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The Impact of Harvesting and Site Preparation on Stormflow and Water Quality in East Texas

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RESEARCH PROJECT INTERIM REPORT

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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. Stormflow volumes in 1983 were 2.46, 1.75 and 0.84 inches for the sheared, chopped and control watersheds, respectively. 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 decreased 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. Sediment losses in the third year following treatment continued decreasing on the sheared sites

(30.9) and remained approximately the same on the chopped and control sites.

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 watersheds still had a significantly higher concentration. Nitrate concentrations in 1983 remained low at 54, 20 and 10 ppb for the sheared, chopped and control watersheds, respectively. 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 nitrogen loss in the third year after treatment was reduced to 0.37, 0.20 and 0.08 lb/acre for the sheared, chopped and control treatments, respectively. 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%. Total phosphorus export in 1983 decreased on sheared sites

(0.019 lb/acre), but increased slightly on chopped (0.011 lb/acre) and control sites (0.006 lb/acre). 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. Cation concentrations and losses on the treated watersheds continued declining in the third year following treatment.

Increases in stormflow and sediment and nutrient losses appear to be temporary on sheared and chopped treatments. Rapid revegetation established surface cover and reduced mineral soil exposure. 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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THE IMPACT OF HARVESTING AND SITE PREPARATION ON STORMFLOW AND WATER
QUALITY IN EAST TEXAS

INTRODUCTION

This study was 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 four 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 rain-

fall, 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 pre-treatment 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 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 concentration 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 compaction 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
NO ₃ -N	0.170	2.78	0.08	0.28
NH ₄ -N	0.300	5.10	0.84	2.98
PO ₄ P	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 yields 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, 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	NO ₃ -N	NH ₄ -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	NO ₃ -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 range 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 management 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 necessary that the sites be located as near one another as possible. This reduces instrumentation, such as rain gaging 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. Watershed size.

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
Mean	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%.

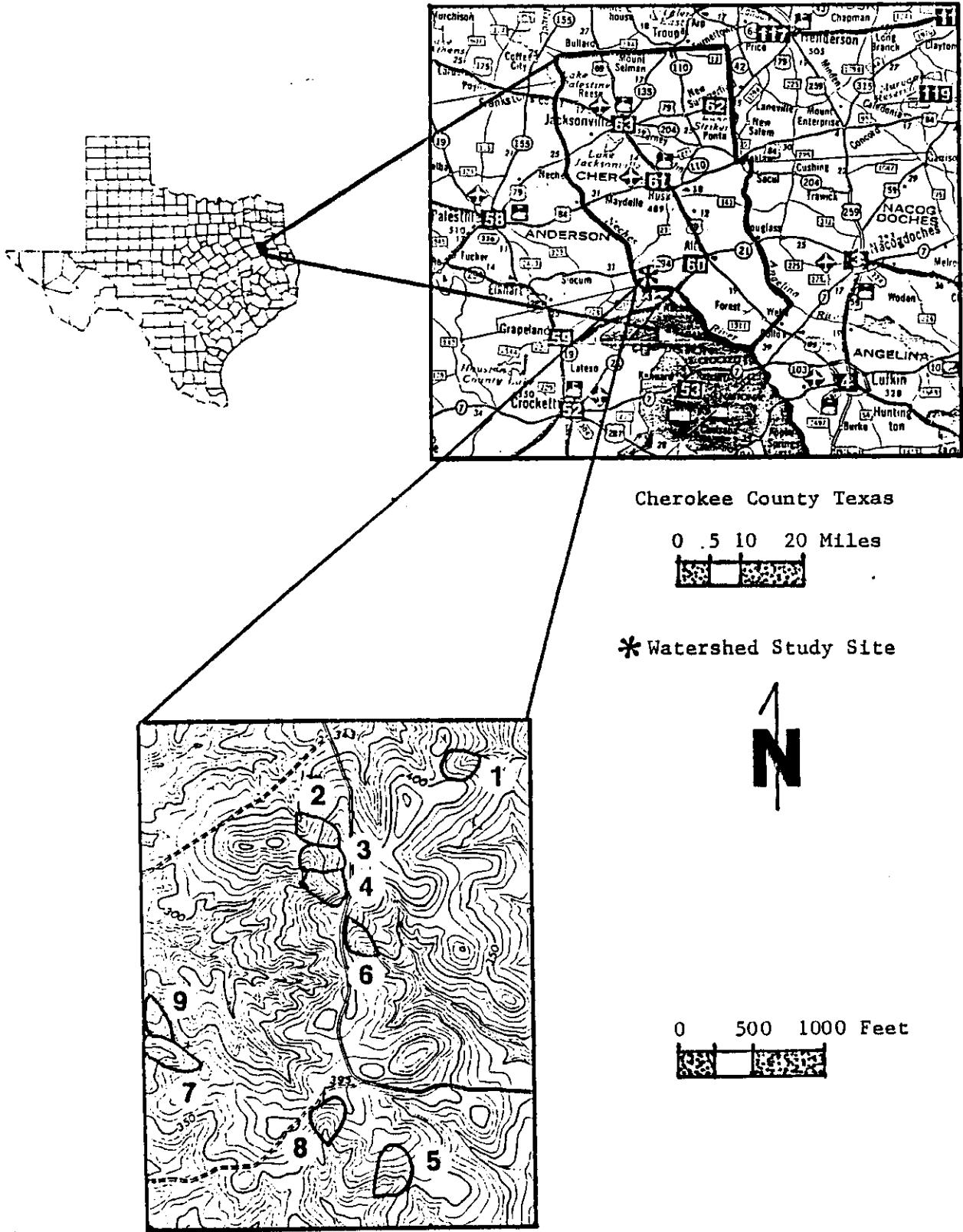


Figure 1. Study site location.

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 Conservation 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 characteristics 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 lar-

ger 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.

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 probability.

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 then 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 rain gages located in a network on each site to provide a minimum of two gages for every watershed. Timing and intensity is obtained from two recording rain gages (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 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 storm and subsamples are collected for analysis.

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 texture.

