%) and about the same on the chopped sites (15%) (Table 21). Active erosion on the sheared watersheds was reduced from 47% of the watersheds in June 1981 to 15% in October 1981. During the same period erosion was reduced on the chopped watersheds from 5.6% to 1.6%. The majority of the revegetation on both treatments was the result of the establishment of numerous grass species. The sheared areas had a grass cover of 11.3%, while the chopped watersheds had a 5.5% grass cover.

Herbaceous biomass producton increased substantially on the treated watersheds since June 1981 (Table 22). Grass production was greatest on the sheared sites with a mean of 1,090 lb/acre, compared to 790 lb/acre on the chopped sites. Forb production was also greatly increased during this period with sheared watersheds accumulating 401 lb/acre and the chopped watersheds 685 lb/acre. The amount of litter remaining on the chopped areas (3,036 lb/acre) was still five times greater than on the sheared areas (565 lb/acre).

Table 20. Post-treatment understory vegetation (stems <1" dbh/acre), for the Alto watersheds, October 1981.

	Shear and Windrow				Roller Chop			
	Watershed No.							
	1	2	3	Avg.	5	7	9	Avg.
Pine								
Loblolly & Shortleaf	417	333	447	339	254	541	519	439
Hardwoods								
Oak	1,000	479	830	770	1,491	1,049	1,000	1,180
Elm	250	63	-0-	104	164	49	250	154
Dogwood	-0-	21	-0-	7	472	180	192	281
Sweetgum	150	104	234	163	1,036	738	1,192	987
Hickory	33	83	191	102	254	16	96	122
Other	1,050	792	1,468	1,103	1,054	7,033	1,651	3,246
TOTAL	2,483	1,542	2,723	2,249	4,471	9,065	4,381	5,970
Shrubs								
American Beautyberry	2,100	2,708	1,617	2,142	5,054	5,623	5,346	5,341
Blackberry	333	458	1,574	788	291	902	2,557	1,250
Southern Waxmyrtle	-0-	-0-	851	284	-0-	738	346	361
Other	450	21	213	228	1,400	393	673	822
TOTAL	2,883	3,187	4,255	3,442	6,745	7,656	8,922	7,774
Vines								
Virginia Creeper	133	42	979	385	163	869	1,231	754
Greenbrier	683	271	106	353	1,200	984	827	1,004
Poison Ivy	17	21	-0-	13	200	98	96	131
Other	350	292	298	313	1,073	38	1,423	1,078
TOTAL	1,183	626	1,383	1,064	2,636	2,689	3,577	2,967

Table 21. Post-treatment ground surface condition (%), for the Alto watersheds, October 1981.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Surface Condition								
Litter	25.3	7.5	15.5	16.1	62.9	49.7	59.8	57.5
Slash	8.2	6.4	8.2	7.6	10.9	18.8	20.8	16.8
Rock	0.6	0.5	0.3	0.5	4.5	0.1	0.1	1.6
Mineral Soil	51.5	70.7	58.6	60.3	17.9	17.9	9.7	15.2
Erosion								
Rill	0.3	0.0	0.5	0.3	0.0	0.1	0.2	0.1
Sheet	3.6	6.4	6.1	5.4	0.3	0.3	0.3	0.3
Deposition	12.5	7.8	6.3	8.9	2.0	0.8	0.7	1.2
Tree	0.1	0.0	0.3	0.1	0.3	0.3	0.5	0.4
Shrub	0.1	0.1	0.3	0.2	0.1	0.4	0.3	0.3
Grass	9.8	11.5	12.5	11.3	2.5	8.2	5.8	5.5
Grasslike	0.9	0.5	1.1	0.8	0.0	1.1	1.6	0.9
Forb	3.1	2.8	3.0	3.0	0.7	1.3	1.4	1.1

Table 22. Post-treatment herbaceous biomass and litter accumulation (lb/acre), for the Alto watersheds, October 1981.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Grass	1,067	879	1,323	1,090	547	1,127	696	790
Grasslike	10	73	2	28	1	18	18	12
Forb	254	578	372	401	652	672	730	685
Litter	69	0	1,627	565	1,641	2,402	5,064	3,036

Seedling Survival

During February 1981 sheared and chopped watersheds were hand planted with 1-0 improved loblolly pine seedlings. The intended spacing was 6 by 9 feet or a stocking of 800 trees per acre. Unfortunately the inexperienced hand planting crew ended up with a stocking average of about 425 trees per acre. A dry summer resulted in a high seedling mortality on both of the treated sites. Survival on the chopped watersheds was 40% and 34% on the sheared watersheds. First year growth did not vary appreciably between treatments. The mean height of seedlings on chopped watersheds was 15.3 inches and on the sheared sites it was 14.5 inches.

Post-treatment October 1982

During October of the second year following treatment, the vegetation inventory was repeated. Results show a continued stabilization of the sites. The number of pine seedlings per acre was reduced from the previous year on both sheared and chopped watersheds (Table 23). Hardwood stems per acre on the chopped watersheds (3,111) were about 50% more than on the sheared sites. The number of shrubs and vine stems per acre was also greatest on the chopped watersheds.

Ground surface condition during the second post-treatment year showed major signs of recovery as the litter and vegetation cover became re-established (Table 24). Exposed mineral soil on the sheared watersheds, reduced from 60% in 1981 to 20% in 1982. Active erosion was present on less than 3% of the sheared watersheds. Mineral soil exposure was also reduced on the chopped sites to 3.6% of the surface area. There was no evidence of erosion on the chopped watersheds. The establishment of a grass cover on both the sheared (12.7%) and the chopped (9.3%) watersheds helped to stabilize the soil surface.

Herbaceous biomass production and litter accumulation, was similar on both sheared and chopped watersheds (Table 25). Grass production on the sheared sites averaged 1,435 lb/acre and 1,370 lb/acre on the chopped sites. Forb production decreased on both treatments from the amount during the previous year. Litter accumulation showed little difference between treatments.

Table 23. Post-treatment understory vegetation (stems < 1" dbh/acre), for the Alto watersheds, October 1982.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Pine								
Loblolly and Shortleaf	295	188	383	289	182	468	481	377
Hardwoods								
Oak	738	563	660	654	963	742	500	735
Elm	197	125	-0-	107	36	32	96	164
Dogwood	-0-	-0-	43	14	567	32	-0-	254
Sweetgum	180	188	404	257	1,410	758	942	1,037
Hickory	16	83	128	76	200	81	19	100
Other	770	500	383	551	473	1,548	442	821
TOTAL	1,901	1,459	1,618	1,659	3,649	3,193	5,192	3,111
Shrubs								
American Beautyberry	1,754	2,333	1,745	1,944	1,636	1,935	1,692	1,754
Blackberry	180	875	2,213	1,089	636	2,113	4,135	2,295
Southern Waxmyrtle	-0-	42	447	163	-0-	677	327	335
Other	1,656	708	1,043	1,136	854	1,645	2,211	1,570
TOTAL	3,590	3,958	5,448	4,332	3,126	6,370	8,365	5,954
Vines								
Virginia Creeper	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Greenbriar	541	208	127	292	873	581	750	735
Poison Ivy	16	83	-0-	33	54	32	38	41
Other	147	250	213	203	200	613	808	540
TOTAL	704	541	340	528	1,127	1,226	2,822	1,316

Table 24. Post-treatment ground surface condition (%), for the Alto watersheds, October 1982.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Surface Condition								
Litter	52.7	56.3	61.4	56.8	65.7	66.0	64.2	65.3
Slash	4.1	5.2	6.3	5.2	16.4	17.4	19.7	17.8
Rock	0.2	0.7	0.8	0.6	3.5	0.0	0.0	1.2
Mineral Soil	21.7	19.7	18.6	20.0	3.4	4.7	2.6	3.6
Erosion								
Rill	0.0	1.0	1.0	0.7	0.0	0.0	0.0	0.0
Sheet	1.5	0.3	0.2	0.7	0.0	0.0	0.0	0.0
Deposition	1.4	1.7	0.5	1.2	0.0	0.0	0.0	0.0
Tree	0.1	0.0	0.3	0.1	0.4	0.3	0.1	0.3
Shrub	0.0	0.1	0.1	0.1	0.1	0.3	0.3	0.2
Grass	15.8	13.4	8.8	12.7	8.3	8.3	11.4	9.3
Grasslike	0.5	0.4	0.4	0.4	0.0	0.5	0.2	0.2
Forb	4.9	4.2	3.3	4.1	2.2	2.5	1.5	2.1

Precipitation and Runoff

Annual precipitation for the three year period, 1980 - 1982, fluctuated from below normal, to above normal, to normal. Precipitation during the pre-treatment year (1980) was 31.15 inches, which is about

Table 25. Post-treatment herbaceous biomass and litter accumulation (lb/acre), for the Alto watersheds, October 1982.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Avg.	5	7	9	Avg.
Grass	1,203	1,675	1,427	1,435	1,147	1,405	1,557	1,370
Grasslike	20	-0-	78	33	55	-0-	65	40
Forb	393	218	446	352	563	226	432	407
Litter	839	971	931	914	917	1,585	717	1,073

14 inches below normal (Table 26). Two-thirds of the precipitation fell between January and May. Precipitation during 1981 was 51.12 inches (Table 27), with an exceptionally wet May, June and October accounting for over half of the 1981 precipitation. During 1982 precipitation totaled 43.95 inches, with the largest accumulations in the spring and late fall (Table 28).

Runoff from these small watersheds is dependent on several factors: 1) rainfall amount - obviously, the input of water is important to the volume of runoff; however, the amount of rainfall necessary to initiate runoff varies with; 2) rainfall intensity - storms of high intensity, especially falling on saturated and/or disturbed soils will produces greater quantities of runoff; 3) antecedent moisture - the time since the last rain and the soil moisture level will significantly influence runoff; and 4) watershed condition - the size, shape, slope, vegetation, ground cover and soil type all modify the amount of runoff. As treatments were applied, changes in the vegetation, ground cover and soil structure were reflected in the quantity and quality of runoff water.

Table 26. Precipitation (inches) 1980.*

DATE	RAINFALL	TOTAL	NORMAL	DATE	RAINFALL	TOTAL	NORMAL
Jan 3	.02			May 14	.48		
10	.03			15	3.20		
16	.61			16	.08		
20	1.03			19	.39	7.00	4.42
21	1.93			Jun 20	.64	.64	3.41
28-30	.56	4.18	3.54	Jul 21	.82		
Feb 3	.06			27-28	.71	1.53	2.67
5	.05			Aug 15	.11		
8	1.52			17	.06		
9	.56			29	.12	.29	2.55
29	.60	2.79	3.36	Sep 6	.46		
Mar 15-17	.69			8	.15		
19-20	.40			18	.93		
23	.21			25	.23		
25	.09			28	.10		
27	1.20			29	.50	2.37	3.76
29	.02	2.61	3.26	Oct 17	.20		
Apr 11	.82			18	.13		
13	1.87			27-28	.78	1.11	2.88
25	1.14	3.83	4.70	Nov 16	2.69		
May 1	.04			23	.68		
2	.23			25	.72	4.09	3.53
3	.03			Dec 7	.10		3.95
9	.17			8	.61	.71	
12	1.23						
13	1.15			TOTAL		31.15	42.03

* Rainfall amounts are reported as an average from all watersheds.

Pre-treatment 1980

During the pre-treatment year (1980), there were nine storms of sufficient size to produce measurable runoff (Table 29). All runoff

Table 27. Precipitation (inches) 1981.*

DATE	RAINFALL	TOTAL	NORMAL	DATE	RAINFALL	TOTAL	NORMAL
Jan 6	.79			Jul 5	1.18		
8	.29			7	1.82		
19-20	1.31			8	.41		
31	.36	2.75	3.54	11	.22		
Feb 2-4	.83			26	.62	4.49	2.67
9-10	1.50			Aug 16	.05		
21	.60			18	.05		
28	.92	3.97	3.36	27	.30		
Mar 3	1.99			30-31	.58	.98	2.55
7	.42			Sep 1	.46		
13	.24			3	.15		
29	1.02	3.67	3.26	4	.35		
Apr 4	.22			5	.39		
14	.07			14	.59		
23	1.28	1.57	4.70	15	.56		
May 3	.35			16	.45	2.95	3.76
4	.73			Oct 6	.89		
9	2.94			7	.90		
13	.23			9	3.05		
15	1.06			12	.15		
24	1.02			13	.05		
26	.05			14	4.78		
30	2.17	8.55	4.42	18	.78		
Jun 2	.80			23	.14		
3	1.10			30	.07	10.81	2.88
4-5	2.03			Nov 1	1.81		
10	.53			8	1.23		
11	.28			18	.06		
12	1.19			29	.26		
14	.02			30	.20	3.56	3.53
15	.02			Dec 5	.08		
16	.44			12	.28		
23	.83			20	.08		
25	.07	7.31	3.41	30	.07	.51	3.95
Jul 2	.24						
				TOTAL		51.12	42.03

* Rainfall amounts are reported as an average from all watersheds.

events occurred between January and May and only the January 21, February 9 and May 15 storms generated runoff from all nine watersheds.

Table 28. Precipitation (inches) 1982.*

DATE	RAINFALL	TOTAL	NORMAL	DATE	RAINFALL	TOTAL	NORMAL
Jan 3	.27			Jun 24	.06		
4	.05			25	.33		
11	.52			27	.16		
13	.45			28	.34		
20	.16			30	1.06	3.63	3.41
21	.11			Jul 2	.19		
22	.18			25	.26	.45	2.67
29	.18			Aug 8	.54		
30	.81	2.73	3.54	17	.46	1.00	2.55
Feb 2	.44			Sep 19	1.20	1.20	3.76
5	.22			Oct 6	.80		
6	.11			7	.19		
8	.39			9	.57		
25	.34			10	.10		
26	.60	1.33	3.36	11	1.45		
Mar 6	.56			17	.05		
21	.65			20	.31		
23	.22			21	.21		
27	.93	2.36	3.26	28	1.43	5.11	2.88
Apr 2	.10			Nov 2	2.10		
10	.24			12	.16		
16	.85			16	.79		
18	.36			19	.21		
19	1.77			23	.07		
20	1.13			26	2.73		
21	1.11			30	.05	6.11	3.53
24	.82			Dec 2	.59		
29	1.09	7.47	4.70	4	.17		
May 1	.08			9	1.39		
6	.85			14	.81		
13	2.24			23	.96		
17	.82			24	1.31		
23	.77			25	.36		
24	.52			26	1.21		
25	.11	5.39	4.42	31	.37	7.17	3.95
Jun 16	1.29						
20	.21			TOTAL		43.95	42.03
21	.18						

* Rainfall amounts are reported as an average from all watersheds.

Base flow was absent, except for one or two days, following a major storm. Total runoff for the year ranged from 0.86 inches on WS 3 to 2.40 inches on WS 9 and averaged 1.47 inches for all nine watersheds. Runoff as a percent of annual precipitation, averaged 5% for the nine watersheds. A single storm on May 15 produced 71% of the total runoff for the year. A maximum peak discharge rate of 13.7 cfs was reached on WS 9 during the May 15 storm. The next highest discharge rate was 0.47 cfs on the same watershed during the January 21 storm.

On January 20, 1980 a 1.3 inch rainfall event produced the first measurable stormflow (Table 29). Only WS 2 responded to this storm, with a stormflow of 0.015 inches. Not until the next day, was there a sufficient amount of rainfall to produce runoff from all watersheds. Rainfall on January 21 totaled 1.93 inches, with a maximum intensity of 0.46 inches per hour. Because of the previous days rain, soil antecedent moisture was high. Runoff began about five hours after the rain started for blocks 1 and 3 and about eight hours after for block 2.

Runoff from the January 21 storm averaged 0.17, 0.13 and 0.47 inches for blocks 1, 2 and 3, respectively. This general pattern of response, by the three blocks, was followed for the remaining 1980 storms. Watersheds in block 3 usually had the fastest response time and the greatest volume of runoff, with blocks 1 and 2 following, respectively. The responsiveness of the block 3 watersheds is related to the higher percentage of Cuthbert and Kirvin series soils. Watersheds 5 and 8 in block 2 are usually the least responsive to precipitation input, especially when soil moisture is low. The reason for this is uncertain, however, several factors could contribute to this delayed response and relatively low volume of runoff. Both watersheds contan about 25 percent sandy soils, which tend to delay rapid runoff. The geology of the particular watersheds may also influence response by routing subsurface water flow to deeper drainage or allowing substantial detention storage of soil water. In the case of WS 5, there is a large percentage of stones in the surface horizon, which generally provide macropores for rapid infiltration of rainfall. However, soil storage is reduced in volume and with high soil antecedent moisture, the likelihood of runoff is increased. This is evident from the storm on May 15, in which WS 5 reported a volume of runoff similar to the watersheds in the more responsive block 3.

On February 8, a 1.52 inch rainfall event generated stormflow from all watersheds except WS 8. Volume of runoff was low from all drainages with the lowest (WS 5) producing only 0.006 inches and the highest (WS 9) 0.114 inches of stormflow. Again, block 3 showed the greatest response to precipitation. The next day, February 9, a 0.56 inch rain generated runoff from all watersheds. This storm, although appreciably less in total rainfall, had a higher intensity than the February 8 storm. On April 13, an intermittent storm with a maximum intensity of 2 inches per hour, produced runoff from all watersheds except 5 and 8 (Table 29). Maximum stormflow for the 1.87 inch rainfall event was from WS 2 (0.16 inches).

Table 29. Event and annual precipitation, runoff, and peak discharge by watershed, for storms producing runoff prior to treatment, 1980.