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. Although 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, ammonium, total nitrogen, ortho and total phosphorus using a Technicon Auto Analyzer II. Total nitrogen, nitrate and ammonium 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 ammonium was measured using the ammonium/salicylate complex method after digestion with a salt/acid catalyst mixture (APHA et al. 1976). The ammonium 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 10% inventory was made prior to treatment 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					Total
	Pine		Hardwood		Pine	Oaks	Hickory	Sweetgum	Others	
	Sawlogs bd.ft./acre	Pulpwood cords/acre	Sawlogs bd.ft./acre	Pulpwood cords/acre						
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
Mean	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.									Mean	
	1	2	3	4	5	6	7	8	9		
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	7,750	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	2,850	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.									Mean
	1	2	3	4	5	6	7	8	9	
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									Mean
	1	2	3	4	5	6	7	8	9	
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 preceding 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					Roiler Chop			
	Watershed Number								
	1	2	3	5	7	9	Mean		
Pine									
Loblolly & Shortleaf	452	680	510	685	838	509	677		
Hardwoods									
Oak	1,467	960	1,298	1,981	1,822	921	1,575		
Elm	339	120	-0-	55	48	137	80		
Dogwood	32	-0-	234	815	32	549	632		
Sweetgum	516	300	170	296	210	274	250		
Hickory	145	180	85	296	113	39	149		
Other	2,290	1,860	1,553	1,944	8,177	2,020	4,047		
TOTAL	4,789	3,420	3,340	5,387	10,902	3,940	6,743		
Shrubs									
American Beautyberry	2,548	3,260	1,489	2,759	3,145	1,529	2,478		
Blackberry	1,435	1,780	2,064	333	1,226	1,647	1,069		
Southern Waxmyrtle	32	-0-	1,234	19	1,306	411	579		
Other	613	260	213	667	177	176	340		
TOTAL	4,628	5,300	5,000	3,778	5,854	3,763	4,465		
Vines									
Virginia Creeper	97	620	1,702	1,055	1,822	1,706	1,528		
Greenbriar	1,290	880	340	1,963	1,290	1,039	1,431		
Poison Ivy	32	760	255	926	564	627	706		
Other	1,339	900	532	1,222	1,919	1,725	1,622		
TOTAL	2,758	3,160	2,829	5,166	5,595	5,097	5,286		

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

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

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

Surface Condition	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Mean	5	7	9	Mean
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	Mean	5	7	9	Mean
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

First Year 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, decreased 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					Watershed Number				
	1	2	3	Mean	5	7	9	Mean		
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	Mean	5	7	9	Mean
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

Second Year Seedling Survival

Seedling survival for the second year following planting remained approximately the same. Mean stocking on the sheared watersheds was 208 trees per acre, with a mean height of 28.8 inches. Roller chopped

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	Mean	5	7	9	Mean
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

watersheds had a stocking of 219 trees per acre with a mean height of 31.1 inches. There was no difference between treatments for stocking or height.

Post-treatment October 1983

Rapid revegetation continued during the third year following treatment. There was little difference in pine seedling densities between treatments, while the number of hardwood stems per acre was 65% greater on the chopped watersheds (Table 26). The number of shrubs and vines continued to increase over the previous years density, with the greatest number found on the chopped watersheds.

Mineral soil exposure on the sheared watersheds decreased to 9.1% in 1983, from the 20% exposure in the previous year (Table 27). Exposure of mineral soil on the chopped sites remained unchanged at 3.6% which is just above the 3.3% exposure found on the undisturbed watersheds prior to treatment. There was little evidence of active ero-

sion on either treatment. Vegetative cover for both treatments averaged about 15%.

Total herbaceous production increased on both sheared and chopped watersheds during 1983. Grass production averaged 1,328 lb/acre on the sheared sites and 1,902 lb/acre on the chopped (Table 28). Litter accumulations were also greater on the chopped watersheds (1,716 lb/acre) than the sheared watersheds (1,431 lb/acre). This was due primarily to the greater density of hardwoods, shrubs and vines.

Table 26. Post-treatment understory vegetation (stems < 1" dbh/acre), for the Alto watersheds, October 1983.

	Shear and Windrow					Roller Chop				
	Watershed Number					Watershed Number				
	1	2	3	5	9	1	2	3	5	9
Pine										
Loblolly and Shortleaf	355	306	469	377	236	484	453	391		
Hardwoods										
Dak	1,129	571	1,204	968	1,182	921	623	909		
Elm	210	122	-0-	111	218	156	151	175		
Dogwood	-0-	20	306	109	182	141	226	183		
Sweetgum	258	184	469	304	1,000	1,125	849	991		
Hickory	81	61	163	102	382	-0-	38	140		
Other	1,145	532	858	845	1,054	2,548	1,887	1,830		
TOTAL	2,823	1,490	3,000	2,438	4,018	4,891	3,151	4,020		
Shrubs										
American Beautyberry	2,710	1,714	1,755	2,060	1,382	1,656	1,585	1,541		
Blackberry	1,661	2,876	3,612	2,716	2,273	6,719	9,679	6,223		
Southern Waxmyrtle	-0-	-0-	388	129	36	266	396	233		
Other	1,242	1,184	1,143	1,190	818	1,390	1,000	1,069		
TOTAL	5,613	5,774	6,898	6,095	4,509	10,031	12,660	9,067		
Vines										
Virginia Creeper	-0-	163	82	82	18	-0-	57	25		
Greenbriar	806	286	224	489	782	1,047	774	868		
Poison Ivy	-0-	61	-0-	20	164	-0-	132	99		
Other	387	245	245	292	363	844	831	679		
TOTAL	1,193	755	551	833	1,327	1,891	1,794	1,671		

Table 27. Post-treatment ground surface condition (%), for the Alto watersheds, October 1983.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Mean	5	7	9	Mean
Surface Condition								
Litter	73.0	71.0	71.9	72.0	72.2	61.6	73.1	69.0
Slash	3.8	3.2	5.1	4.0	8.8	13.9	12.1	11.6
Rock	0.2	0.2	0.3	0.2	1.6	0.0	0.0	0.5
Mineral Soil	9.3	9.6	8.4	9.1	4.5	5.3	1.0	3.6
Erosion								
Rill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sheet	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0
Deposition	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tree	0.1	0.0	0.1	0.1	0.1	0.2	0.4	0.2
Shrub	0.4	0.2	0.4	0.3	0.2	1.1	0.4	0.6
Grass	10.3	11.3	9.6	10.4	10.9	15.0	11.2	12.4
Grasslike	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Forb	2.9	4.5	4.2	3.9	1.7	2.8	1.8	2.1

Table 28. Post-treatment herbaceous biomass and litter accumulation (lb/acre), for the Alto watersheds, October 1983.