Storm Date	Watershed No.	Precipitation / Runoff area inches		Runoff as a % of Precipitation* %	Peak rate of Discharge cfs
			Per event		
Jan 20	1	1.13	0.015	1	0.01
Jan 21	1	1.79	0.124	7	0.16
	2	1.81	0.440	7	0.45
	3	1.85	0.123	7	0.12
	4	1.91	0.134	7	0.15
	5	2.03	0.182	6	0.16
	6	1.97	0.416	21	0.47
	7	1.99	0.258	13	0.22
	8	2.00	0.090	4	0.14
	9	1.95	0.566	29	0.47
Feb 8	1	1.56	0.026	2	0.08
	2	1.51	0.085	6	0.15
	3	1.54	0.019	1	0.04
	4	1.55	0.019	1	0.04
	5	1.51	0.006	<1	0.02
	6	1.54	0.096	6	0.15
	7	1.51	0.048	3	0.06
	9	1.48	0.114	8	0.16
Feb 9	1	.58	0.027	-	0.07
	2	.56	0.094	-	0.17
	3	.57	0.024	-	0.04
	4	.57	0.019	-	0.04
	5	.56	0.033	-	0.04
	6	.57	0.089	-	0.17
	7	.56	0.053	-	0.07
	8	.54	0.007	-	0.02
	9	.55	0.120	-	0.19
Mar 27	2	1.21	0.005	<1	0.01
	6	1.20	0.004	<1	0.01
	9	1.20	0.004	<1	0.01
Apr 13	1	1.79	0.033	2	0.07
	2	1.90	0.161	8	0.33
	3	1.88	0.026	1	0.03
	4	1.88	0.024	1	0.05
	6	1.86	0.096	5	0.17
	7	1.89	0.055	3	0.08
	9	1.86	0.103	5	0.15
May 13	2	1.31	0.044	3	0.21
	3	1.26	0.006	<1	0.02
	4	1.21	0.002	<1	0.01

Table 29. Continued.

Storm Date	Watershed No.	Precipitation area inches	Runoff area inches	Runoff as a % of Precipitation %	Peak rate of Discharge cfs
May 13	6	1.09	0.006	<1	0.02
	9	1.27	0.013	1	0.06
May 14	2	.46	0.012	-	0.03
	3	.45	0.002	-	0.01
	6	.48	0.002	-	0.01
	7	.47	0.002	-	0.01
	9	.47	0.005	-	0.02
May 15	1	3.01	0.760	25	7.00
	2	3.08	1.232	40	8.99
	3	3.03	0.657	22	5.79
	4	3.10	0.803	26	6.08
	5	3.45	1.218	35	6.80
	6	3.23	1.350	42	11.23
	7	3.15	0.969	31	10.05
	8	3.42	0.921	27	9.04
	9	3.18	1.470	46	13.71
		Annual			
	1	31.15	0.985	3#	-
	2	31.15	2.073	7	-
	3	31.15	0.857	3	-
	4	31.15	1.001	3	-
	5	31.15	1.439	5	-
	6	31.15	2.059	7	-
	7	31.15	1.385	4	-
	8	31.15	1.018	3	-
	9	31.15	2.395	8	-
	Mean		1.468	5	

* Calculated for storms with greater than one inch of precipitation.
# Percent of mean annual precipitation (31.15 inches) measured as runoff.

A series of storms beginning on May 12 produced several runoff events. A 1.23 inch rainfall event on May 12 failed to generate stormflow from any watershed, however, a May 13 storm of 1.15 inches generated stormflow from watersheds 2, 3, 4, 6 and 9. The volume of runoff from this storm averaged less than 0.014 inches. A third storm occurred the following day, May 14, although precipitation was only 0.48 inches, it produced a measurable volume of runoff from watersheds 2, 3, 6, 7 and 9.

On May 15, after three consecutive days of rain (2.86 inches total), a 3.20 inch rainfall event occurred. Soil antecedent moisture was high and a large volume of stormflow was recorded on all watersheds. Runoff volumes ranged from 0.66 inches to 1.47 inches for watersheds 3 and 9, respectively (Table 29). Runoff as a percent of precipiatation was 22 and 46 percent for the same two watersheds. Maximum ranfall intensity for the storm was 2.10 inches per hour.

The combination of a high intensity and relatively large rainfall event on an already saturated soil, produced the large runoff volumes and sharp peak discharge rates. Evidence of overland flow was observed during this storm and is supported by the rapid response and the volume of discharge.

As mentioned earlier, the nine watersheds are divided into blocks of three, according to similarities. Analysis of the hydrographs support this classification, as responses and volumes are very similar within each block.

<u>Post-treatment 1981</u>

During 1981, 69 storms produced 31 runoff events (Table 30). Runoff was generated on all watersheds during six events and was exclusive on the sheared and windrowed watersheds for 14 of the events. The majority of the runoff occurred during the spring and fall months. Sheared and windrowed watersheds produced the largest volume of runoff (5.76 inches) for the year, followed by the roller chopped (3.26 inches) and then the undisturbed control (1.03 inches) watersheds (Table 30). Runoff volumes for the year were significatly different between all three treatments. Runoff as a percent of annual precipitation averaged 11, 6 and 2 percent for the sheared and windrowed, chopped and undisturbed watersheds, respectively. A maximum peak discharge rate of 17.7 cfs was reached on the sheared WS 2, during the October 14 runoff event. Precipitation and runoff for the year, by treatment and storm, is summarized in Table 30.

The winter and early spring of 1981 was unusually dry. During January, 2.75 inches of rain fell with no runoff occurring. Rainfall for February was 3.97 inches which produced only small amounts of runoff from the sheared watersheds and from one of the control watersheds.

On March 1, a 0.92 inch rainfall produced 0.016 inches of runoff on the sheared watersheds. Two days later on March 3, a 1.99 inch rainfall generated runoff from all nine watersheds. Runoff from the sheared watersheds averaged 0.52 inches, as compared to 0.21 inches from the chopped and 0.06 inches from the control watersheds. Two small runoff events were recorded on the sheared watersheds on March 7 and 29.

April, which is normally the wettest month of the year, had a total rainfall of only 1.57 inches. Only a trace amount of runoff was

Table 30. Mean event and annual precipitation, runoff and peak discharge by treatment, for storms producing runoff the first year following treatment, 1981.

Storm Date	Treatment	Precipitation	Runoff	Runoff as a % of Precipitation*	Peak rate of Discharge
		area inches		%	cfs
		Per event			
Feb 5	Shear (1)#	0.83	0.016	-	0.03
Feb 10	Shear (3)	1.50	0.068	5	0.37
	Control (1)		0.003	<1	0.02
Mar 1	Shear (3)	0.92	0.016	-	0.11
Mar 3	Shear (3)	1.99	0.517	26	4.79
	Chop (3)		0.210	11	0.84
	Control (3)		0.055	3	0.22
Mar 7	Shear (2)	0.42	0.005	-	0.02
Mar 29	Shear (3)	1.02	0.015	1	0.26
Apr 23	Shear (1)	1.28	0.004	<1	0.01
May 4	Shear (3)	0.73	0.003	-	0.06
	Chop (1)		0.001	-	0.01
May 9	Shear (3)	2.94	0.498	17	3.10
	Chop (3)		0.367	12	1.64
	Control (3)		0.020	1	0.12
May 16	Shear (3)	1.06	0.083	8	1.29
	Chop (3)		0.019	2	0.06
May 24	Shear (3)	1.02	0.008	1	0.14
	Chop (1)		0.010	<1	0.02
May 30	Shear (3)	2.17	0.462	21	5.79
	Chop (3)		0.251	12	2.13
	Control (3)		0.038	2	0.29
Jun 2	Shear (3)	0.80	0.005	-	0.11
Jun 3	Shear (3)	1.10	0.213	19	0.63
	Chop (3)		0.152	14	0.24
	Control (3)		0.022	2	0.05
Jun 4	Shear (3)	2.03	0.738	36	4.34
	Chop (3)		0.545	27	1.06
	Control (3)		0.168	8	0.38
Jun 10	Shear (2)	0.53	0.013	-	0.40
	Chop (1)		0.004	-	0.02
Jun 11	Shear (2)	0.28	0.001	-	0.01
Jun 12	Shear (3)	1.19	0.156	13	2.18
	Chop (3)		0.116	10	0.26
	Control (2)		0.011	1	0.02
Jun 16	Shear (3)	0.44	0.005	-	0.15
Jun 23	Shear (3)	0.83	0.017	-	0.48
Jul 5	Shear (2)	1.18	0.005	<1	0.11
Jul 7	Shear (3)	1.82	0.227	12	2.83
	Chop (2)		0.044	2	0.22

Table 30. Continued.

Storm Date	Treatment	Precipitation / area inches	Runoff	Runoff as a % of Precipitation %	Peak rate of Discharge cfs
Jul 7	Control (2)		0.007	<1	0.04
Jul 8	Shear (3)	0.41	0.063	-	1.78
Jul 26	Shear (1)	0.62	0.003	-	0.12
Sep 15	Shear (3)	0.56	0.004	-	0.21
Sep 16	Shear (2)	0.45	0.002	-	0.09
Oct 9	Shear (3)	3.05	0.254	8	1.42
	Chop (1)		0.005	<1	0.04
	Control (1)		0.005	<1	0.02
Oct 14	Shear (3)	4.78	2.138	45	15.04
	Chop (3)		1.384	29	4.94
	Control (3)		0.693	14	3.18
Oct 18	Shear (3)	0.78	0.037	-	0.31
	Chop (3)		0.020	-	0.07
	Control (1)		0.003	-	0.02
Nov 1	Shear (3)	1.81	0.146	8	1.04
	Chop (3)		0.100	5	0.29
	Control (2)		0.014	1	0.04
Nov 8	Shear (3)	1.23	0.061	5	0.19
	Chop (3)		0.058	5	0.11
	Control (2)		0.007	<1	0.01
			Annual		
	Shear	51.12	5.759 a+	11&	-
	Chop	51.12	3.259 b	6	-
	Control	51.12	1.025 c	2	-

* Calculated for storms with greater than 1 inch of precipitation.
# The number of samples in each mean.
\+ Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.
& Percent of mean annual precipitation (51.12 inches) measured as runoff.

recorded on one of the sheared watersheds, following a 1.28 inch rainfall event.

During May, over 8.5 inches of rainfall resulted in five runoff events. On May 9, several scattered storms with intensities of up to 3 inches per hour, produced runoff from all nine watersheds. The amount of runoff ranged from 0.02 inches on the control sites to 0.50 inches on the sheared sites. On May 16, runoff from a 1.06 inch rain, produced runoff of less than 0.10 inches from the treated watersheds and no runoff on the controls. A similar storm on May 24 caused runoff from the sheared watersheds and one of the chopped. A 2.17 inch rain on May 30, generated runoff from all watersheds. Runoff averaged 0.46 inches for the sheared watersheds, 0.25 inches for the chopped, an 0.04 inches for the undisturbed control watersheds. As a percent of precipitation, runoff was 21, 12 and 2 percent for the sheared, chopped, and undisturbed watersheds, respectively.

An unusually wet June, with 7.31 inches of precipitation on soils with high antecedent soil moisture, resulted in 8 separate runoff events. Rainfall on June 2 (0.80 inches), produced a mean runoff of 0.05 inches of stormflow on the more responsive sheared watersheds. However, on June 3, runoff ranged from 0.006 inches on WS 8 (control), to 0.31 inches on WS 2 (sheared), following a 1.10 inch rain. The following day, June 4, 2.03 inches of rain fell on the already saturated soils. A maximum rainfall intensity of 3.3 inches per hour was reached during one 10 minute period. Stormflow from the sheared watersheds averaged 0.74 inches, 0.55 inches from the chopped and 0.17 inches from the control watersheds. The volume of runoff was significantly different between treatments for this storm. Two small storms occurred on June 10 and 11 and produced low volumes of runoff on the sheared and chopped sites. On June 12, 1.19 inches of rain generated runoff from all watersheds except WS 8 (control). Mean volumes ranged from 0.16 inches on the sheared sites to 0.01 inches on the control sites. On June 16 and 23, measurable runoff was recorded for the sheared watersheds following two small storms.

During July, three storms produced runoff. The first storm on July 5, generated only trace amounts of runoff from WS 2 and 3 (sheared), following a 1.18 inch rain. However, on July 7, a 1.82 inch rainfall event generated stormflow from all watersheds except WS 8 (control) and WS 5 (chopped). Runoff volume from the sheared, chopped and undisturbed watersheds averaged 0.23, 0.04 and 0.007 inches, respectively. On July 8 and 26 two small storms produced low volumes of stormflow on the treated watersheds.

The summer months were fairly dry and not until September did any runoff producing storms occur. On September 15 and 16 low volumes of runoff were measured from two separate rainfall events on the sheared watersheds.

Rainfall during the month of October was over 10 inches and resulted in three runoff events. On October 9, a 3.05 inch rainfall produced runoff on all the sheared watersheds, one of the chopped (WS 9) and one of the control watersheds (WS 6). Because of the very low soil antecedent moisture, stormflow was minimal. On October 14, an intense storm dropped 4.78 inches of rainfall in 4.5 hours. This resulted in the largest volume of runoff for the year for all treatments. Mean stormflow on the sheared watersheds was 2.14 inches with a peak flow rate of 15.0 cfs. Mean stormflow on the chopped sites was 1.38 inches and 0.69 inches on the control sites. The peak rate of runoff on the chopped watersheds was one-third and the control watersheds one-fifth of that on the sheared sites. Runoff during this single event represents 37%, 42% and 68% of the 1981 total runoff for the sheared, chopped and undisturbed watersheds, respectively. On October 18, a small storm generated low volumes of runoff.

During November the last two runoff events of the year occurred. A 1.81 inch rainfall on November 1 produced 0.15 inches of runoff on the sheared sites, 0.10 inches on the chopped and 0.01 inches on the control sites. On November 8, low volumes of runoff resulted following a 1.23 inch rainfall.

The loss of protective cover on the sheared watersheds was the primary cause for the greater stormflow during this first year following treatment. Compaction from heavy machinery during site preparation along with the deleterious effects of raindrop impact on the bare soil, reduced infiltration rates. As a result overland flow occurred and stormflow volumes were increased. Conversely, chopped watersheds were covered with a layer of slash and organic matter which restricted overland flow and protected the soil from raindrop impact, thus allowing time for infiltration. Also, the blade of the roller chopper has a tillage effect which usually improves aeration, soil density and detention storage (Switzer et al. 1978). Runoff from the undisturbed watersheds was very low and occurred only when soil antecedent moisture was high.

Post-treatment 1982

During the second year following treatment there were 73 rainfall events which generated 22 runoff events (Table 31). Precipitation for this year, although about the long term average, was 7 inches lower than for 1981. There were no really large storms which contribute a lot to annual runoff on small watersheds. These factors along with the rapid revegetation occurring on the treated watersheds, resulted in over a 50% decrease in runoff during 1982 from the previous year. Mean annual stormflow from the sheared watersheds was 1.97 inches, 1.40 inches from the chopped and 0.47 from the control watersheds. Sheared and chopped watershed volumes were not significantly different, although both were significantly higher than the control. Runoff as a percent of annual precipitation was 4, 3 and 1% for the sheared, chopped and control treatments, respectively. The highest mean rate of discharge for the year was 3.37 cfs on the sheared sites during the April 19 runoff event. The highest discharge rate for the chopped watersheds was 0.84 cfs and occurred on the same date.

There were very few major rainfall events during the first 3 months of 1982. The only measurable runoff during this period was following a 0.81 inch rain on January 30.

Higher rainfal amounts and increasing soil moisture resulted in five runoff events during April. The largest runoff event of the year occurred on April 19, following 2.90 inches of rain. The sheared watersheds responded with 0.56 inches of runoff, the chopped with 0.24 inches and the controls 0.14 inches. On the April 21 runoff event,

Table 31. Mean event and annual precipitation, runoff and peak discharge by treatment, for storms producing runoff the second year following treatment, 1982.

Storm Date	Treatment	Precipitation/	Runoff	Runoff as a % of Precipitation*	Peak Rate of Discharge
		area inches		%	cfs
		Per event			
Jan 30	Shear (3)#	0.81	0.016	-	0.30
	Chop (1)		0.012	-	0.05
	Control (1)		0.003	-	0.02
Apr 17	Shear (2)	0.85	0.003	-	0.10
	Chop (1)		0.002	-	0.03
Apr 19	Shear (3)	2.90	0.556	19	3.37
	Chop (3)		0.244	8	0.84
	Control (3)		0.138	5	0.37
Apr 21	Shear (3)	1.11	0.087	8	0.08
	Chop (3)		0.134	12	0.06
	Control (2)		0.038	3	0.02
Apr 24	Shear (3)	0.82	0.070	-	0.12
	Chop (3)		0.074	-	0.06
	Control (2)		0.024	-	0.02
Apr 28	Shear (3)	1.09	0.155	14	2.19
	Chop (3)		0.048	4	0.16
	Control (2)		0.037	3	0.17
May 6	Shear (1)	0.85	0.001	-	0.02
	Chop (1)		0.004	-	0.02
May 13	Shear (3)	2.24	0.203	9	0.57
	Chop (3)		0.166	7	0.22
	Control (3)		0.066	3	0.07
May 17	Shear (3)	0.82	0.040	-	0.23
	Chop (2)		0.010	-	0.02
	Control (2)		0.010	-	0.02
May 23	Shear (2)	0.77	0.005	-	0.07
	Chop (1)		0.008	-	0.06
May 24	Shear (3)	0.52	0.005	-	0.06
	Chop (1)		0.008	-	0.08
Jun 16	Shear (3)	1.29	0.005	<1	0.25
	Chop (1)		0.001	<1	0.02
Jun 30	Shear (2)	1.06	0.005	<1	0.22
Oct 28	Shear (2)	1.43	0.003	<1	0.01
Nov 2	Shear (3)	2.10	0.019	1	0.08
Nov 26	Shear (3)	2.73	0.265	10	1.05
	Chop (3)		0.122	4	0.26
	Control (2)		0.094	3	0.22
Dec 11	Shear (2)	1.39	0.020	1	0.04
	Chop (2)		0.034	2	0.04
Dec 14	Shear (3)	0.81	0.060	-	0.16

Table 31. Continued.

Storm Date	Treatment	Precipitation/ area inches	Runoff area inches	Runoff as a % of Precipitation %	Peak Rate of Discharge cfs
Dec 14	Chop (3)		0.036	-	0.06
	Control (1)		0.007	-	0.01
Dec 23	Shear (3)	0.96	0.029	-	0.17
	Chop (2)		0.042	-	0.09
	Control (2)		0.002	-	0.01
Dec 24	Shear (3)	1.31	0.232	18	0.53
	Chop (3)		0.193	15	0.20
	Control (2)		0.055	4	0.05
Dec 25	Shear (3)	0.36	0.020	-	0.03
	Chop (3)		0.046	-	0.03
Dec 26	Shear (3)	1.21	0.186	15	0.44
	Chop (3)		0.266	22	0.36
	Control (3)		0.087	7	0.14
		Annual			
	Shear	43.95	1.972 a+	4&	-
	Chop	43.95	1.400 a	3	-
	Control	43.95	0.466 b	1	-

* Calculated for storms with greater than 1 inch of precipitation.
# The number of samples in each mean.
\+ Means for each treatment followed by the same letter are not significantly different ($P < .05$) according to Duncan's multiple range test.
& Percent of mean annual precipitation (43.95 inches) measured as runoff.

mean stormflow on the chopped watersheds (0.13 inches) exceeded the amount on the sheared (0.09 inches) for the first time. With the addition of two more runoff events (April 24 and 28) runoff for April was the highest for the year.

Frequent rains continued during May, which produced five separate runoff events. On May 13, the largest event of the month occurred after a 2.24 inch rain. Runoff was 0.20, 0.17 and 0.07 inches, for the sheared, chopped and control watersheds, respectively. Low volumes of runoff were recorded following four other events during May.

Two small storms on June 16 and 30 produced less than 0.01 inch of stormflow from the sheared and chopped sites. These were the last runoff events prior to the annual summer drought.

Runoff for the fall began on October 28, after a 1.43 inch rain generated stormflow on two of the sheared watersheds. On November 2, 2.10 inches of rain still only produced runoff on the sheared sites. The second largest storm (2.73 inches) of the year occurred on November 26. Rainfall from this storm was spread over a 24 hour period, with fairly low intensities. Runoff from this storm was measured on all watersheds except WS 8 (control). Sheared sites had mean runoff of 0.27 inches, compared to 0.12 inches on the chopped and 0.09 inches on the control sites.

Six storms during December were of sufficient size to generate measurable runoff. Two runoff events occurred on December 11 and 14 and a series of events from December 23 thru 26. The month of December had the second highest volume of runoff for the year. The December 26 storm of 1.21 inches on the saturated soils produced the largest volumes of runoff for the month. The chopped watersheds had the highest mean volume of runoff with 0.27 inches followed by the sheared with 0.19 inches and the controls with 0.09 inches.

It is difficult to compare runoff volumes between years because of the differences in rainfall amounts, distribution and intensity. However, it appears that the differences in runoff between sheared and chopped treatments is diminishing in this second year following treatment. Statistically there was no difference between runoff volumes between the two site preparation treatments (Table 31). Rapid revegetation with a reduction in exposed mineral soil has helped to retard the surface runoff that was occurring on the sheared sites during the first year.

Water Quality

Sediment

Pre-treatment - 1980

During 1980 only six runoff events were of sufficient size to initiate water sampling equipment on some or all of the undisturbed watersheds. Only two storms during this pre-treatment year generated runoff from all nine of the watersheds. The mean discharge weighted suspended sediment concentration for 1980 was 220 ppm (Table 32). Total sediment loss for this period averaged 181.3 lb/acre for the nine undisturbed watersheds. This total loss figure includes a 77.7 lb/acre contribution from suspended sediment and 103.6 lb/acre from bedload deposition. Thus over half of the sediment export is attributed to bedload.

Table 32. Mean event and annual stormflow and sediment concentrations and losses by watershed prior to treatment, 1980.

Storm Date	Watershed	Runoff (inches)	Suspended Sediment (ppm)	Suspended Sediment (lb/ac)	Bedload (lb/ac)	Total Sediment (lb/ac)
			Per event			
Jan 21	1	.124	24	0.7	0.0	0.7
	2	.440	48	4.8	0.0	4.8
	3	.123	80	2.2	0.0	2.2
	4	.134	60	1.8	0.0	1.8
	5	.182	60	2.5	0.0	2.5
	6	.416	48	4.5	0.0	4.5
	7	.258	36	2.1	0.0	2.1
	8	.090	12	0.2	0.0	0.2
	9	.566	12	1.5	0.0	1.5
Feb 8-9	2	.179	76	3.1	0.0	3.1
	6	.185	44	1.8	0.0	1.8
	9	.234	20	1.1	0.0	1.1
Mar 27	9	.004	17	<0.1	0.0	<0.1
Apr 13	1	.033	56	0.4	0.0	0.4
	2	.161	141	5.1	0.0	5.1
	6	.096	79	1.7	0.0	1.7
	9	.103	31	0.7	0.0	0.7
May 13	2	.044	241	2.4	0.0	2.4
May 15	1	.760	174	29.9	124.6	154.5
	2	1.232	1,309	364.7	93.8	459.5
	3	.657	169	25.1	254.5	279.6
	4	.803	435	79.0	116.4	195.4
	5	1.218	34	9.3	37.7	47.0
	6	1.350	199	60.7	165.9	226.6
	7	.969	108	23.7	32.1	55.8
	8	.921	108	22.5	37.9	60.4
	9	1.470	144	47.9	69.5	117.4
			Annual			
		1.468	220*	77.7	103.6	181.3

* Mean concentration is discharge weighted by stormflow.

Sediment concentrations and export from all but the May 15 runoff event were fairly low (Table 32). During this period, sediment concentrations ranged from 12 ppm on WS 8 and WS 9 on January 21 to 241 ppm on WS 2 on a small event on May 13. The greatest sediment export occurred on WS 2 during the April 13 runoff event when 5.1 lb/acre of sediment was lost. No bedload deposition was recorded during these first five events.

An intense storm on May 15 was the primary source of sediment loss during 1980. Total sediment export from this one storm averaged 177.2 lb/acre which represents 98% of the total sediment loss for the year. Suspended sediment concentration was highest on WS 2 (1309 ppm) and lowest on WS 5 (34 ppm), even though both watersheds had similar volumes of runoff (1.2 inches). Bedload was measured on all watersheds and averaged 103.6 lb/acre. Bedload export accounted for 58% of the total sediment export for this storm.

Observation from this limited amount of pre-treatment data indicates the watersheds to be fairly uniform with low concentrations of sediment and small sediment losses. However, the potential for large sediment losses from the undisturbed forest exists under the right conditions, as evidenced by the May 15 storm. When soil antecedent moisture is high and a storm of high intensity and sufficient duration occurs , the result is larger volumes of runoff, which carry higher concentrations of sediment. Sediment losses from all but the May 15 storm, were most likely the result of channel scouring. This was probably the major source of sediment on May 15 because of the large volume of rapid runoff, although overland flow was also evident.

Post-treatment - 1981

Sediment samples during the first year following treatment were collected from 18 storm events. Sediment losses were highest in the months with the greatest precipitation and runoff: May, June and October. The mean discharge weighted suspended sediment concentration for the year was 925, 30 and 90 ppm for the sheared, chopped and undisturbed watersheds, respectively (Table 33). The sediment concentration on the sheared watersheds was significantly higher than chopped and undisturbed areas which were not significantly different. The lower volumes of runoff on the undisturbed areas resulted in greater concentrations of sediment than the chopped areas. Total sediment loss for 1981 showed significantly greater export on the sheared watersheds (2,620.2 lb/acre) than the chopped (22.4 lb/acre) or the control watersheds (29.3 lb/acre). The greater sediment export from the undisturbed watersheds than the chopped is attributed almost entirely to the high sediment concentration and runoff from WS 6 during the October 14 event. Bedload deposition occurred only on the sheared watersheds and totaled 1,404.3 lb/acre for the year. The bedload export represents over 50% of the total 1981 sediment loss on the sheared sites.

Six storms during 1981 produced runoff from all three of the treatments. These six storms account for 75, 90 and 100 percent of the first year sediment loss from the sheared, chopped and undisturbed watersheds, respectively. Only during the June 4 and October 14 runoff events were water samples collected from all three of the con-

Table 33. Mean event and annual stormflow and sediment concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Runoff (inches)	Suspended Sediment (ppm)	Suspended Sediment (lb/ac)	Bedload (lb/ac)	Total Sediment (lb/ac)
			Per event			
Feb 10	Shear (1)*	.140	346	11.0	0.0	11.0
Mar 3	Shear (3)	.517	1,518	138.9	83.0	221.9
	Chop (3)	.210	37	1.9	0.0	1.9
	Control (1)	.139	42	1.3	0.0	1.3
May 9	Shear (3)	.498	888	114.3	198.3	312.6
	Chop (3)	.367	30	2.5	0.0	2.5
	Control (1)	.052	57	0.7	0.0	0.7
May 16	Shear (3)	.083	1,711	32.5	49.3	81.8
	Chop (1)	.054	40	0.5	0.0	0.5
May 24	Shear (1)	.009	673	1.4	0.0	1.4
May 30	Shear (3)	.462	1,680	185.6	251.3	436.9
	Chop (3)	.251	42	2.4	0.0	2.4
	Control (1)	.097	40	0.9	0.0	0.9
Jun 3	Shear (3)	.213	656	29.9	16.0	45.9
	Chop (3)	.152	25	1.0	0.0	1.0
	Control (1)	.048	64	0.7	0.0	0.7
Jun 4	Shear (3)	.738	1,157	190.5	210.0	400.5
	Chop (3)	.545	25	3.2	0.0	3.2
	Control (3)	.168	46	1.6	0.0	1.6
Jun 10	Shear (2)	.013	425	0.9	3.0	3.9
Jun 12	Shear (3)	.156	1,022	32.3	87.3	119.6
	Chop (3)	.116	28	0.9	0.0	0.9
Jun 23	Shear (2)	.020	624	2.6	3.5	6.1
Jul 7	Shear (3)	.227	1,468	73.1	195.6	268.7
	Chop (1)	.074	42	0.7	0.0	0.7
Jul 8	Shear (2)	.087	1,533	29.6	66.5	96.1
Oct 9	Shear (3)	.254	831	66.5	29.7	96.2
Oct 14	Shear (3)	2.138	612	309.7	231.7	541.4
	Chop (3)	1.384	30	9.1	0.0	9.1
	Control (3)	.693	112	26.5	0.0	26.5
Oct 18	Shear (2)	.046	237	2.6	0.0	2.6
Nov 1	Shear (3)	.146	414	13.2	3.3	16.5
	Chop (2)	.146	37	1.2	0.0	1.2
Nov 8	Shear (3)	.061	99	1.5	0.0	1.5
	Chop (1)	.128	26	0.8	0.0	0.8

Table 33. Continued.

Storm Date	Treatment	Runoff (inches)	Suspended Sediment (ppm)	Suspended Sediment (lb/ac)	Bedload (lb/ac)	Total Sediment (lb/ac)
			Annual			
	Shear	5.759	925a#+	1215.9a	1404.3a	2620.2a
	Chop	3.259	30b	22.4b	0.0b	22.4b
	Control	1.025	90b	29.3b	0.0b	29.3b

* The number of samples in each mean.
# Mean concentration is discharge weighted by stormflow.
+ Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

trol watersheds. On the remaining four runoff events, WS 6 was the only undisturbed watershed to reach sampling stage.

Analysis of the individual storm events shows the sheared sites to have consistantly higher sediment concentration than the other two treatments throughout the year (Table 33). Control sites on all but one event had greater sediment concentrations than the chopped watersheds. This is attributed to the dilution of the sample because of the higher volumes of runoff on the chopped sites.

The October 14 rainfall event of 4.78 inches contributed the most to both water and sediment yield during 1981. The mean total sediment export from this storm, for the sheared, chopped and control sites was 541.4, 9.1 and 26.5 lb/acre, respectively. Total sediment loss from the October 14 storm, represents 21% of the annual loss on sheared sites, 41% on the chopped and 90% on the undisturbed sites. This storm illustrates as the May 15, 1980 storm does, the role of the large storm in determining annual runoff and sediment exports.

The accumulation of bedload on the sheared sites occurred on 14 of the 18 events in 1981. Bedload loss ranged from 3.0 lb/acre during a 0.01 inch runoff on June 10 to 251.3 lb/acre during a 0.46 inch runoff event on May 30 (Table 33). This higher value is comparable to the loss incurred on WS 3 (254.5 lb/acre) on May 15, 1980, prior to treatment. Texture analysis shows the bedload to be composed of 87% sand and 11% clay. The source of the bedload is most likely a combination channel scouring and surface erosion. The soil series (Rentzel) found along the stream channels has a comparable composition (78% sand, 8% clay). The exclusive bedload deposition found on the sheared areas can be related primarily to the exposure of the mineral soil and the high volume of runoff.

In summary, shearing and windrowing results in significantly larger first year losses of sediment. The primary reason for the higher values on sheared compared to chopped watersheds, is the amount of surface cover and the disruption of the soil surface. The sheared watersheds following site preparation had 57 percent of the surface soil exposed as compared to 16 percent for the chopped watersheds. The bare soil offered no resistance to raindrop impact and overland flow. Thus, sheet and rill eroson resulted, with larger volumes of runoff scouring the channel and carrying higher concentrations of sediment.

The chopped watersheds were covered with a layer of slash and organic matter which impeded overland flow and allowed time for infiltration and detention storage. As a result sediment concentrations from the chopped watersheds were not significantly different from the undisturbed watersheds. Because of the low suspended sediment concentrations, the annual sediment loss was less than the control watersheds. The source of the sediment from the chopped as well as the control areas was probably from channel scouring.

Post-treatment - 1982

Sediment samples were collected on 14 runoff events during 1982 (Table 34). Six of these events generated runoff from all three of the treatments. Stormflow events were concentrated in the spring (April and May) and winter (November - January).

The second year following treatment, sediment concentrations and losses were considerably lower than 1981. The mean discharge weighted suspended sediment concentration was 113, 24 and 58 ppm for the sheared, chopped and undisturbed watersheds, respectively (Table 34). Although the sheared treatment is still significantly higher than the chopped and undisturbed treatments, it is considerably lower than the 925 ppm recorded during 1981. Bedload deposition on the sheared watersheds was only recorded during two storms. Annual sediment export also dropped substantially during this second year. The mean total sediment loss was 71.3 lb/acre from the sheared sites, 4.9 lb/acre from the chopped and 4.5 lb/acre from the control sites. Sediment loss was significantly greater on the sheared watersheds.

The first and largest event occurred on April 19. The runoff from this storm carried the largest quantity of sediment during the year. The mean sediment loss from the sheared watersheds was 31.8 lb/acre, compared to 2.2 lb/acre on the chopped and 4.1 on the control watersheds. This is a considerable decrease in the amount of sediment exported during the largest storm event of 1981 (541.4 lb/acre on the sheared sites). Sediment concentration on the sheared watersheds were also much lower during this second year. The highest mean concentration (286 ppm) was recorded on the sheared sites during the January 30 runoff event. By the fall suspended sediment concentrations had dropped to as low as 9 ppm on the sheared watersheds. Bedload was also reduced significantly during 1982 with only two storms producing small quantities on the sheared areas.

The same relationship existed between chopped and control watersheds for 1982. Generally, the control sites had slightly higher suspended sediment concentrations than the chopped. Mean sediment concentrations ranged from 10 to 58 ppm on the chopped sites and from 12 to 102 ppm on the control sites. Total sediment yield for the chopped and control areas were very similar; the chopped sites having greater runoff volumes but lower sediment concentrations and the reverse occurring on the control sites.