	Shear and Windrow				Roller Chop			
	Watershed Number							
	1	2	3	Mean	5	7	9	Mean
Grass	1,432	1,370	1,183	1,328	2,035	2,162	1,509	1,902
Grasslike	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Forb	602	541	569	571	698	678	373	583
Litter	2,131	1,078	1,085	1,431	1,656	1,905	1,588	1,716

Precipitation and Runoff

Annual precipitation for the four year period, 1980 - 1983, fluctuated from below normal, to above normal, to normal, to above normal. Precipitation during the pre-treatment year (1980) was 31.15 inches, which is about 14 inches below normal (Table 29). Two-thirds of the precipitation fell between January and May. Precipitation during 1981 was 51.12 inches (Table 30), with an exceptionally wet May, June and October accounting for over half of the 1981 precipitation. During 1982 precipitation totaled 44.90 inches, with the largest accumulations in the spring and late fall (Table 31). Rainfall for 1983 was 46.50 inches, which is about 4.5 inches above normal. Over 45% of the annual rainfall occurred in the months of March, May and August (Table 32).

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 produce 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.

Pre-treatment 1980

During the pre-treatment year (1980), there were nine storms of sufficient size to produce measurable runoff (Table 33). All runoff events occurred between January and May and only the January 21, February 9 and May 15 storms generated runoff from all nine 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.

Table 29. 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			TOTAL		31.15	42.03
13	1.15						

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

On January 20, 1980 a 1.3 inch rainfall event produced the first measurable stormflow (Table 33). 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.

Table 30. 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.

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

Table 31. 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	1.21	1.21	3.76
5	.22			Oct 6	.80		
6	.11			7	.19		
8	.39			9	.57		
25	.34			10	.11		
26	.60	2.10	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	5.12	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	2.88		
21	1.11			30	.05	6.26	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	.97		
17	.82			24	1.31		
23	.77			25	.36		
24	.52			26	1.21		
25	.11	5.39	4.42	31	.37	7.18	3.95
Jun 16	1.29			TOTAL		44.90	42.03
20	.21						
21	.18						

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

Table 32. Precipitation (inches) 1983.*

DATE	RAINFALL	TOTAL	NORMAL	DATE	RAINFALL	TOTAL	NORMAL
Jan 1	.51			Jul 15	.22		
19	.43			16	1.76		
21	.09			18	.12		
31	1.61	2.64	3.54	21	.03	2.97	2.67
Feb 5	2.13			Aug 2	.09		
9	.89			3	1.62		
20	1.21	4.23	3.36	4	.07		
Mar 3	.21			7	.20		
4	1.30			9	1.21		
16	.15			12	.40		
19	.65			18	2.44		
23	2.10			27	.23	6.26	2.55
26	.91			Sep 1	.55		
30	.23	5.55	3.26	7	.32		
Apr 4	.09	.09	4.70	9	.35		
May 2	.16			18	.43		
11	1.60			19	.38	2.03	3.76
15	.61			Oct 11	.83		
18	1.56			20	.95	1.78	2.88
19	1.97			Nov 6	1.03		
20	.38			10	.07		
21	1.54			19	1.40		
30	1.18			22	.28		
31	.13	9.13	4.42	23	.42		
Jun 6	1.81			25	.47		
15	.33			29	.06	3.73	3.53
23	.13			Dec 2-3	1.39		
25	1.08			10	1.67		
28	.14			16	.78		
29	.55	4.04	3.41	21	.21	4.05	3.95
Jul 1	.42						
13	.42						
					TOTAL	46.50	42.03

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

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 contain 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

Table 33. 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
Jan 21	1	1.79	0.124	7
	2	1.81	0.440	7
	3	1.85	0.123	7
	4	1.91	0.134	7
	5	2.03	0.182	6
	6	1.97	0.416	21
	7	1.99	0.258	13
	8	2.00	0.090	4
	9	1.95	0.566	29
Feb 8	1	1.56	0.026	2
	2	1.51	0.085	6
	3	1.54	0.019	1
	4	1.55	0.019	1
	5	1.51	0.006	<1
	6	1.54	0.096	6
	7	1.51	0.048	3
	9	1.48	0.114	8
Feb 9	1	.58	0.027	-
	2	.56	0.094	-
	3	.57	0.024	-
	4	.57	0.019	-
	5	.56	0.033	-
	6	.57	0.089	-
	7	.56	0.053	-
	8	.54	0.007	-
	9	.55	0.120	-
Mar 27	2	1.21	0.005	<1
	6	1.20	0.004	<1
	9	1.20	0.004	<1
Apr 13	1	1.79	0.033	2
	2	1.90	0.161	8
	3	1.88	0.026	1
	4	1.88	0.024	1
	6	1.86	0.096	5
	7	1.89	0.055	3
	9	1.86	0.103	5
May 13	2	1.31	0.044	3
	3	1.26	0.006	<1
	4	1.21	0.002	<1

Table 33. Continued.

Storm Date	Watershed No.	Precipitation / 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.

intensity of 2 inches per hour, produced runoff from all watersheds except 5 and 8 (Table 33). Maximum stormflow for the 1.87 inch rainfall event was from WS 2 (0.16 inches).

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 33). Runoff as a percent of precipitation was 22 and 46 percent for the same two watersheds. Maximum rainfall 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.

Post-treatment 1981

During 1981, 69 storms produced 31 runoff events (Table 34). 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 34). Runoff volumes for the year were significantly 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 34.

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 and 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.

Table 34. 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 / area inches	Runoff	Runoff as a % of Precipitation* %	Peak rate of Discharge 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 34. Continued.

Storm Date	Treatment	Precipitation / area inches	Runoff 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.

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 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 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 35). Precipitation for this year, although about the long term average, was 7 inches lower than for 1981. There were no really large storms which are major contributors 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 rainfall 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 35. 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/ area inches	Runoff	Runoff as a % of Precipitation* %	Peak Rate of Discharge 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 35. Continued.

Storm Date	Treatment	Precipitation/ area inches	Runoff Runoff	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	44.90	1.972 a+	4&	-
	Chop	44.90	1.400 a	3	-
	Control	44.90	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 (44.90 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 (2.88 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 35). 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.

Post-treatment 1983

Stormflow the third year following treatment increased slightly above 1982 levels. Of the 64 rainfall events during the year, 22 were of sufficient intensity and amount to generate runoff. Runoff from the sheared watersheds averaged 2.46 inches, which was significantly greater than from the control watersheds (0.84 inches), but not different from the chopped watersheds (1.75 inches) (Table 36). Runoff volumes from the chopped and control watersheds were not different. Stormflow as a percent of precipitation was 5, 4 and 2% for the sheared, chopped and control watersheds, respectively. The highest rate of discharge for the year was during a 1.54 inch rainfall event on May 21, when the peak stage on the sheared watersheds averaged 1.93 cfs, compared to 0.75 cfs on the chopped and 0.47 cfs on the undisturbed watersheds.

During January there were two storms responsible for producing runoff. A 0.51 inch rainfall event on January 1, generated a small volume of runoff on both sheared and chopped watersheds (Table 36). While a larger storm on January 31 resulted in mean runoff volumes of 0.096 inches on the sheared watersheds, 0.086 inches on the chopped and 0.014 inches on the control watersheds.

During February there were three runoff producing storms. The largest on February 5, when a 2.13 inch rainfall initiated runoff from all nine watersheds. The 0.62 inch runoff volume from the sheared watersheds represents a return ratio of 29% of the precipitation. Chopped and control watersheds had stormflow volumes of 0.45 and 0.26 inches, respectively.

March was the third wettest month of the year and during this period there were three runoff events. Total runoff for this month was 0.67, 0.46 and 0.23 inches for the sheared, chopped and undisturbed watersheds, respectively.

April, which is historically the wettest month of the year was the driest, with only 0.09 inches of rainfall and no runoff from any of the treatments.

A total of 9.13 inches of rain during May made up for the dry April. There were six storms during May in which measureable runoff was produced. The largest occurring on May 21, following three days of rainfall. Stormflow from this 1.54 inch rainfall was 0.47 inches on the sheared sites, 0.43 inches on the chopped and 0.24 inches on

Table 36. Mean event and annual precipitation, runoff and peak discharge by treatment, for storms producing runoff the third year following treatment, 1983.

Storm Date	Treatment	Precipitation / area inches	Runoff Precipitation* %	Peak rate of Discharge cfs	
Per event					
Jan 1	Shear (2)#	0.51	0.017	-	0.21
	Chop (2)		0.021	-	0.01
Jan 31	Shear (3)	1.61	0.096	6	0.39
	Chop (2)		0.086	5	0.31
	Control (2)		0.014	1	0.03
Feb 5	Shear (3)	2.13	0.622	29	0.90
	Chop (3)		0.446	21	0.54
	Control (3)		0.263	12	0.29
Feb 9	Shear (3)	0.89	0.102	-	0.20
	Chop (3)		0.079	-	0.07
	Control (2)		0.036	-	0.03
Feb 20	Shear (3)	1.21	0.040	3	0.10
	Chop (3)		0.042	3	0.06
	Control (1)		0.025	2	0.04
Mar 4	Shear (3)	1.30	0.096	7	0.21
	Chop (3)		0.077	6	0.11
	Control (2)		0.035	3	0.05
Mar 23	Shear (3)	2.10	0.401	19	0.79
	Chop (3)		0.277	13	0.49
	Control (3)		0.132	6	0.25
Mar 26	Shear (3)	0.91	0.173	-	0.55
	Chop (3)		0.105	-	0.15
	Control (3)		0.060	-	0.08
May 11	Chop (1)	1.60	0.001	<1	0.01
May 18	Shear (3)	1.56	0.020	1	0.42
	Chop (1)		0.012	1	0.14
May 19	Shear (3)	1.97	0.248	13	1.18
	Chop (3)		0.138	7	0.35
	Control (3)		0.046	2	0.12
May 20	Shear (3)	0.38	0.034	-	0.08
	Chop (3)		0.033	-	0.05
	Control (2)		0.006	-	0.01
May 21	Shear (3)	1.54	0.465	30	1.93
	Chop (3)		0.429	28	0.75
	Control (3)		0.238	15	0.47
May 30	Shear (2)	1.18	0.003	<1	0.01
	Chop (2)		0.006	<1	0.03
	Control (1)		0.003	<1	0.01
Jun 6	Shear (3)	1.81	0.035	2	0.19
	Chop (3)		0.031	2	0.06

Table 36. Continued.

Storm Date	Treatment	Precipitation / area inches	Runoff Runoff	Runoff as a % of Precipitation* %	Peak rate of Discharge cfs
Jun 6	Control (3)		0.004	<1	0.02
Jul 16	Shear (1)	1.76	0.003	<1	0.02
	Chop (1)		0.001	<1	0.02
Aug 9	Shear (1)	1.21	0.003	<1	0.03
Aug 18	Shear (1)	2.44	0.021	1	0.18
	Chop (1)		0.007	<1	0.07
	Control (1)		0.002	<1	0.02
Nov 6	Shear (1)	1.03	0.002	<1	0.02
Nov 19	Shear (2)	1.40	0.006	<1	0.07
Dec 3	Shear (1)	1.39	0.052	4	0.05
Dec 10	Shear (3)	1.67	0.084	5	0.90
	Chop (2)		0.022	1	0.21
	Control (3)		0.025	1	0.16
Annual					
	Shear	46.50	2.461 a+	5&	-
	Chop	46.50	1.753 ab	4	-
	Control	46.50	0.839 b	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 Duncans multiple range test.