The large drop in sediment concentrations and yield during 1982 can be attributed to several factors. The quantity of rainfall during 1982 was about 7 inches less than 1981. Rainfall was more evenly distributed throughout the year and fell in smaller quantities. The dry

Table 34. Mean event and annual stormflow and sediment concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Runoff (inches)	Suspended Sediment (ppm)	Suspended Sediment (lb/ac)	Bedload (lb/ac)	Total Sediment (lb/ac)
			Per event			
Jan 30	Shear (2)*	.021	286	1.4	0.0	1.4
Apr 19	Shear (3)	.556	146	21.8	10.0	31.8
	Chop (3)	.244	36	2.2	0.0	2.2
	Control (2)	.202	79	4.1	0.0	4.1
Apr 21	Shear (3)	.087	106	2.9	0.0	2.9
Apr 24	Shear (2)	.075	129	3.0	0.0	3.0
Apr 28	Shear (3)	.155	243	10.4	7.6	18.0
	Chop (2)	.065	58	1.0	0.0	1.0
	Control (1)	.058	102	1.3	0.0	1.3
May 13	Shear (3)	.203	126	5.9	0.0	5.9
	Chop (3)	.166	25	1.0	0.0	1.0
	Control (1)	.157	49	1.7	0.0	1.7
May 17	Shear (1)	.100	266	6.0	0.0	6.0
Nov 2	Shear (1)	.031	171	1.2	0.0	1.2
Nov 26	Shear (3)	.265	80	4.5	0.0	4.5
	Chop (3)	.122	18	0.4	0.0	0.4
	Control (1)	.183	12	0.5	0.0	0.5
Dec 11	Shear (1)	.027	9	0.1	0.0	0.1
Dec 14	Shear (2)	.073	9	0.1	0.0	0.1
Dec 23	Shear (2)	.030	69	0.5	0.0	0.5
	Chop (1)	.066	17	0.3	0.0	0.3
Dec 24	Shear (3)	.023	34	1.5	0.0	1.5
	Chop (1)	.272	10	0.6	0.0	0.6
	Control (1)	.078	57	1.0	0.0	1.0
Dec 26	Shear (3)	.186	20	0.9	0.0	0.9
	Chop (2)	.252	13	0.5	0.0	0.5
	Control (3)	.087	36	0.3	0.0	0.3
			Annual			
	Shear	1.972	113a#+	53.7a	17.6a	71.3a
	Chop	1.400	24b	4.9b	0.0b	4.9b
	Control	0.466	58b	4.5b	0.0b	4.5b

* The number of samples in each mean.
# Mean concentration is discharge weighted by stormflow.
+ Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

winter of 1982 never allowed soil moisture to build up, which is so essential to producing runoff on these small watersheds. Revegetation and stabilization of the watersheds was also instrumental in reducing sediment concentrations. The establishement of herbaceous and woody cover helped to both stabilize the soil and increase the transpiration rate. A reduction in the amount of mineral soil exposed played a major role in decreasing the amount of runoff and the accompanying sediment. Exposed mineral soil was 20% on the sheared watersheds and less than 4% on the chopped watersheds. The establishment of a surface cover of litter and vegetation to protect the mineral soil was probably the most important factor in reducing sediment losses. With continued revegetation sediment losses can be expected to continue declining on the sheared treatments back to pre-treatment levels.

Nutrients-Nitrogen

Water samples were analyzed for nitrates, ammonia and total nitrogen (filtered and unfiltered).

Pre-treatment - 1980

Nitrate concentrations and losses were very low during the pre-treatment year. The mean discharge weighted nitrate concentration for the year was 20 ppb (Table 35). Nitrate concentrations ranged from less than detectable to 83 ppb. The concentration of nitrates fluctuated very little between watersheds or storms. Obviously, there is little nitrate available for transport from these undisturbed watersheds, as only 0.007 lb/acre were lost during 1980.

Ammonia concentrations although somewhat higher than nitrate nitrogen were still very low. A maximum concentration of 220 ppb was reached on WS 9 during both the January 21 and the February 8-9 storm (Table 35). The mean discharge weighted concentration of ammonia was 80 ppb during 1980. Total ammonia export for the year amounted to only 0.026 lb/acre.

The concentration of total nitrogen (unfiltered) varied between 262 ppb for WS 4 on January 21 to 2,186 ppb for WS 6 during the February 8-9 runoff event (Table 35). There was little difference between filtered and unfiltered discharge weighted total nitrogen concentrations for the year, 728 and 904 ppb, respectively. Most of the total nitrogen export for the year occurred during the May 15 storm event, when over 70% was lost. The mean annual total nitrogen (unfiltered) loss was 0.286 lb/acre.

Post-treatment - 1981

The first year following site preparation revealed several differences in nitrate concentrations and losses. The mean discharge weighted nitrate concentration was significantly different between all treatments (Table 36). The sheared watersheds had a concentration of 205 ppb, the chopped 96 ppb and the control watersheds 10 ppb. The maximum nitrate concentration for the sheared (904 ppb) and chopped (576 ppb) watersheds occurred during the May 9 runoff event, and on March 3 for the control watersheds (47 ppb). Nitrate concentrations appeared to drop off for all treatments during the fall, probably as

Table 35. Mean event and annual nitrogen concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Nitrate ppb	Nitrate lb/ac	Ammonia ppb	Ammonia lb/ac	Total Nitrogen filtered ppb	Total Nitrogen filtered lb/ac	Total Nitrogen unfiltered ppb	Total Nitrogen unfiltered lb/ac
				Per Event					
Jan 21	1	31	.0008	146	.0021	639	.0907	854	.0234
	2	24	.0023	213	.0207	935	.0907	1177	.1142
	3	25	.0007	132	.0022	666	.0173	901	.0234
	4	37	.0011	65	.0038	397	.0115	262	.0076
	5	24	.0009	194	.0070	2179	.0862	565	.0023
	6	25	.0023	146	.0190	872	.0805	497	.0459
	7	20	.0011	132	.0156	814	.0464	538	.0307
	8	5	.0002	206	.0033	713	.0143	942	.0190
	9	5	.0013	220	.0258	1130	.1416	1009	.1264
Feb 8-9	2	20	.0008	179	.0056	621	.0237	944	.0361
	6	83	.0033	213	.0388	1227	.0486	2186	.0865
	9	44	.0022	220	.0404	810	.0399	1702	.0839
Mar 27	9	0	.0000	77	.0008	729	.0008	836	.0009
Apr 13	1	34	.0002	104	.0032	695	.0047	547	.0037
	2	5	.0002	82	.0263	954	.0339	787	.0279
	6	8	.0002	110	.0108	885	.0182	667	.0137
	9	10	.0002	81	.0008	692	.0150	1025	.0222
May 13	2	70	.0007	86	.0009	1387	.0138	893	.0089
May 15	1	4	.0008	66	.0740	979	.1663	639	.1085
	2	11	.0031	36	.0073	429	.1198	576	.1609
	3	25	.0037	102	.0152	785	.1161	1291	.1909
	4	14	.0025	61	.0109	500	.0895	1282	.2296
	5	3	.0013	49	.0105	346	.0933	528	.1423
	6	61	.0185	49	.0152	729	.2211	1224	.3712
	7	9	.0019	67	.0168	600	.1293	878	.1892
	8	26	.0054	37	.0070	771	.1592	974	.2011
	9	23	.0075	26	.0068	926	.3001	720	.2333
				Annual					
		20*	.0070	80	.0263	728	.2379	904	.2858

* Mean concentration is discharge weighted by stormflow.

the result of plant uptake from rapid revegetation. The mean total nitrate export for the year was 0.267, 0.071 and 0.003 lb/acre for the sheared, chopped and undisturbed watersheds, respectively. Loss on the sheared watersheds was significantly greater than from the other two treatments.

Mean ammonia concentrations, during 1981, were actually lower following treatment than during the pre-treatment year. Ammonia concentrations were 76, 56 and 48 ppb for the sheared, chopped and undisturbed watersheds, respectively (Table 36). There was no significant difference in concentration between treatments. As did nitrate nitrogen, concentrations peaked during the spring storms and declined by the fall. Because of the greater volume of runoff on the sheared sites, ammonia export was significantly greater (0.101 lb/acre) than the chopped (0.044 lb/acre) and the control sites (0.012 lb/acre).

Filtered total nitrogen appeared to be affected little by treatment as concentrations were not significantly different between treatments or the 1980 concentration (Table 36). Filtered total nitrogen concentrations were 787, 676 and 646 ppb, for the sheared, chopped and undisturbed areas, respectively. A look at unfiltered total nitrogen concentrations shows a significant increase on sheared watersheds (2155 ppb), compared to chopped (999 ppb) and undisturbed (996 ppb) watersheds. The concentration on chopped and control sites was not substantially different from the 1980 concentration (904 ppb). The high concentration on the sheared watersheds can be related to the large amount of organic sediments carried in the stormflow. The result of these high concentrations, along with large volumes of runoff, is the significantly higher unfiltered total nitrogen loss found on the sheared sites. The mean annual export of total nitrogen

Table 36. Mean event and annual nitrogen concentration and loss the first year following treatment, 1981.

						Total Nitrogen			
						filtered		unfiltered	
Storm Date	Treatment	Nitrate ppb	Nitrate lb/ac	Ammonia ppb	Ammonia lb/ac	ppb	lb/ac	ppb	lb/ac
				Per event					
Feb 10	Shear (2)*	133	.0028	113	.0026	902	.0183	1754	.0349
Mar 1	Shear (1)	23	.0002	<24	.0001	671	.0045	1263	.0086
Mar 3	Shear (3)	181	.0197	-#	-	830	.0928	2011	.2040
	Chop (3)	167	.0074	-	-	480	.0238	894	.0444
	Control (1)	47	.0015	-	-	499	.0157	800	.0251
Mar 29	Shear (2)	357	.0016	218	.0010	966	.0044	2019	.0090
May 9	Shear (3)	904	.0998	235	.0275	1014	.1110	4465	.5185
	Chop (3)	576	.0473	188	.0176	1043	.0905	1383	.1272
	Control (1)	<5	<.0001	138	.0016	1143	.0134	1202	.0141
May 16	Shear (3)	430	.0083	255	.0046	770	.0150	5050	.0947
	Chop (1)	47	.0006	62	.0008	1716	.0210	1542	.0189
May 24	Shear (2)	555	.0013	385	.0011	1556	.0041	3846	.0101
May 30	Shear (3)	272	.0289	122	.0133	547	.0576	5213	.5743
	Chop (3)	182	.0103	171	.0114	1066	.0695	1313	.0774
	Control (1)	39	.0009	138	.0030	783	.0172	960	.0236
Jun 3	Shear (3)	381	.0194	84	.0041	1304	.0588	1870	.0794
	Chop (3)	33	.0011	71	.0025	2046	.0786	1526	.0602
	Control (1)	<5	<.0001	77	.0008	1692	.0184	1440	.0156
Jun 4	Shear (3)	160	.0287	163	.0291	655	.1127	852	.1435
	Chop (3)	19	.0018	58	.0066	707	.0925	893	.1151
	Control (3)	7	.0002	172	.0059	613	.0252	759	.0288
Jun 10	Shear (2)	307	.0008	29	.0001	806	.0020	3121	.0100
Jun 12	Shear (3)	101	.0039	98	.0036	726	.0258	706	.0253
	Chop (3)	<5	.0001	64	.0016	770	.0223	706	.0210
Jun 23	Shear (2)	425	.0019	89	.0004	739	.0034	2760	.0118
Jul 7	Shear (3)	96	.0050	88	.0043	778	.0356	3159	.1487
	Chop (1)	0	.0000	48	.0008	582	.0097	987	.0165
Jul 8	Shear (2)	185	.0037	56	.0010	557	.0107	2881	.0558
Oct 9	Shear (3)	126	.0069	42	.0025	414	.0226	1670	.1172
Oct 14	Shear (3)	77	.0373	14	.0065	583	.2763	1547	.7393
	Chop (3)	9	.0028	10	.0036	613	.1903	867	.2745
	Control (3)	9	.0018	20	.0042	647	.1091	1070	.1830
Oct 18	Shear (2)	8	.0001	22	.0002	361	.0038	1001	.0104
Nov 1	Shear (3)	22	.0007	17	.0004	510	.0157	1282	.0400
	Chop (2)	<5	.0001	21	.0005	614	.0208	983	.0334
Nov 8	Shear (3)	27	.0004	24	.0003	353	.0049	814	.0115
	Chop (1)	5	.0001	31	.0009	687	.0199	867	.0251

Table 36. Continued.

Storm Date	Treatment	Nitrate ppb	Nitrate lb/ac	Ammonia ppb	Ammonia lb/ac	Total Nitrogen filtered ppb	Total Nitrogen filtered lb/ac	Total Nitrogen unfiltered ppb	Total Nitrogen unfiltered lb/ac
Annual									
	Shear	205a+&	.267a	76a	.101a	787a	.861a	2155a	2.794a
	Chop	96b	.071b	56a	.044b	676a	.598a	999b	0.762b
	Control	10c	.003b	48a	.012b	646a	.156b	996b	0.237b

* The number of samples in each mean.
\# No sample.
\+ Mean concentration is discharge weighted by stormflow.
& Means for each treatment followed by the same letter are not significantly different ($P < .05$) according to Duncan's multiple range test.

for the sheared, chopped and undisturbed watersheds was 2.79, 0.76 and 0.24 lb/acre, respectivley. The annual loss of total nitrogen on the sheared watersheds is greater than three times the loss on chopped watersheds and nearly 12 times the loss from control watersheds.

Post-treatment - 1982

The second year following treatment continued to show a decrease in the concentration of nitrogen. Mean discharge weighted nitrate concentrations were reduced to 65, 26 and 13 ppb for the sheared, chopped and undisturbed watersheds, respectively (Table 37). Nitrate concentration on the sheared sites were still significantly higher than chopped or undisturbed sites. Nitrate concentrations were highest for all treatments during the April 28 runoff event. The highest concentration of the year (204 ppb) was recorded on WS 6 (control), during this storm. Lower concentrations and volumes of runoff helped to reduce nitrate yield during this second year. The mean total nitrate export was 0.029, 0.005 and 0.002 lb/acre for the sheared, chopped and undisturbed watersheds, respectively. The total export on the sheared treatments was significantly greater than on the other treatments.

Ammonia concentrations for 1982 showed a slight increase on sheared sites, with a decrease on chopped and control sites, from 1981 levels. Mean discharge weighted concentrations were not significantly different between treatments: sheared (98 ppb), chopped (30 ppb) and control (19 ppb) (Table 37). Ammonia concentrations ranged from 0.0 ppb on the chopped watersheds during the April 28 storm event to 121 ppb on the control watersheds for the December 26 storm. The annual export for ammonia was reduced below 1981 losses on sheared (0.013 lb/acre), chopped (0.005 lb/acre) and control (0.005 lb/acre) sites. Differences between treatments for annual ammonia export were not significant.

Total nitrogen concentrations and export for 1982 were lower for all treatments than the levels recorded in 1981. Both filtered and unfiltered nitrogen concentrations showed no significant difference between treatments (Table 37). The mean discharge weighted total nitrogen (unfiltered) concentration was 1,050, 831 and 693 ppb for the sheared chopped and undisturbed watersheds, respectively. The reduction in unfiltered total nitrogen on the sheared treatments, is attributable to the decrease in organic sediments. The highest concentration (1,382 ppb) of total unfiltered nitrogen was found on WS 2

Table 37. Mean event and annual nitrogen concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Nitrate ppb	Nitrate lb/ac	Ammonia ppb	Ammonia lb/ac	Total Nitrogen filtered ppb	Total Nitrogen filtered lb/ac	Total Nitrogen unfiltered ppb	Total Nitrogen unfiltered lb/ac
				Per event					
Jan 30	Shear (2)*	90	.0004	34	.0002	1083	.0051	1467	.0070
Apr 19	Shear (3)	59	.0080	33	.0037	848	.1050	1044	.1343
	Chop (3)	34	.0016	48	.0045	826	.0620	907	.0650
	Control (2)	24	.0013	112	.0034	966	.0413	1161	.0523
Apr 21	Shear (3)	26	.0005	45	.0008	454	.0105	720	.0148
Apr 24	Shear (2)	30	.0003	78	.0017	449	.0080	645	.0128
Apr 28	Shear (3)	174	.0080	58	.0022	548	.0232	1035	.0464
	Chop (2)	123	.0018	0	.0000	999	.0148	890	.0137
	Control (1)	204	.0027	20	.0003	639	.0084	910	.0119
May 13	Shear (3)	13	.0007	20	.0014	1055	.0500	1147	.0517
	Chop (2)	13	.0006	8	.0002	980	.0329	1236	.0420
	Control (1)	25	.0009	<3	.0001	632	.0224	993	.0352
May 17	Shear (1)	22	.0005	27	.0006	1200	.0271	1382	.0313
Nov 2	Shear (1)	172	.0012	53	.0004	481	.0034	623	.0044
Nov 26	Shear (3)	154	.0099	48	.0029	326	.0195	607	.0358
	Chop (3)	38	.0008	40	.0011	304	.0075	696	.0201
	Control (1)	9	.0004	20	.0008	212	.0088	493	.0204
Dec 11	Shear (1)	23	.0001	28	.0002	20	.0001	380	.0023
Dec 14	Shear (2)	17	.0003	22	.0004	110	.0026	510	.0093
Dec 23	Shear (2)	20	.0002	17	.0001	448	.0038	600	.0049
	Chop (1)	34	.0005	51	.0008	450	.0067	474	.0071
Dec 24	Shear (3)	24	.0013	12	.0005	368	.0186	513	.0262
	Chop (1)	<3	.0001	8	.0005	257	.0158	661	.0407
	Control (1)	11	.0002	6	.0001	469	.0083	558	.0098
Dec 26	Shear (3)	8	.0003	<3	.0001	408	.0184	506	.0205
	Chop (2)	10	.0004	5	.0002	152	.0083	405	.0188
	Control (3)	<3	<.0001	121	.0018	113	.0017	871	.0115
				Annual					
	Shear	65a#+	.029a	98a	.013a	617a	.266a	1050a	.360a
	Chop	26b	.005b	30a	.005a	490a	.105b	831a	.143b
	Control	13b	.002b	19a	.005a	418a	.045b	693a	.072b

* The number of samples in each mean.
\# Mean concentration is discharge weighted by stormflow.
\+ Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

(sheared) following a small storm on May 17. The larger volume of runoff on the sheared sites produced a significantly greater total nitrogen (unfiltered) loss on the sheared sites (0.360 lb/acre), than on chopped (0.143 lb/acre) or control sites (0.072 lb/acre). Although the total nitrogen loss for all treatments dropped below 1981 losses, chopped watersheds recorded only 40% of the loss found on the sheared sites and control watersheds only 20% of the sheared loss.

A decrease in nitrogen concentrations and losses during 1982 is the result of the same factors discussed under Sediment. The stabilization of the surface soil along with revegetation and litter accumulation, has reduced runoff and the concentration of sediments and nutrients it carries. Nitrate and ammonia concentrations can be expected to decrease as plant uptake increases with revegetation. Organic nitrogen losses should also decline to pre-treatment levels, as runoff volume decreases and sediment concentrations are reduced. These trends are likely to continue as rehabilitation on the treated sites progresses.

Nutrients-Phosphorus

All samples were analyzed unfiltered for ortho and total phosphorus concentrations.

Pre-treatment - 1980

The discharge weighted concentration of ortho-phosphate, for 1980, was less than 5 ppb, which is the detection limit for our equipment (Table 38). Apparently ortho-P is not readily available in the undisturbed forest for transport. The total loss for ortho-P during 1980 was an insignificant 0.0004 lb/acre.

Total phosphorus concentrations and losses were also very low during this pre-treatment period. Total phosphorus concentrations ranged from 31 ppb on WS 9 during the February 8-9 storm event to 159 ppb for WS 4 on May 15 (Table 38). The mean discharge weighted concentration for total phosphorus was 80 ppb. A mean total loss of 0.025 lb/acre was recorded during 1980.

Post-treatment - 1981

Ortho-phosphate concentrations remained low even following treatment. The maximum concentrations of ortho-P for the chopped and control watersheds occurred on the March 3 runoff event, when the chopped watersheds recorded 89 ppb and the control sites 29 ppb (Table 39). It was during the March 29 event the sheared watersheds recorded the maximum ortho-P concentration of 117 ppb. The sheared sites had a significantly greater (27 ppb) discharge weighted ortho-P concentration than the chopped (15 ppb) or undisturbed sites (11 ppb). Annual ortho-P loss, although significantly higher on the sheared sites (0.035 lb/acre), than the chopped (0.013 lb/acre) or undisturbed (0.003 lb/acre) sites, was very low.

Table 38. Mean event and annual phosphorus concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Ortho-P ppb	Ortho-P lb/ac	Total P ppb	Total P lb/ac
		Per event			
Jan 21	1	5	.0001	50	.0014
	2	5	.0005	50	.0049
	3	5	.0001	50	.0013
	4	5	.0002	50	.0014
	5	5	.0002	50	.0020
	6	5	.0005	50	.0046
	7	5	.0003	50	.0028
	8	5	.0001	40	.0008
	9	5	.0006	40	.0050
Feb 8-9	2	17	.0006	47	.0018
	6	5	.0004	33	.0013
	9	5	.0005	31	.0015
Mar 27	9	0	.0000	57	.0001
Apr 13	1	0	.0000	40	.0003
	2	0	.0000	67	.0024
	6	0	.0000	53	.0011
	9	0	.0000	47	.0010
May 13	2	0	.0000	127	.0013
May 15	1	0	.0000	103	.0175
	2	0	.0000	57	.0159
	3	0	.0000	73	.0108
	4	0	.0000	159	.0285
	5	0	.0000	57	.0154
	6	0	.0000	116	.0352
	7	0	.0000	73	.0157
	8	0	.0000	75	.0155
	9	0	.0000	84	.0272
		Annual			
		<5*	.0004	80	.0245

* Mean concentration is discharge weighted by stormflow.

Total phosphorus concentrations increased significantly on the sheared treatments above the levels on chopped and control treatments. Mean discharge weighted concentrations were 221, 85 and 54 ppb for the

Table 39. Mean event and annual phoshorus concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Ortho-P ppb	Ortho-P lb/ac	Total P ppb	Total P lb/ac
		Per event			
Feb 10	Shear (2)*	73	.0017	231	.0047
Mar 1	Shear (1)	67	.0005	241	.0016
Mar 3	Shear (3)	104	.0112	-#	-
	Chop (3)	89	.0049	-	-
	Control (1)	29	.0009	-	-
Mar 29	Shear (2)	117	.0005	29	.0001
May 9	Shear (3)	26	.0030	203	.0172
	Chop (3)	20	.0021	70	.0065
	Control (1)	11	.0001	-	-
May 16	Shear (3)	47	.0009	633	.0119
	Chop (1)	3	<.0001	38	.0005
May 24	Shear (2)	98	.0003	290	.0006
May 30	Shear (3)	35	.0038	372	.0418
	Chop (3)	13	.0009	71	.0025
	Control (1)	5	.0001	53	.0012
Jun 3	Shear (3)	6	.0003	204	.0095
	Chop (3)	5	.0002	35	.0012
	Control (1)	3	<.0001	26	.0003
Jun 4	Shear (3)	22	.0035	322	.0561
	Chop (3)	6	.0008	-	-
	Control (3)	6	.0002	-	-
Jun 10	Shear (2)	20	<.0001	170	.0005
Jun 12	Shear (3)	10	.0004	336	.0112
	Chop (3)	0	.0000	38	.0010
Jun 23	Shear (2)	23	.0001	227	.0010
Jul 7	Shear (3)	28	.0015	370	.0192
	Chop (1)	5	.0001	41	.0007
Jul 8	Shear (2)	27	.0005	370	.0072
Oct 9	Shear (3)	14	.0009	217	.0167
Oct 14	Shear (3)	13	.0065	210	.1053
	Chop (3)	11	.0038	75	.0224
	Control (3)	12	.0025	106	.0132
Oct 18	Shear (1)	9	.0001	84	.0009
Nov 1	Shear (3)	16	.0005	81	.0025
	Chop (2)	9	.0003	51	.0017
Nov 8	Shear (3)	7	.0001	44	.0007
	Chop (1)	8	.0002	35	.0010

Table 39. Continued.

Storm Date	Treatment	Ortho-P ppb	Ortho-P lb/ac	Total-P ppb	Total-P lb/ac
		Annual			
	Shear	27 a+&	.0348 a	221 a	.2967 a
	Chop	15 b	.0130 b	85 b	.0346 b
	Control	11 b	.0030 b	54 b	.0137 b

* The number of samples in each mean.
\# No sample.
\+ Mean concentration is discharge weighted by stormflow.
& Means for each treatment followed by the same letter are not significantly different($P < .05$) according to Duncan's multiple range test.

sheared, chopped and undisturbed watersheds, respectively (Table 39). The higher phosphorus concentration on the sheared sites can be explained by the higher concentration of suspended sediments for this treatment, as phosphorus is generally associated with the sediment. This is evident by comparing sediment concentrations (Table 33) with total phosphorus concentrations (Table 39). Whenever sediment concentrations are highest, phosphorus concentrations are also highest and vice versa. This positive correlation makes suspended sediment concentrations a good indicator of total P concentrations. The total phosphorus loss for 1981 was significantly higher on the sheared watersheds (0.297 lb/acre), than chopped (0.035 lb/acre) or control watersheds (0.014 lb/acre). Although relatively small, the loss on the sheared watersheds is over 20 times greater than the undisturbed export of phosphorus.

Post-treatment - 1982

As did sediment and nitrogen concentrations, phosphorus concentrations dropped substantially during the second year following treatment. The concentration of ortho-phosphate for 1982 was 25, 6 and 6 ppb for the sheared, chopped and undisturbed watersheds, respectively (Table 40). There was no significant difference between treatments. The range of concentrations was much lower during 1982, with the high occurring on the control watersheds (39 ppb) during the December 26 runoff event. Annual ortho-P export was not significantly different between treatments: sheared (0.0028 lb/acre), chopped (0.0011 lb/acre) and control (0.0008 lb/acre).

Total phosphorus concentrations, particularly on the sheared sites, dropped below 1981 levels. The reduction in total phosphorus concentrations on the sheared sites (76 ppb) follows the reduction in suspended sediment concentrations. There was no significant difference between treatments in total P concentrations. The 1982 total phosphorus export on the sheared watersheds was reduced over 90% below the 1981 loss. The loss of 0.026 lb/acre from the sheared sites was still significantly greater than the 0.008 lb/acre loss from the chopped sites and the 0.004 lb/acre loss from the control sites. The loss from the sheared sites is similar to the export recorded during the 1980 pre-treatment year, of 0.025 lb/acre.

Phosphorus concentrations and export for both ortho-P and total P appear to be approaching pre-treatment levels in this second year followng treatment. As site stabilization continues and erosion decreases, phosphorus losses can be expected to continue decreasing.

Table 40. Mean event and annual phosphorus concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Ortho-P ppb	Ortho-P lb/ac	Total P ppb	Total P lb/ac
		Per event			
Jan 30	Shear (2)*	15	.0001	96	.0005
Apr 19	Shear (3)	7	.0010	64	.0089
	Chop (3)	5	.0003	48	.0030
	Control (2)	8	.0004	67	.0033
Apr 21	Shear (3)	9	.0002	41	.0006
Apr 24	Shear (2)	7	.0002	45	.0010
Apr 28	Shear (3)	6	.0002	93	.0038
	Chop (2)	4	<.0001	58	.0009
	Control (1)	6	.0001	72	.0009
May 13	Shear (3)	4	.0002	53	.0024
	Chop (2)	4	.0002	28	.0011
	Control (1)	4	.0001	33	.0012
May 17	Shear (1)	36	.0008	75	.0017
Nov 2	Shear (1)	<3	<.0001	103	.0007
Nov 26	Shear (3)	4	.0002	67	.0037
	Chop (3)	14	.0003	75	.0019
	Control (1)	3	.0001	20	.0008
Dec 11	Shear (1)	3	<.0001	40	.0002
Dec 14	Shear (2)	3	<.0001	26	.0004
Dec 23	Shear (2)	5	<.0001	63	.0006
	Chop (1)	12	.0002	59	.0009
Dec 24	Shear (3)	3	.0002	56	.0031
	Chop (1)	4	.0002	32	.0020
	Control (1)	3	<.0001	36	.0006
Dec 26	Shear (3)	5	.0002	18	.0008
	Chop (2)	4	.0002	19	.0009
	Control (3)	39	.0004	80	.0009
		Annual			
	Shear	25 a#+	.0028 a	76 a	.0262 a
	Chop	6 a	.0011 a	58 a	.0081 b
	Control	6 a	.0008 a	40 a	.0043 b

* The number of samples in each mean.
# Mean concentration is discharge weighted by stormflow.
+ Means for each treatment followed by the same letter are not significantly different ($P < .05$) according to Duncan's multiple range test.

Nutrients-Calcium, Magnesium, Potassium and Sodium

Pre-treatment - 1980

Of the nutrients analyzed, calcium and potassium showed the highest concentration during the pre-treatment year. The mean discharge weighted Ca and K concentration was 2.3 and 2.4 ppm, respectively (Table 41). The supply of these elements is usually high in forest soils. Export of both calcium and potassium was 0.71 lb/acre for the year. The magnesium and sodium discharge weighted concentrations were both 0.8 ppm. Magnesium concentrations were consistent between watersheds and storms, and ranged from 0.4 to 1.7 ppm. Magnesium loss during 1980 was 0.26 lb/acre, while sodium loss was 0.31 lb/acre.

Post-treatment - 1981

The first year following treatment revealed several differences in element concentrations. Potassium concentrations were again the highest of the four elements measured. The chopped watersheds had the highest concentration with 5.7 ppm, followed by the sheared (5.0 ppm) and the control watersheds (3.0 ppm) (Table 42). There was no significant difference in concentration between the sheared and chopped treatments, however, the concentration on the chopped sites was significantly greater than on the control sites. Annual export of K showed significant differences between all three treatments, because of the differences in volume of runoff. three treatments. On the sheared watersheds the annual export of K was 6.41 lb/acre, compared to 4.07

Table 41. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Calcium ppm	Calcium lb/ac	Magnesium ppm	Magnesium lb/ac	Potassium ppm	Potassium lb/ac	Sodium ppm	Sodium lb/ac
				Per event					
Jan 21	1	3.0	.084	1.0	.028	1.6	.045	-*	-
	2	5.0	.497	1.4	.139	10.4	1.035	-	-
	3	4.0	.111	1.4	.039	3.0	.083	-	-
	4	3.0	.091	0.7	.021	2.6	.079	-	-
	5	3.0	.123	0.7	.027	0.5	.021	-	-
	6	1.3	.117	0.4	.033	0.2	.023	-	-
	7	4.0	.233	1.4	.082	2.4	.140	-	-
	8	3.0	.061	1.0	.020	1.6	.033	-	-
	9	4.0	.512	1.7	.217	2.4	.307	-	-
Feb 8-9	2	2.5	.101	0.5	.020	0.4	.016	-	-
	6	1.8	.073	0.6	.023	0.5	.019	-	-
	9	3.8	.198	1.5	.077	1.4	.074	-	-
Apr 13	1	3.0	.023	0.9	.007	1.0	.007	1.1	.008
	2	2.9	.107	0.9	.033	2.0	.073	1.0	.034
	6	2.1	.045	1.0	.021	1.6	.034	1.9	.042
	9	1.3	.031	0.6	.013	1.3	.031	-	-
May 13	2	4.6	.046	0.8	.008	1.7	.017	3.0	.030
May 15	1	2.3	.392	0.4	.069	0.4	.072	0.9	.158
	2	1.6	.457	0.9	.262	0.4	.123	2.0	.554
	3	2.3	.348	0.6	.094	7.6	1.123	-	-
	4	2.1	.387	0.7	.131	2.2	.390	1.1	.207
	5	1.9	.521	0.8	.218	2.3	.631	1.4	.383
	6	0.6	.174	0.5	.140	1.0	.290	0.3	.082
	7	2.1	.467	0.9	.193	2.2	.471	1.1	.237
	8	2.3	.477	0.8	.171	2.3	.481	1.1	.225
	9	2.1	.688	0.8	.256	2.4	.788	1.5	.505
				Annual					
		2.3#	.707	0.8	.260	2.4	.712	0.8	.308

* No sample.
\# Mean concentration is discharge weighted by stormflow.

lb/acre on the chopped and 0.66 lb/acre on the control. Roughly a 10 times greater export of K from the sheared watersheds than the controls.

Table 42. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Calcium ppm	Calcium lb/ac	Magnesium ppm	Magnesium lb/ac	Potassium ppm	Potassium lb/ac	Sodium ppm	Sodium lb/ac
				Per event					
Feb 10	Shear (2)*	0.9	.018	2.5	.051	6.8	.135	5.1	.090
Mar 1	Shear (1)	0.8	.006	2.5	.017	4.7	.032	2.5	.017
Mar 3	Shear (3)	1.5	.175	1.6	.178	6.0	.696	2.5	.247
	Chop (3)	4.4	.208	1.1	.054	6.8	.320	2.1	.101
	Control (1)	1.4	.045	1.0	.030	2.2	.069	2.1	.066
Mar 29	Shear (2)	0.7	.003	2.7	.012	5.8	.026	3.7	.017
May 9	Shear (3)	0.8	.087	2.5	.287	6.7	.751	1.3	.143
	Chop (3)	4.1	.259	2.0	.188	5.6	.629	2.4	.140
	Control (1)	1.5	.017	1.5	.018	1.6	.019	1.4	.016
May 16	Shear (3)	0.3	.007	1.8	.036	5.0	.096	1.1	.021
	Chop (1)	2.1	.025	2.4	.029	5.0	.061	3.1	.038
May 24	Shear (2)	1.0	.003	2.8	.008	6.4	.017	2.3	.006
May 30	Shear (3)	0.9	.091	2.3	.240	5.4	.575	2.9	.315
	Chop (3)	2.2	.127	1.4	.078	3.6	.254	0.9	.065
	Control (1)	1.4	.032	1.4	.031	1.8	.040	1.0	.022
Jun 3	Shear (3)	1.3	.063	2.4	.110	7.8	.366	2.0	.096
	Chop (3)	1.8	.065	1.5	.053	3.7	.142	1.8	.068
	Control (1)	1.3	.014	1.5	.016	1.7	.018	1.5	.017
Jun 4	Shear (3)	0.8	.124	1.5	.259	5.1	.837	0.8	.156
	Chop (3)	2.9	.322	1.5	.181	6.3	.754	2.1	.235
	Control (3)	2.1	.043	1.3	.031	3.3	.075	1.6	.031
Jun 10	Shear (2)	0.9	.002	1.5	.004	6.4	.018	2.7	.006
Jun 12	Shear (3)	0.6	.022	1.4	.048	6.1	.218	0.9	.031
	Chop (3)	2.1	.054	1.5	.041	4.8	.144	1.8	.044
Jun 23	Shear (2)	0.5	.003	1.6	.008	4.9	.022	3.2	.015
Jul 7	Shear (3)	0.8	.039	1.1	.054	3.5	.180	0.9	.044
	Chop (1)	1.7	.029	1.0	.016	2.8	.047	1.6	.026
Jul 8	Shear (2)	0.8	.015	1.4	.027	4.0	.077	3.0	.052
Oct 9	Shear (3)	0.4	.019	0.8	.053	3.4	.194	1.2	.066
Oct 14	Shear (3)	0.8	.357	1.0	.484	4.3	2.072	1.2	.537
	Chop (3)	1.4	.462	1.0	.327	6.0	1.861	1.3	.393
	Control (3)	1.8	.279	1.1	.179	3.0	.481	0.9	.131
Oct 18	Shear (2)	0.8	.008	0.9	.009	4.1	.042	2.4	.025
Nov 1	Shear (3)	1.4	.043	1.0	.034	4.0	.129	1.3	.043
	Chop (2)	1.6	.050	1.0	.034	3.8	.130	1.7	.061
Nov 8	Shear (3)	1.0	.014	0.9	.012	3.9	.054	1.7	.020
	Chop (1)	1.2	.035	1.2	.036	5.0	.145	2.8	.082

Table 42. Continued.