& Percent of mean annual precipitation (45.60 inches) measured as runoff.

the control sites. This storm also recorded the highest peak discharge rates during the year for all three treatments. Total stormflow for May was 31, 35 and 35% of the annual volume of stormflow for the sheared, chopped and undisturbed watersheds, respectively.

The summer months of June, July and August although above average in rainfall, produced limited volumes of stormflow. The greatest amount of runoff during this period was on June 6, when precipitation

of 1.81 inches generated runoff of 0.035, 0.031 and 0.004 inches from the sheared, chopped and undisturbed treatments, respectively. Although August was the second wettest month of the year with 6.26 inches, evapotranspiration is so high at this time of year that very little runoff occurs.

Below normal rainfall in September and October did not produce measurable runoff. During November and December, four runoff events generated small volumes of runoff. For three of these events runoff was exclusive on the sheared watersheds. Only the December 10 storm of 1.67 inches resulted in runoff from all of the treatments. The runoff from this storm was 0.084, 0.022 and 0.025 inches from the sheared, chopped and undisturbed watersheds, respectively.

As the treated watersheds continue to revegetate, differences between treatments diminish. During 1982 both sheared and chopped watersheds had significantly greater stormflow than the controls. Whereas, in 1983 only the sheared treatment had significantly greater stormflow than the controls.

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 wat-

ersheds. 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 37). 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.

Sediment concentrations and export from all but the May 15 runoff event were fairly low (Table 37). 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

Table 37. Mean event and annual stormflow and sediment concentrations and losses by watershed prior to treatment, 1980.

Storm Date	Watershed	Runoff	Suspended Sediment		Bedload	Total Sediment
		(inches)	(ppm)	(lb/ac)	(lb/ac)	(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 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 38). 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 from 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 dur-

ing 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 control 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 consistently higher sediment concentration than the other two treatments throughout the year (Table 38). 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.

Table 38. Mean event and annual stormflow and sediment concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Runoff	Suspended Sediment		Bedload	Total Sediment
		(inches)	(ppm)	(lb/ac)	(lb/ac)	(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 38. Continued.

Storm Date	Treatment	Runoff (inches)	Suspended Sediment (ppm)	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.

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 38). 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 compared to 16 percent for the chopped watersheds. The bare soil offered no resistance to raindrop impact and overland flow. Thus, sheet and rill erosion 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 39). 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 39). 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

Table 39. Mean event and annual stormflow and sediment concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Runoff	Suspended Sediment		Bedload	Total Sediment
		(inches)	(ppm)	(lb/ac)	(lb/ac)	(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.

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 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 establishment 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.

Post-treatment - 1983

Sediment concentrations continued to decrease in the third year following treatment. The greatest decrease in concentration occurred on the sheared sites, which had a mean discharge weighted concentration of 38 ppm (Table 40). Concentrations were lowest on the chopped watersheds at 12 ppm, followed by the undisturbed watersheds at 24

ppm. Although concentrations were very low, there was a significant difference between treatments. Mean sediment concentrations on the sheared watersheds ranged from a low of 8 ppm to a high of 179 ppm. Considerably less than the maximum concentrations of 1,711 ppm reached during the first year following harvesting and site preparation.

Bedload deposition was recorded only following the two largest runoff events of the year and was exclusive on the sheared watersheds. Total bedload loss for the year averaged 11.0 lb/acre from the sheared watersheds (Table 40).

Total sediment loss for the year was 30.9, 4.8 and 4.3 lb/acre for the sheared, chopped and control watersheds, respectively (Table 40). There were no treatment differences in sediment yield. Sediment loss was 57% less on the sheared sites than the amount lost during 1982. Losses on the chopped and control sites were essentially the same as 1982 levels. A 1.54 inch rainfall on May 21 was responsible for the largest sediment export during the year. The sheared watersheds recorded a loss of 13.4 lb/acre compared to 1.1 lb/acre on the chopped and 1.7 lb/acre on the control watersheds. Losses from this storm represent 43, 23 and 39% of the annual sediment export, for the sheared, chopped and control watersheds, respectively.

As revegetation continues on the treated watersheds and the surface soil stabilizes, sediment concentrations and losses also begin to stabilize. Sediment concentrations on the chopped watersheds, during the three years following treatment, have remained below levels recorded on the control watersheds. Sediment losses on the chopped sites also

Table 40. Mean event and annual stormflow and sediment concentration and loss the third year following treatment, 1983.

Storm Date	Treatment	Runoff (inches)	Suspended Sediment (ppm)	Sediment (lb/ac)	Bedload (lb/ac)	Total Sediment (lb/ac)
Per event						
Jan 31	Shear (3)*	.096	64	1.3	0.0	1.3
	Chop (2)	.086	20	0.4	0.0	0.4
Feb 5	Shear (3)	.622	8	1.0	4.0	5.0
	Chop (3)	.446	8	0.8	0.0	0.8
	Control (3)	.263	11	0.8	0.0	0.8
Feb 9	Shear (2)	.137	34	1.0	0.0	1.0
	Control (1)	.060	52	0.7	0.0	0.7
Feb 20	Shear (1)	.087	40	0.8	0.0	0.8
	Chop (1)	.081	17	0.3	0.0	0.3
Mar 4	Shear (2)	.127	24	0.7	0.0	0.7
	Chop (2)	.111	5	0.1	0.0	0.1
	Control (1)	.057	27	0.3	0.0	0.3
Mar 23	Shear (3)	.401	32	2.7	0.0	2.7
	Chop (3)	.277	14	1.1	0.0	1.1
	Control (2)	.191	29	1.1	0.0	1.1
Mar 26	Shear (3)	.173	26	0.9	0.0	0.9
	Chop (2)	.141	14	0.4	0.0	0.4
	Control (1)	.140	25	0.8	0.0	0.8
May 19	Shear (3)	.248	47	2.1	0.0	2.1
	Chop (3)	.138	20	0.6	0.0	0.6
May 21	Shear (3)	.465	55	6.4	7.0	13.4
	Chop (3)	.429	12	1.1	0.0	1.1
	Control (3)	.238	31	1.7	0.0	1.7
Jun 6	Shear (2)	.046	54	0.7	0.0	0.7
	Chop (1)	.070	53	0.8	0.0	0.8
Dec 10	Shear (3)	.084	179	3.6	0.0	3.6
	Chop (1)	.038	37	0.3	0.0	0.3
	Control (1)	.067	83	1.3	0.0	1.3
Annual						
	Shear	2.461	38a##+	19.9a	11.0a	30.9a
	Chop	1.753	12c	4.8b	0.0a	4.8a
	Control	0.839	24b	4.3b	0.0a	4.3a

* 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.

have not been significantly different from those on the control sites. Sediment concentrations and losses from the sheared treatments have dropped drastically in the three years following treatment. 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, ammonium 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 41). Nitrate concentrations ranged from less than detectable to 83 ppb. The concentration of nitrates fluctuated very little between watersheds or storms. Apparently there is little nitrate available for transport from these undisturbed watersheds, as only 0.007 lb/acre were lost during 1980.