Storm Date	Treatment	Calcium ppm	Calcium lb/ac	Magnesium ppm	Magnesium lb/ac	Potassium ppm	Potassium lb/ac	Sodium ppm	Sodium lb/ac
				Annual					
	Shear	0.9b#+	1.08ab	1.5a	1.88a	5.0ab	6.41a	1.5a	1.87a
	Chop	2.2a	1.56a	1.3ab	0.97b	5.7a	4.07b	1.7a	1.14a
	Control	1.8a	0.38b	1.1b	0.26c	3.0b	0.66c	1.0a	0.22b

* The number of samples in each mean.
\# Mean concentration is discharge weighted by stormflow.
\+ Means for each treatment followed by the same letter are not significantly different ($P < .05$) according to Duncan's multiple range test.

Chopped watersheds also had the highest concentration of calcium during 1981. Discharge weighted concentrations were 0.9, 2.2 and 1.8 ppm for the sheared, chopped and undisturbed watersheds, respectively (Table 42). The sheared treatment had the lowest concentration of Ca, which was significantly lower than the other two treatments. Apparently soluble calcium is available in limited quantities and the low concentration on the sheared watersheds reflects dilution. Higher concentrations of both Ca and K on the chopped watersheds may be the consequence of the broadcast burn used following roller chopping. Because of the higher Ca concentrations on the chopped sites, export was significatly greater than on the control sites. Annual Ca export ranged from 0.38 lb/acre on the control watersheds, to 1.08 lb/acre on the sheared and 1.56 lb/acre on the chopped watersheds.

The discharge weighted concentration of magnesium for the sheared, chopped and control watersheds was 1.5, 1.3 and 1.1 ppm, respectively

(Table 42). Although concentrations were uniformly low, runoff from sheared sites had a significantly higher concentration than control sites. Magnesium export, as well as the other elements, was greatest during the large runoff event on October 14. During this storm 26, 34 and 68% of the annual Mg was lost from the sheared, chopped and control treatments, respectively. Differences between treatments were not significant.

The concentration of sodium was highest on the chopped watersheds (1.7 ppm), followed by the sheared (1.5 ppm) and the control watersheds (1.0 ppm) (Table 42). Sodium concentrations were not significantly different between treatments. Total sodium loss during 1981 was 1.87 , 1.14 and 0.22 lb/acre, for the sheared, chopped and undisturbed watersheds, respectively. The loss on the sheared and chopped sites was significantly greater than on the control sites.

Post-treatment - 1982

During the second year following site preparation, differences in elemental concentrations due to treatment were diminished. The discharge weighted calcium concentration on the sheared watersheds averaged 3.1 ppm compared to 1.8 ppm on both the chopped and the undisturbed sites (Table 43). Because of the high variability in concentration on the sheared sites there were no significant differences between treatments. Calcium concentrations on the sheared watersheds were over 3 times greater than 1981 levels, with a slight decrease on chopped sites and no change on the control sites. Calcium export from the sheared sites (1.29 lb/acre) was significantly greater than the chopped (0.34 lb/acre) or undisturbed watersheds (0.14 lb/acre).

The concentration of magnesium in 1982 was very similar to 1981 figures for all treatments. The Mg concentration on the sheared sites was 1.3 ppm, which did not differ significatly from the 1.2 ppm found on the chopped and control sites (Table 43). The April 19 runoff event accounted for at least a third of the Mg loss during the year for the 3 treatments. The annual magnesium export was 0.50, 0.26 and 0.12 lb/acre for the sheared, chopped and undisturbed watersheds, respectively. The sheared site with twice the Mg export of the chopped sites, and over 4 times the export on the controls, was significantly higher.

Potassium concentration for 1982 dropped on both the sheared and chopped sites with a small elevation on the control sites. The range in K concentrations for the year, varied from 2.3 ppm on WS 6 (control) during the May 13 event to a 5.4 ppm mean on two of the chopped sites during the April 28 event (Table 43). Annual discharge weighted concentrations were not significantly different between treatments. Potassium concentrations were 3.3, 3.2 and 3.4 ppm for the sheared, chopped and control watersheds, respectively. Potassium export for the year was significantly greater on the sheared (1.54 lb/acre) than the control (0.27 lb/acre), but not different from the chopped (0.67 lb/acre).

Table 43. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Calcium ppm	Calcium lb/ac	Magnesium ppm	Magnesium lb/ac	Potassium ppm	Potassium lb/ac	Sodium ppm	Sodium lb/ac
				Per event					
Jan 30	Shear (2)*	5.4	.026	1.6	.007	3.9	.018	3.6	.017
Apr 19	Shear (3)	4.1	.393	1.1	.149	3.4	.526	1.3	.213
	Chop (3)	2.4	.130	1.5	.090	3.8	.229	1.9	.136
	Control (2)	1.8	.087	1.5	.071	3.5	.159	1.4	.061
Apr 21	Shear (3)	3.8	.121	1.3	.025	3.6	.105	2.9	.088
Apr 24	Shear (1)	9.2	.251	1.3	.021	4.9	.133	7.3	.197
Apr 28	Shear (3)	5.6	.212	1.3	.042	4.6	.186	3.9	.145
	Chop (2)	1.9	.027	1.4	.022	5.4	.084	2.4	.041
	Control (1)	1.5	.019	1.3	.017	4.1	.053	1.1	.015
May 13	Shear (3)	6.7	.325	1.2	.053	4.7	.219	5.3	.221
	Chop (3)	2.1	.077	1.2	.050	2.7	.135	1.6	.084
	Control (1)	1.5	.051	1.3	.047	2.3	.081	1.2	.043
May 17	Shear (1)	-#	-	1.0	.023	4.5	.101	6.3	.141
Nov 2	Shear (1)	1.3	.009	1.1	.007	4.4	.031	2.2	.015
Nov 26	Shear (3)	1.4	.081	1.2	.072	3.9	.253	3.3	.170
	Chop (3)	1.3	.028	1.2	.034	4.1	.117	4.8	.128
	Control(1)	1.2	.050	1.3	.052	3.5	.146	2.0	.081
Dec 11	Shear (1)	1.5	.009	1.3	.008	3.3	.020	2.2	.013
Dec 14	Shear (2)	1.3	.021	1.1	.018	3.1	.052	2.3	.035
Dec 23	Shear (2)	1.5	.013	1.1	.010	3.2	.030	2.3	.020
	Chop (1)	1.6	.024	1.5	.022	4.3	.064	5.3	.079
Dec 24	Shear (3)	1.7	.082	1.2	.064	4.0	.214	2.3	.110
	Chop (1)	1.7	.105	1.4	.089	3.4	.209	3.4	.210
	Control (1)	1.8	.031	1.4	.024	2.7	.048	5.0	.089
Dec 26	Shear (3)	1.3	.056	1.0	.043	3.8	.168	1.9	.075
	Chop (2)	1.5	.066	1.1	.051	2.8	.124	1.8	.082
	Control (3)	1.7	.026	1.2	.025	3.3	.051	2.1	.039
				Annual					
	Shear	3.1a+&	1.29a	1.3a	.50a	3.3a	1.54a	2.3a	1.04a
	Chop	1.8a	.34b	1.2a	.26b	3.2a	.67ab	2.4a	.50ab
	Control	1.8a	.14b	1.2a	.12b	3.4a	.27b	1.9a	.16b

* The number of samples in each mean.

\# No sample.

\+ Mean concentration is discharge weighted by stormflow.

& Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

Sodium concentrations were elevated above 1981 levels on all three treatments, although there was no significant difference between the treatments. Annual discharge weighted concentrations ranged from 1.9 ppm on the control sites, to 2.4 ppm on the chopped sites (Table 43). The mean total export of Na was 1.04, 0.50 and 0.16 lb/acre, on the sheared, chopped and control watersheds, respectively. There was no significant difference between sheared or chopped sites or between chopped and control sites.

pH, Specific Conductivity and Turbidity

Pre-treatment-1980

During 1980, pH, specific conductivity and turbidity were taken fo several of the storms. The pH was measured only on the May 15 storm event and averaged 5.4 for the 9 watersheds (Table 44). Specific conductivity measurements were taken on two storms with a mean of 36 umhos/cm. Turbidity for the April 13 runoff event was 36 NTU's and following the largest event on May 15, it was 66 NTU's.

Post-treatment-1981

The first year following site preparation revealed little variation between treatments for pH values. Mean pH values for the year ranged from 5.9 on the controls to 6.1 on the chopped sites (Table 45). There was no significant difference in pH between the three treat-

Table 44. Mean pH, specific conductivity, and turbidity prior to treatment, 1980.

Storm Date	pH	Specific Conductivity umhos/cm	Turbidity NTU
Jan 22 (9)*	-#	27	-
Feb 8-9 (9)	-	24	-
Apr 13 (9)	-	-	36
May 15 (9)	5.4	-	66

* The number of samples in each mean.
\# No sample.

ments. A slight elevation in pH on the two site prepared areas may have resulted from a higher cation concentration (Table 42). Specific conductivity for the year ranged from 5 umhos/cm on the chopped watersheds during the March 3 runoff event to 75 umhos/cm for the sheared watersheds on Febuary 10. There was no significant difference between the mean annual treatment values of 36, 37 and 33 umhos/cm for the sheared, chopped and undisturbed watersheds, respectively. Mean annual turbidity values indicate no significant difference between sheared (153 NTU's) and control (140 NTU's) watersheds, which were both greater than chopped (59 NTU's) values (Table 45). Maximum turbidity values for the three treatments were reached during the runoff event on October 14. Water samples from the chopped sites had the highest mean turbidity during this storm, with a measurement of 360 NTU's. Mean annual turbidity values for the control watersheds are somewhat misleading. Because of the few runoff events, the October 14 stormflow is the major component of annual turbidity on the control watersheds. In the five other storms, where runoff occurred on all three treatments, the sheared watersheds had the highest turbidity followed by the control and the chopped watersheds.

Post-treatment-1982

During 1982, mean annual pH values for all treatments dropped several tenths below 1981 levels. The pH values for the sheared, chopped and undisturbed watersheds were 5.8, 5.6 and 5.4, respectively (Table 46). No significant difference was found between the treatments. Specific conductivity on the control sites increased slightly above the previous years mean, while sheared and chopped watersheds increased substantially. The specific conductivity on the sheared sites (95 umhos/cm) was not significantly different from the chopped (61 umhos/cm) or the control (38 umhos/cm) sites (Table 46). Turbidity decreased sharply the second year after treatment. As suspended sediment concentrations dropped, so did the stormflow turbidity. A maximum turbidity of 235 NTU's was reached on the sheared treatments during the May 13 runoff event. The mean annual turbidity was 60 NTU's on the sheared sites, 16 NTU's on the chopped and 61 NTU's on the undisturbed sites. The chopped sites appear to be very effective in filtering stormflow and reducing turbidity.

Table 45. Mean pH, specific conductivity and turbidity the first year following treatment, 1981.

Storm Date	Treatment	pH	Specific Conductivity umhos/cc	Turbidity NTU
Feb 10	Shear (2)	6.8	75	233
Mar 3	Shear (3)	5.4	11	213
	Chop (3)	5.2	5	33
	Control (1)	4.9	9	36
May 9	Shear (3)	6.7	49	186
	Chop (3)	7.3	53	21
	Control (1)	6.7	34	62
May 16	Shear (3)	5.8	30	220
	Chop (1)	6.6	56	14
May 24	Shear (2)	-*	-	84
May 30	Shear (3)	6.6	43	130
	Chop (3)	6.0	36	17
	Control (1)	5.7	30	27
Jun 3	Shear (3)	6.4	46	130
	Chop (3)	6.5	40	10
	Control (1)	6.9	35	35
Jun 4	Shear (3)	6.1	33	150
	Chop (3)	6.4	43	12
	Control (3)	6.3	35	22
Jun 10	Shear (2)	6.9	52	143
Jun 12	Shear (3)	6.0	41	178
	Chop (3)	6.5	45	15
Jun 23	Shear (2)	6.4	37	170
Jul 7	Shear (3)	5.9	25	140
	Chop (1)	6.7	40	19
Jul 8	Shear (2)	6.1	28	175
Oct 9	Shear (3)	4.8	26	97
Oct 14	Shear (3)	5.1	31	341
	Chop (3)	5.1	39	360
	Control (3)	5.1	34	322
Oct 18	Shear (2)	5.5	33	74
Oct 30	Shear (3)	5.7	33	72
	Chop (2)	5.7	40	9
Nov 8	Shear (3)	5.8	39	52
	Chop (1)	6.0	48	12
Mean	Shear	6.0 a#	36 a	153 a
	Chop	6.1 a	37 a	59 b
	Control	5.9 a	33 a	140 a

* No sample.

\# Means for each treatment followed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

Table 46. Mean pH, specific conductivity and turbidity the second year following treatment, 1982.

Storm Date	Treatment	pH	Specific Conductivity umhos/cc	Turbidity NTU
Jan 31	Shear (2)	4.8	75	170
Apr 19	Shear (1)	5.3	30	86
	Chop (1)	5.3	38	66
	Control (1)	5.5	47	17
Apr 20	Shear (3)	5.7	71	57
	Chop (3)	5.4	47	21
	Control (2)	5.7	48	48
Apr 21	Shear (3)	6.0	117	80
Apr 24	Shear (2)	6.7	204	99
Apr 29	Shear (3)	6.2	198	96
	Chop (2)	5.6	51	25
	Control (1)	5.4	34	67
May 13	Shear (3)	6.3	94	66
	Chop (3)	6.5	94	18
	Control (1)	6.0	47	42
May 17	Shear (1)	6.7	-*	235
Nov 2	Shear (1)	5.7	125	100
Nov 26	Shear (3)	5.7	43	34
	Chop (3)	5.6	54	16
	Control (1)	5.7	51	45
Dec 11	Shear (1)	5.7	42	43
Dec 14	Shear (2)	5.8	40	24
Dec 23	Shear (2)	5.2	43	56
	Chop (1)	5.5	78	8
Dec 24	Shear (3)	5.4	49	24
	Chop (1)	4.9	58	8
	Control (1)	5.4	55	31
Dec 26	Shear (3)	4.4	35	7
	Chop (2)	4.9	34	2
	Control (3)	5.0	32	47
Mean - 1982	Shear	5.8 a#	95 a	60 a
	Chop	5.6 a	61 a	16 a
	Control	5.4 a	38 a	61 a

* No sample.

\# Means for each treatment folloed by the same letter are not significantly different (P < .05) according to Duncan's multiple range test.

SUMMARY AND RECOMMENDATIONS

The first year following site preparation revealed significant differences in runoff volumes and sediment and nutrient losses between sheared and chopped watersheds. The greater stormflow and peak discharge from the sheared watersheds, was the result of several factors. The primary cause being a loss of protective cover and the exposure of the mineral soil. Infiltration rates were reduced due to the effects of rain drop impact and the compaction of the surface soil that resulted from the use of heavy equipment in shearing and windrowing. In several locations the shearing operation and exposed the clay textured B horizon. These areas soon became erosion pathways, with surface runoff occurring on the exposed subsoil. Sediment and nutrient losses from the sheared sites were related to the volume of stormflow. Overland flow plus the increase in channel flow, resulted in a greater erosion rate with generally greater concentrations of sediment and nutrients.

Chopped watersheds had minimal surface disturbance. Mineral soil exposed was less than a third of the amount on the sheared watersheds. The organic matter and slash from logging covered the soil surface and allowed time for infiltration. Since stormflow resulted from subsurface flow and volumes were low, sediment and nutrient concentrations and losses remained very similar to the levels from the undisturbed watersheds.

During the second year following treatment, revegetation on the sheared watersheds had reduced water yield by 60%. Sediment and nutrient concentrations also dropped, as differences between treatments narrowed. Chopped watersheds also benefited from the re-establishment of vegetation as runoff volumes, sediment and nutrient export decreased.

The increase in sediment and nutrient export following site preparation appears to be temporary. Although the quantity of nutrients lost is relatively small, several steps can be taken to minimize losses from these activities. A site preparation method should be chosen which causes the least disturbance to the soil surface. On the Alto study sites roller chopping appears to be the most effective practice. Shearing and windrowing on the relatively steep slopes at Alto, resulted in greater soil displacement than would have occurred on more gentle slopes, where maintaining dozer blade heights and turning is not as difficult. The windrowing operation also carried surface soil into the windrows, which displaces soil nutrients. For these reasons shearing and windrowing probably should be confined to sites with stable soils and slopes less than 5 to 8%. If areas with greater slopes than this are sheared and windrowed, equipment operators should be carefully supervised. Buffer strips along stream channels should also be wider when shearing and windrowing instead of roller chopping, especially on steeper slopes. Roller chopping on slopes of at least 25% appears to be feasible without seriously degrading water quality or reducing site productivity.

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Appendix A

TABLE OF SCIENTIFIC NAMES

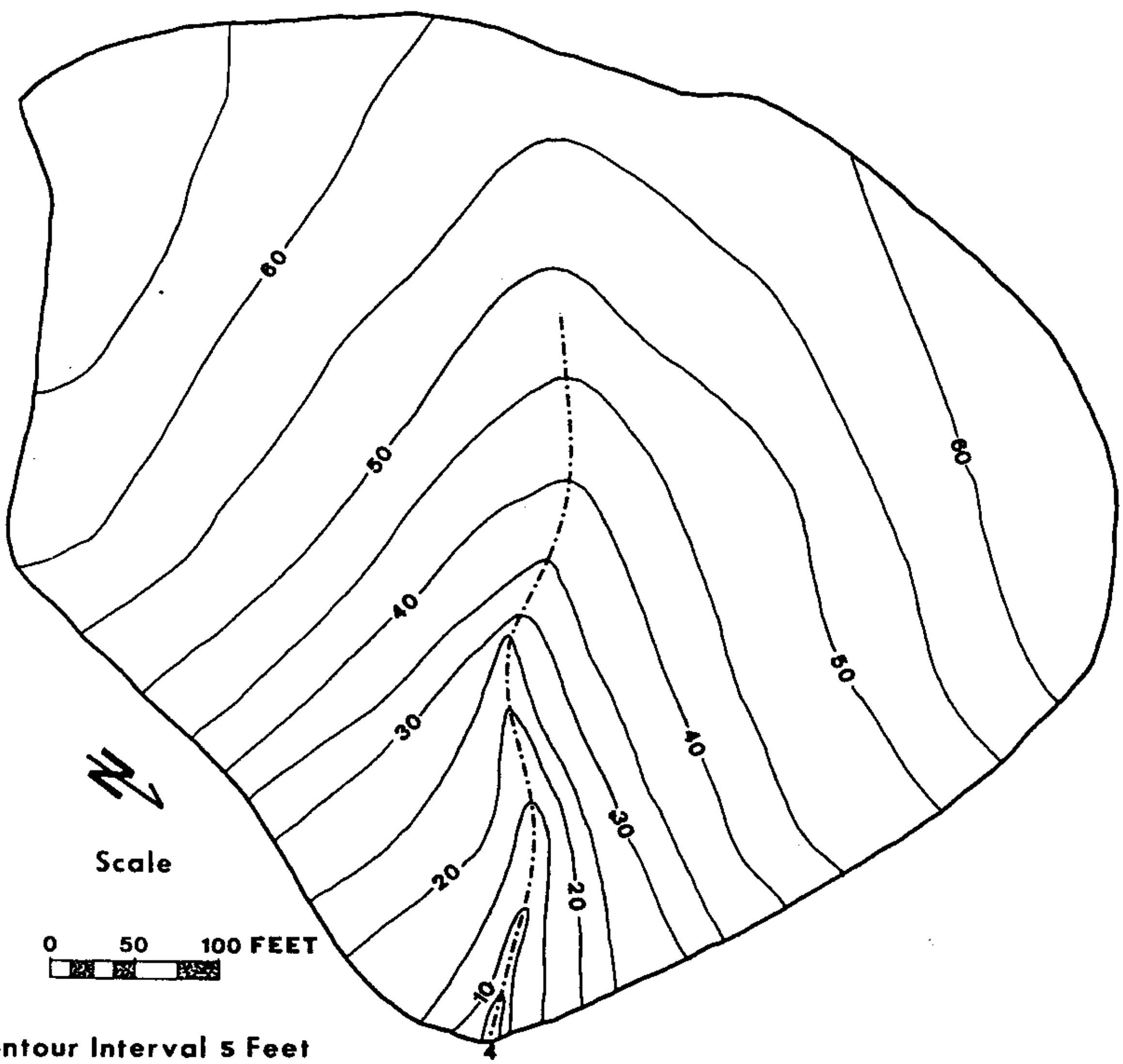
Common Names	Scientific Names
Trees	
Pine	
Loblolly Pine	Pinus taeda
Shortleaf Pine	Pinus echinata
Oak	
Southern Red Oak	Quercus falcata
Blackjack Oak	Quercus marlandica
Post Oak	Quercus stellata
White Oak	Quercus alba
Water Oak	Quercus nigra
Hickory	
Mockernut Hickory	Carya tomentosa
Elm	
Winged Elm	Ulmus alata
Slippery Elm	Ulmus rubra
Sweetgum	Liquidambar styraciflua
Dogwood	Cornus florida
Shrubs and Vines	
American Beautyberry	Calicarpa americana
Blackberry	Rubus spp.
Southern Waxmyrtle	Myrica cerifera
Virginia Creeper	Parthenocisus queinequefolia
Greenbriar	Smilax spp.
Poison Ivy	Toxicodendron radicans

Appendix B

WATERSHED MAPS

EXPERIMENTAL WATERSHED

NUMBER 1 6.46 ACRES



Contour Interval 5 Feet

Cherokee County Texas

EXPERIMENTAL WATERSHED

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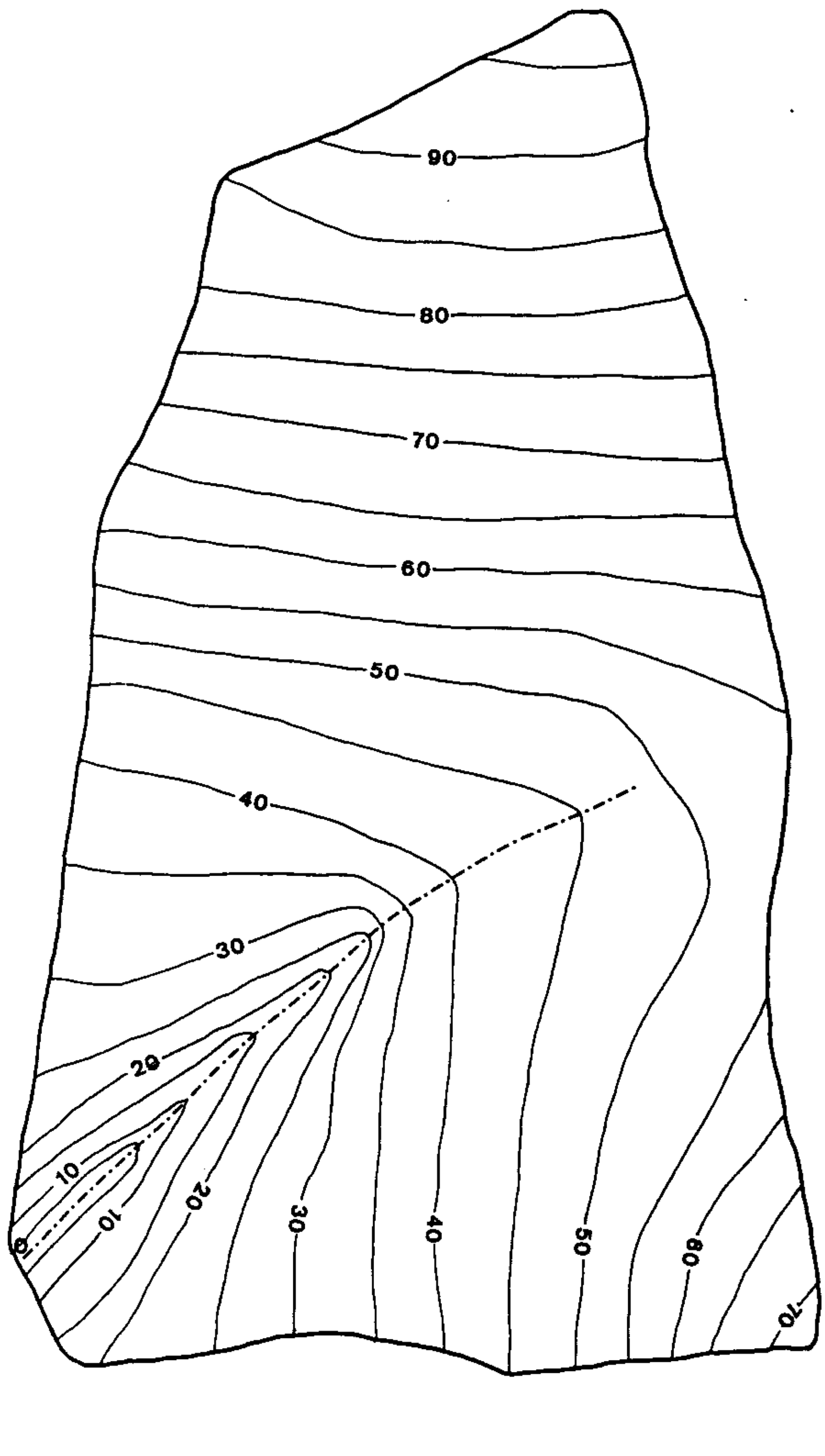

Scale

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Contour Interval 5 Feet

Cherokee County Texas

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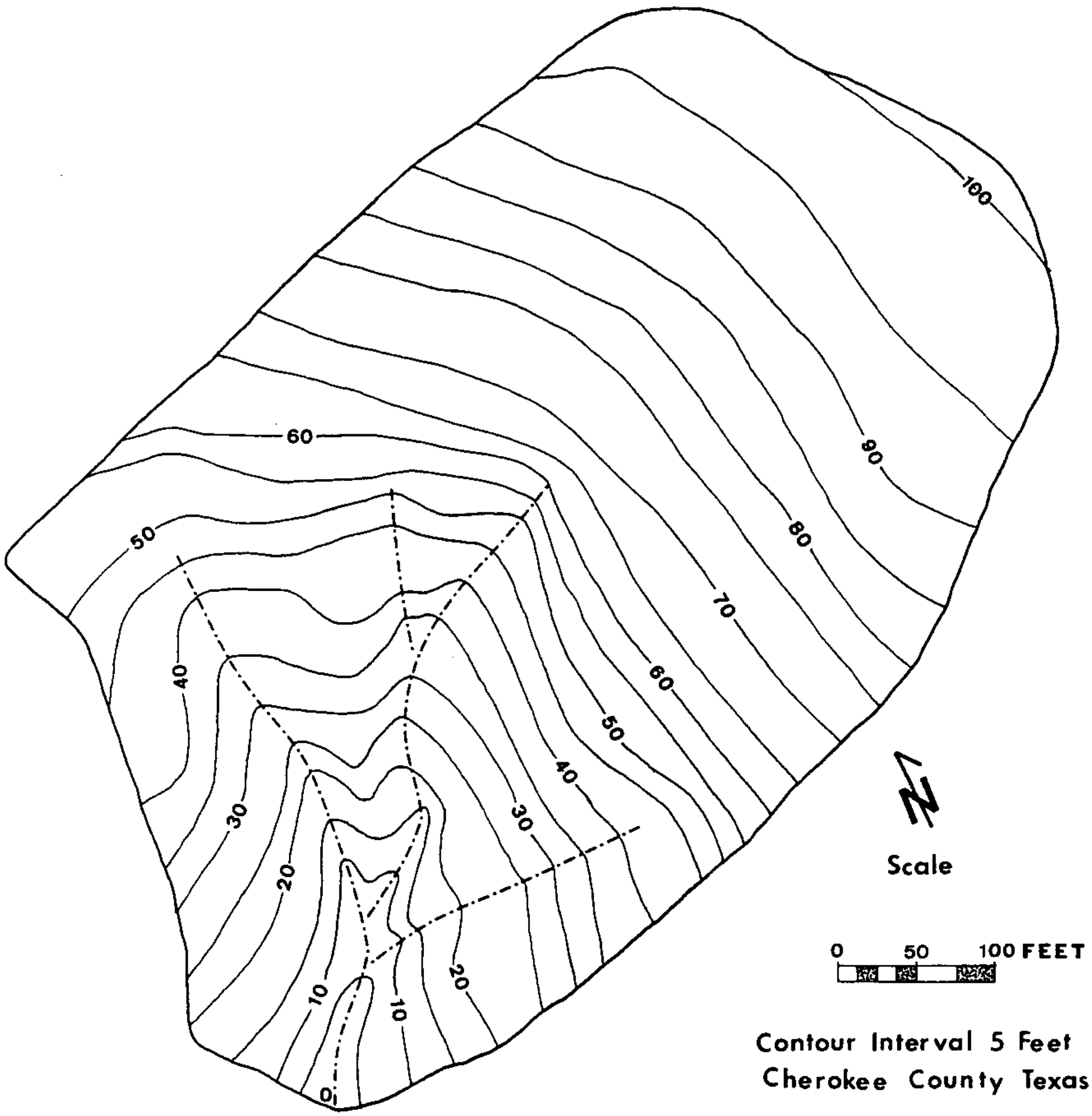

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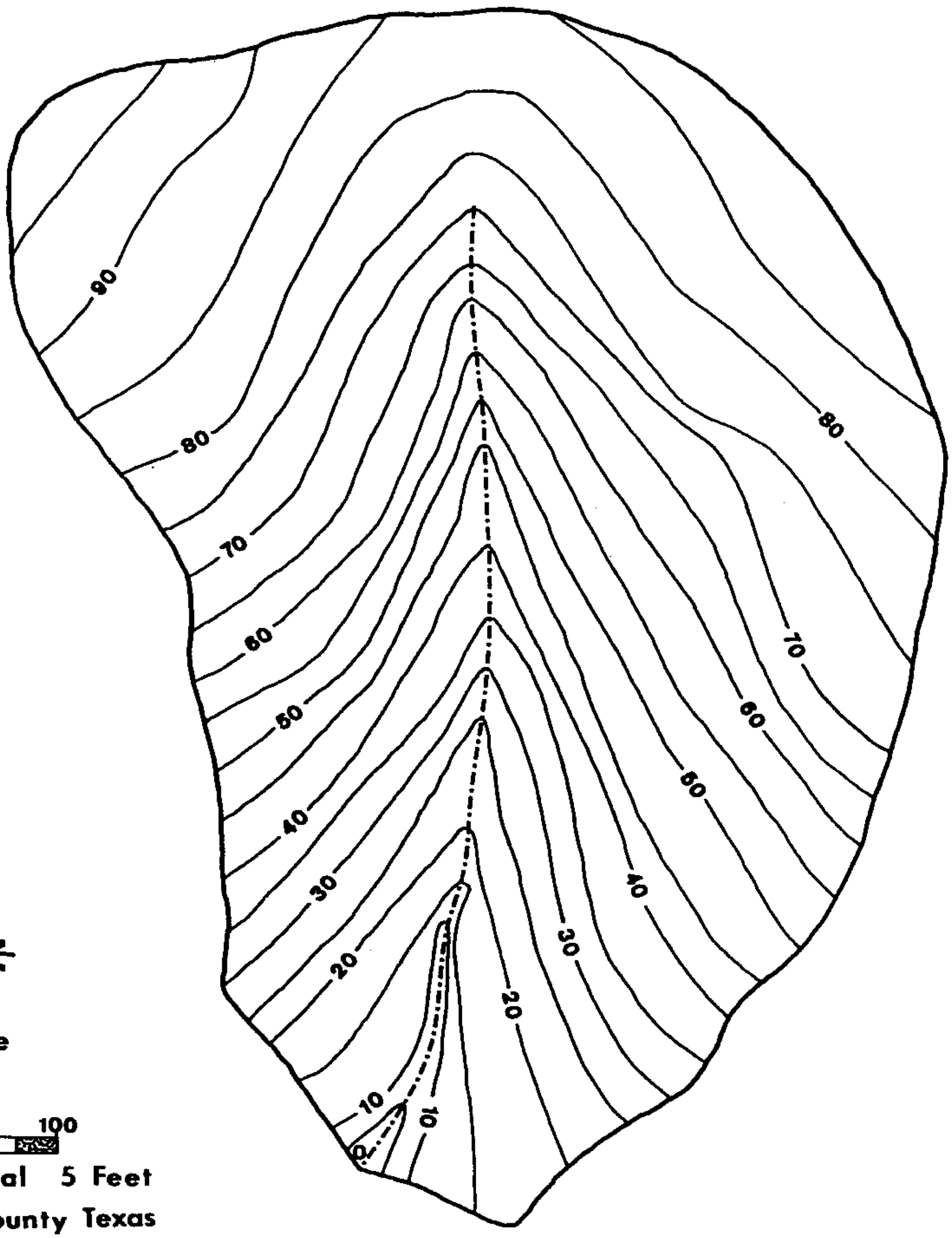