Ammonium 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 41). The mean discharge weighted concentration of ammonium was 80 ppb during 1980. Total ammonium export for the year amounted to only 0.026 lb/acre.

Table 41. Mean event and annual nitrogen concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Nitrate		Ammonium		Total Nitrogen			
		ppb	lb/ac	ppb	lb/ac	filtered		unfiltered	
						ppb	lb/ac	ppb	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 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 41). There was little difference between fil-

tered 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 42). 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 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 from the sheared watersheds was significantly greater than from the other two treatments.

Mean ammonium concentrations, during 1981, were actually lower following treatment than during the pre-treatment year. Ammonium concentrations were 76, 56 and 48 ppb for the sheared, chopped and undisturbed watersheds, respectively (Table 42). There was no significant

Table 42. Mean event and annual nitrogen concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Nitrate		Ammonia		Total Nitrogen				
		ppb	lb/ac	ppb	lb/ac	Filtered		unfiltered		
						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 42. Continued.

Storm Date	Treatment	Nitrate		Ammonia		Total Nitrogen				
		ppb	lb/ac	ppb	lb/ac	filtered		unfiltered		
						ppb	lb/ac	ppb	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.

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, ammonium 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 little affected by treatment as concentrations were not significantly different between treatments or the 1980 concentration (Table 42). 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 for the sheared, chopped and undisturbed watersheds was 2.79, 0.76 and 0.24 lb/acre, respectively. 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 43). 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.

Ammonium concentrations for 1982, decreased on both sheared and chopped watersheds, while increasing on control watersheds, from 1981 levels. Mean discharge weighted concentrations were not significantly different between treatments: sheared (30 ppb), chopped (19 ppb) and control (98 ppb) (Table 43). Ammonium 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 of ammonium 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 ammonium 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 43). 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 attributed to the decrease in organic sediments. The highest concentration (1,382 ppb) of total unfiltered nitrogen was found on WS 2 (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.

Table 43. Mean event and annual nitrogen concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Nitrate		Ammonium		Total Nitrogen				
		ppb	lb/ac	ppb	lb/ac	filtered		unfiltered		
						ppb	lb/ac	ppb	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	30a	.013a	617a	.266a	1050a	.360a	
	Chop	26b	.005b	19a	.005a	490a	.105b	831a	.143b	
	Control	13b	.002b	98a	.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.

Post-treatment - 1983

Nitrate concentrations remained low and were less than values recorded in 1982. The mean discharge weighted concentration of nitrate nitrogen was 54, 20 and 10 ppb for the sheared chopped and control watersheds, respectively (Table 44). The concentration for the sheared watersheds was significantly greater than on the chopped and control watersheds. A maximum nitrate concentration of 321 ppb was reached on WS 9 (chopped) during the June 6 runoff event. Nitrate nitrogen losses were essentially the same as the previous year with the sheared sites recording 0.029 lb/acre, the chopped 0.007 lb/acre and the undisturbed 0.002 lb/acre. Stormflow and nitrate concentrations were high enough on the sheared sites to produce significantly greater nitrate loss than chopped and control sites, which were not different.

Ammonium nitrogen concentrations showed no difference between treatments in 1983. Discharge weighted means were 30, 22 and 23 ppb for the sheared, chopped and control watersheds, respectively (Table 44). Values for sheared and chopped remained about the same as for 1982, while the mean concentration on the control watersheds decreased. Ammonium export increased geometrically from control (0.004 lb/acre) to chopped (0.008 lb/acre) to sheared (0.016 lb/acre) watersheds. The greater volume of runoff on the sheared sites resulted in a significantly greater ammonium loss than the other treatments.

Total nitrogen concentrations both filtered and unfiltered were lower in 1983 than the levels recorded in the previous two years. The

mean discharge weighted total nitrogen (unfiltered) concentrations were 734, 541 and 443 ppb for the sheared, chopped and control sites, respectively (Table 44). This represents over a 30% reduction from 1982 concentrations for all treatments. The decrease can be traced primarily to the reduction in sediment concentrations. Although total nitrogen concentrations were lower than 1982 levels, total nitrogen loss was elevated slightly, due to the larger volume of runoff. The total nitrogen loss from the sheared watersheds (0.371 lb/acre) was significantly greater than the loss from the chopped (0.196 lb/acre) and the undisturbed watersheds (0.082 lb/acre).

A decrease in nitrogen concentrations and losses during 1982 and 1983 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 ammonium 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.

Table 44. Mean event and annual nitrogen concentration and loss the third year following treatment, 1983.

Storm Date	Treatment	Nitrate		Ammonium		Total Nitrogen				
		ppb	lb/ac	ppb	lb/ac	filtered		unfiltered		
						ppb	lb/ac	ppb	lb/ac	
Per event										
Jan 31	Shear (3)*	76	.0017	20	.0004	489	.0106	810	.0165	
	Chop (2)	39	.0007	17	.0003	472	.0093	737	.0146	
Feb 5	Shear (3)	91	.0130	5	.0005	382	.0527	335	.0439	
	Chop (3)	25	.0021	9	.0010	360	.0368	233	.0227	
	Control (3)	15	.0009	8	.0002	413	.0246	191	.0155	
Feb 9	Shear (2)	27	.0009	9	.0003	442	.0142	700	.0218	
	Control (1)	9	.0001	0	.0000	401	.0054	742	.0101	
Feb 20	Shear (1)	28	.0006	30	.0006	438	.0086	675	.0133	
	Chop (1)	26	.0005	40	.0007	446	.0082	811	.0149	
Mar 4	Shear (2)	12	.0004	19	.0005	444	.0129	688	.0203	
	Chop (2)	7	.0002	20	.0005	437	.0111	633	.0170	
	Control (1)	6	.0001	13	.0002	387	.0050	601	.0077	
Mar 23	Shear (3)	21	.0021	7	.0006	451	.0403	789	.0677	
	Chop (3)	9	.0005	17	.0012	444	.0317	651	.0466	
	Control (2)	8	.0003	19	.0009	369	.0182	508	.0219	
Mar 26	Shear (3)	12	.0005	17	.0009	401	.0156	609	.0230	
	Chop (2)	<3	.0001	10	.0003	410	.0135	548	.0190	
	Control (1)	7	.0002	13	.0004	396	.0125	554	.0175	
May 19	Shear (3)	80	.0045	133	.0076	729	.0411	1244	.0666	
	Chop (3)	47	.0012	59	.0015	579	.0169	900	.0245	
May 21	Shear (3)	12	.0013	41	.0045	440	.0458	800	.0850	
	Chop (3)	5	.0005	28	.0026	371	.0358	611	.0572	
	Control (3)	4	.0002	32	.0018	359	.0177	599	.0328	
Jun 6	Shear (2)	57	.0007	51	.0006	341	.0038	488	.0055	
	Chop (1)	321	.0051	31	.0005	352	.0056	723	.0114	
Dec 10	Shear (3)	246	.0041	29	.0005	735	.0134	1812	.0320	
	Chop (1)	<3	<.0001	27	.0002	707	.0061	989	.0085	
	Control (1)	140	.0021	286	.0043	1248	.0189	1477	.0224	
Annual										
	Shear	54a#†	.029a	30a	.016a	469a	.243a	734a	.371a	
	Chop	20b	.007b	22a	.008b	411a	.150ab	541b	.196b	
	Control	10b	.002b	23a	.004b	397a	.068b	443b	.082b	

* 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.

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 45). 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 45). 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 46). 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 45. Mean event and annual phosphorus concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Ortho-P		Total P	
		ppb	lb/ac	ppb	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 46. Mean event and annual phosphorus concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Ortho-P		Total P	
		ppb	lb/ac	ppb	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 46. Continued.

Storm Date	Treatment	Ortho-P		Total-P	
		ppb	lb/ac	ppb	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 46). 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 45) with total phosphorus concentrations (Table 46). 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 47). 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.

Table 47. Mean event and annual phosphorus concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Ortho-P		Total P	
		ppb	lb/ac	ppb	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.

Post-treatment - 1983

A decrease in ortho-phosphate concentrations were recorded in the third year after treatment. Discharge weighted ortho-phosphate concentrations were less than 3 ppb on both sheared and chopped watersheds with a mean of only 5 ppb on the control watersheds (Table 48). A maximum concentration of 14 ppb was found on both chopped and control sites during the year. Ortho-phosphate losses were negligible at 0.006 lb/acre for the sheared watersheds, 0.0010 lb/acre for the chopped and 0.0005 lb/acre for the control watersheds. There was no difference between treatments.

Total phosphorus concentrations also declined in 1983. Discharge weighted total-P concentrations were 35, 30 and 35 ppb, for the sheared chopped and undisturbed treatments, respectively (Table 48). The continued reduction in sediment concentrations and the associated organic phosphorus, has resulted in lower total-P concentrations. Total phosphorus export decreased on sheared sites (0.0185 lb/acre), but increased slightly on chopped (0.0112 lb/acre) and control sites (0.0056 lb/acre). There was no difference in losses between sheared and chopped sites or between chopped and control sites.

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

Table 48. Mean event and annual phosphorus concentration and loss the third year following treatment, 1983.

Storm Date	Treatment	Ortho-P		Total P	
		ppb	lb/ac	ppb	lb/ac
Per event					
Jan 31	Shear (3)*	3	.0001	47	.0009
	Chop (2)	11	.0002	43	.0008
Feb 5	Shear (3)	<3	<.0001	17	.0023
	Chop (3)	3	.0004	23	.0024
Feb 9	Control (3)	14	.0004	41	.0020
	Shear (2)	<3	<.0001	5	.0001
Feb 20	Control (1)	<3	<.0001	7	.0001
	Shear (1)	0	.0000	38	.0007
Mar 4	Chop (1)	4	.0001	37	.0007
	Shear (2)	<3	<.0001	32	.0010
Mar 23	Chop (2)	<3	<.0001	33	.0009
	Control (1)	<3	<.0001	34	.0004
	Shear (3)	<3	<.0001	28	.0025
Mar 26	Chop (3)	<3	<.0001	31	.0020
	Control (2)	<3	<.0001	37	.0018
	Shear (3)	<3	<.0001	28	.0011
May 19	Chop (2)	<3	<.0001	20	.0007
	Control (1)	0	.0000	22	.0007
	Shear (3)	<3	<.0001	72	.0040
May 21	Chop (3)	<3	<.0001	43	.0013
	Shear (3)	0	.0000	37	.0041
	Chop (3)	<3	<.0001	33	.0033
Jun 6	Control (3)	0	.0000	32	.0017
	Shear (2)	<3	<.0001	37	.0004
	Chop (1)	3	<.0001	55	.0009
Dec 10	Shear (3)	7	.0001	134	.0024
	Chop (1)	14	.0001	60	.0005
	Control (1)	6	.0001	57	.0009
Annual					
	Shear	<3 a#+	.0006 a	35 a	.0185 a
	Chop	<3 a	.0010 a	30 a	.0112 ab
	Control	5 a	.0005 a	35 a	.0056 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 49). 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 50). 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. On the sheared watersheds the annual export of K was 6.41 lb/acre, compared to 4.07 lb/acre on the chopped

Table 49. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss by watershed prior to treatment, 1980.

Storm Date	Watershed	Calcium		Magnesium		Potassium		Sodium	
		ppm	lb/ac	ppm	lb/ac	ppm	lb/ac	ppm	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.