Scale

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Cherokee County Texas

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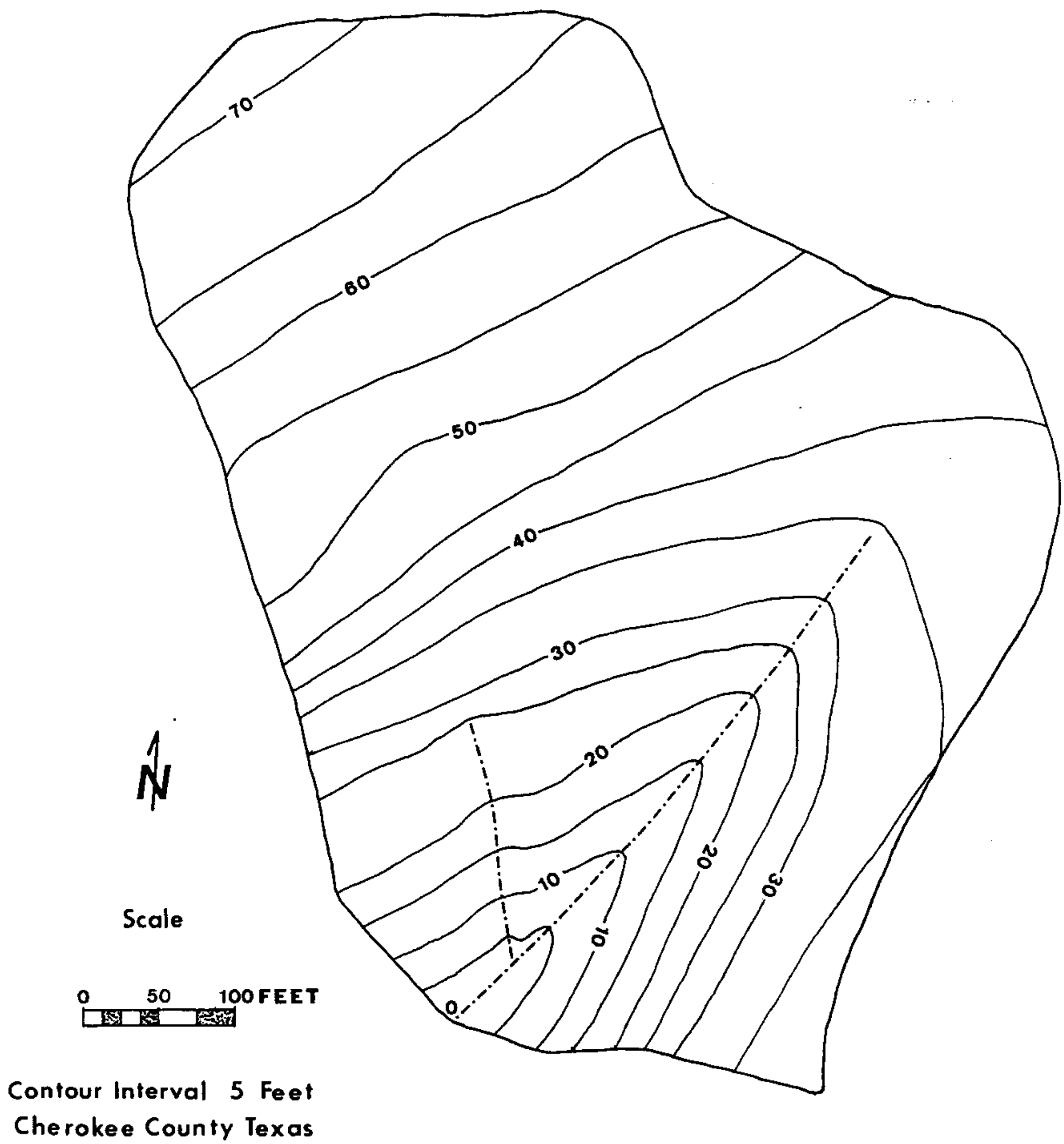

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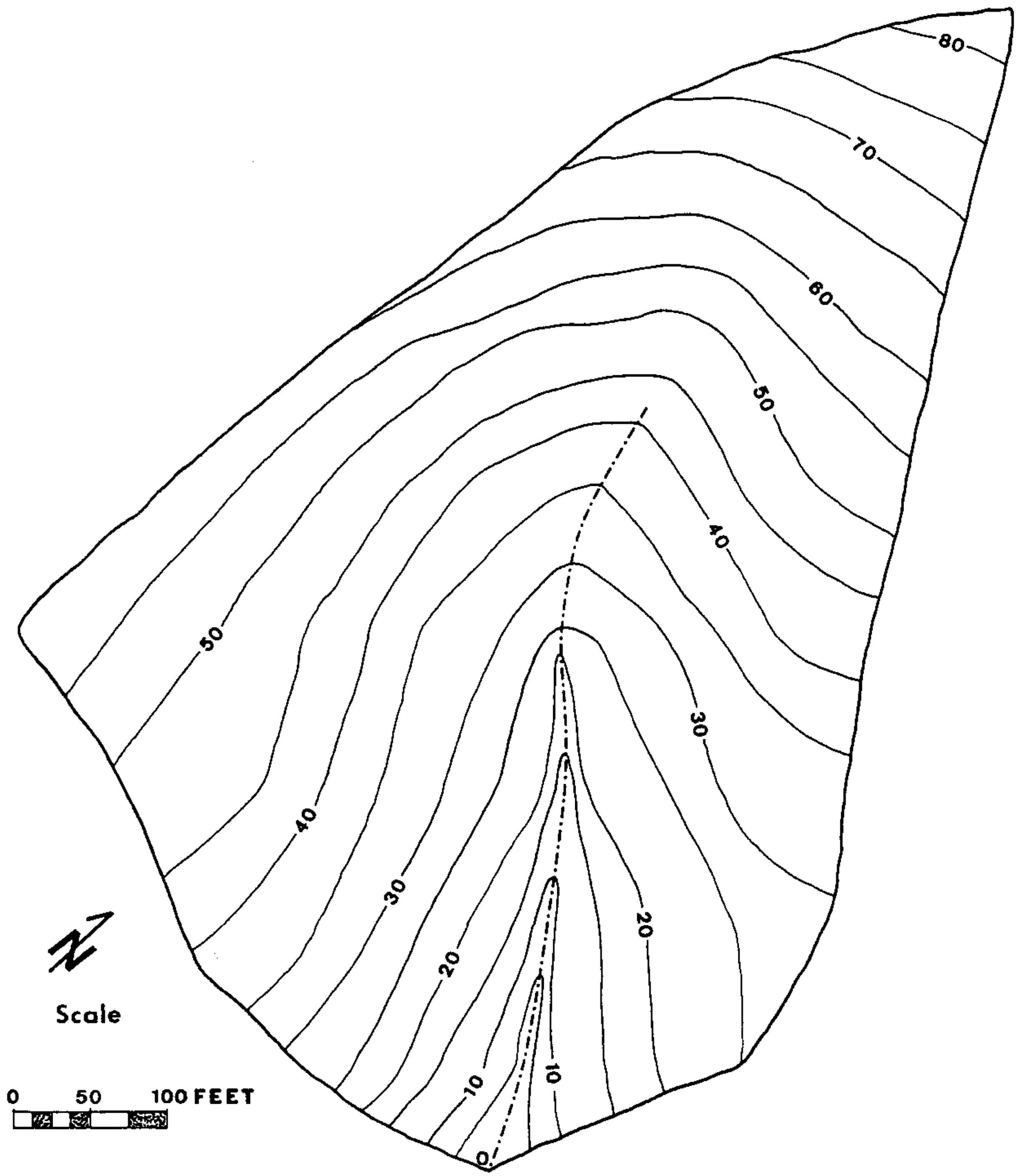

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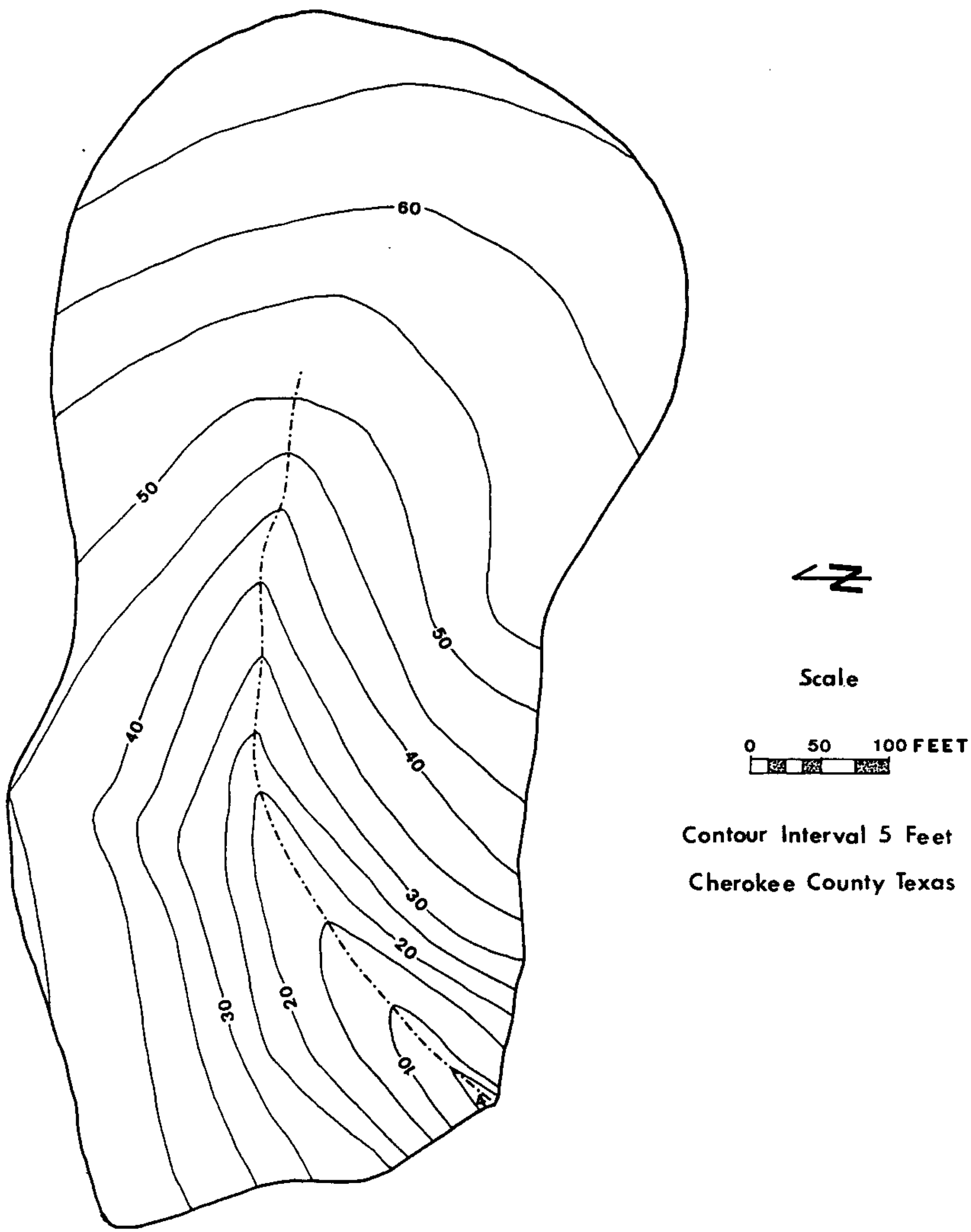

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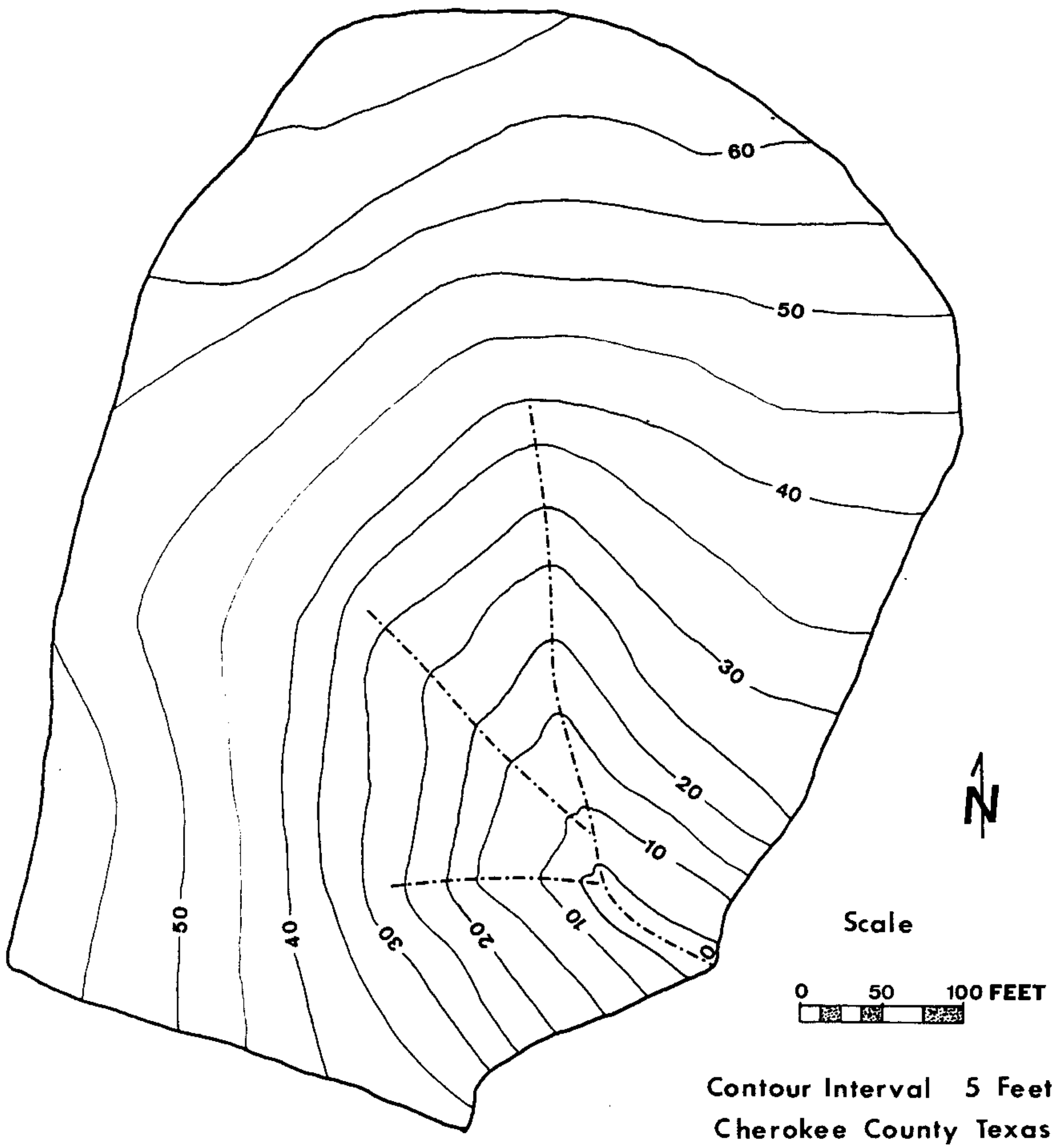

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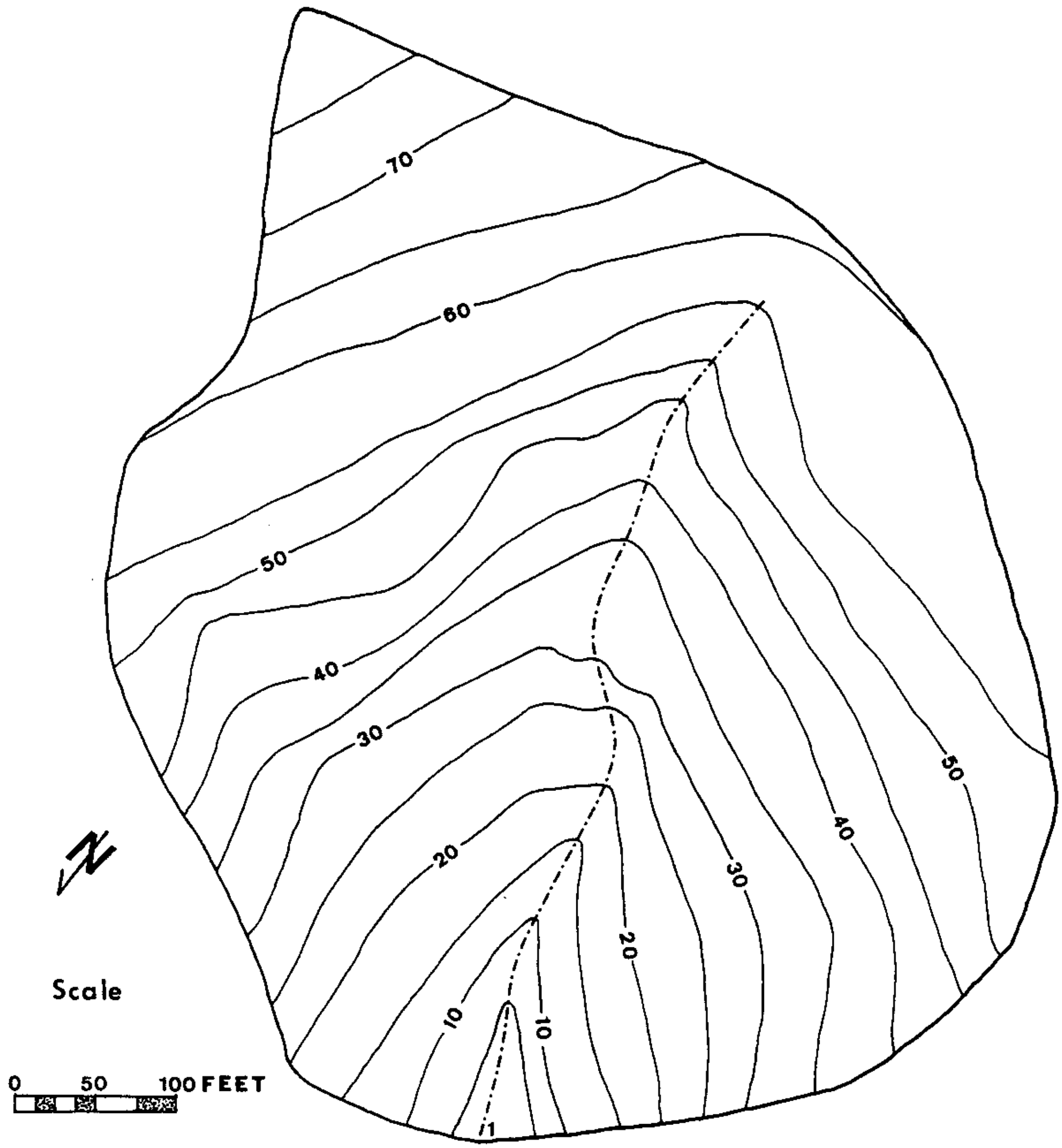

Contour Interval 5 Feet

Cherokee County Texas