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

Table 50. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss the first year following treatment, 1981.

Storm Date	Treatment	Calcium		Magnesium		Potassium		Sodium	
		ppm	lb/ac	ppm	lb/ac	ppm	lb/ac	ppm	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 50. Continued.

Storm Date	Treatment	Calcium		Magnesium		Potassium		Sodium	
		ppm	lb/ac	ppm	lb/ac	ppm	lb/ac	ppm	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 50). 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 significantly 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 50). 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 50). 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 cation 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 51). 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 values for all treatments. The Mg concentration on the sheared sites was 1.3 ppm, which did not differ significantly from the 1.2 ppm found on the chopped and control sites (Table 51). 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 51). 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).

Sodium concentrations were elevated above 1981 levels on all three treatments, although there was no significant difference between the

Table 51. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss the second year following treatment, 1982.

Storm Date	Treatment	Calcium		Magnesium		Potassium		Sodium	
		ppm	lb/ac	ppm	lb/ac	ppm	lb/ac	ppm	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
	Control (1)	1.2	.050	1.3	.052	3.5	.146	2.0	.081
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.

treatments. Annual discharge weighted concentrations ranged from 1.9 ppm on the control sites, to 2.4 ppm on the chopped sites (Table 51). 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.

Post-treatment-1983

Cation concentrations continued to decline in the third year following treatment. The discharge weighted calcium concentration was 0.9 ppm for all three treatments (Table 52). Calcium concentrations during the year ranged from 0.7 ppm to 1.7 ppm, both of which occurred on the control watersheds. Calcium export (0.44 lb/acre) decreased 65% on sheared watersheds below the previous years level, while remaining about the same on chopped (0.37 lb/acre) and control watersheds (0.14lb/acre). There was no difference between treatments.

Magnesium concentrations were also lower during 1983 on sheared and chopped sites, with no change on the control sites. The magnesium concentration on the sheared watersheds was 1.0 ppm and was not significantly different from 1.1 ppm recorded on the chopped watersheds or the 1.2 ppm on the control watersheds. Over one-third of the magnesium export for the year occurred during the month of May. The sheared sites recorded the greatest loss with 0.51 lb/acre, followed by the chopped with 0.44 lb/acre and the control with 0.20 lb/acre. The loss from the control sites was significantly lower than from the sheared and chopped sites.

Table 52. Mean event and annual calcium, magnesium, potassium and sodium concentration and loss the third year following treatment, 1983.

Storm Date	Treatment	Calcium		Magnesium		Potassium		Sodium	
		ppm	lb/ac	ppm	lb/ac	ppm	lb/ac	ppm	lb/ac
Per event									
Jan 31	Shear (3)*	0.8	.019	1.0	.023	3.8	.078	2.7	.043
	Chop (3)	1.1	.022	1.4	.028	4.1	.082	3.0	.061
Feb 5	Shear (3)	0.8	.110	0.9	.121	3.0	.401	1.0	.131
	Chop (3)	1.0	.103	1.1	.109	2.7	.291	1.3	.137
	Control (3)	0.9	.049	1.2	.071	2.3	.125	1.8	.079
Feb 9	Shear (2)	0.8	.024	1.0	.030	3.0	.094	1.3	.038
	Control (1)	1.7	.022	1.3	.017	3.2	.043	1.4	.018
Feb 20	Shear (1)	0.8	.016	1.1	.021	3.3	.064	1.7	.034
	Chop (1)	1.4	.025	1.6	.028	5.0	.092	4.7	.085
Mar 4	Shear (2)	0.8	.023	1.0	.030	3.1	.087	1.5	.042
	Chop (2)	1.0	.025	1.3	.033	3.6	.096	2.5	.069
	Control (1)	0.7	.008	1.2	.016	2.5	.032	1.6	.020
Mar 23	Shear (3)	0.8	.067	0.9	.080	2.8	.236	1.3	.101
	Control (2)	0.7	.026	1.1	.047	2.2	.094	1.3	.063
Mar 26	Shear (3)	0.8	.030	0.9	.035	2.8	.103	1.4	.050
	Chop (2)	1.0	.031	1.2	.039	3.4	.112	2.2	.075
	Control (1)	0.7	.023	1.2	.037	2.2	.070	1.4	.043
May 19	Shear (3)	0.9	.049	1.2	.064	3.2	.174	1.9	.104
	Chop (3)	1.6	.064	1.3	.047	3.4	.150	2.4	.113
May 21	Shear (3)	1.0	.105	1.1	.111	2.9	.299	1.4	.144
	Chop (3)	1.3	.137	1.2	.118	4.0	.373	1.8	.172
	Control (3)	0.9	.051	1.2	.066	2.4	.121	1.2	.063
Jun 6	Shear (2)	0.8	.007	1.0	.010	2.5	.025	2.9	.030
	Chop (1)	1.0	.016	1.8	.028	5.4	.085	7.6	.120
Dec 10	Shear (3)	0.7	.015	1.2	.024	7.0	.151	5.0	.093
	Chop (1)	0.7	.006	1.2	.010	9.1	.078	11.5	.099
	Control (1)	1.0	.015	1.3	.020	5.2	.079	1.0	.015
Annual									
	Shear	0.9a#	.44a	1.0a	.51a	3.2a	1.60a	1.5a	.77a
	Chop	0.9a	.37a	1.1a	.44a	3.4a	1.24a	1.9a	.75a
	Control	0.9a	.14a	1.2a	.20b	2.4a	0.38b	1.4a	.22a

* 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.

The concentration of potassium remained relatively unchanged in 1983 for the sheared and chopped sites and decreased 1.0 ppm on the control sites. Mean discharge weighted concentrations were 3.2, 3.4 and 2.4 ppm for the sheared, chopped and undisturbed watersheds, respectively (Table 52). As during the previous year there was no difference between treatments. Potassium losses during 1983 were 75, 70 and 42% less than the amounts recorded in the first year following treatment, from the sheared, chopped and control watersheds, respectively. Total potassium export was significantly lower on the undisturbed sites (0.38 lb/acre) than the sheared (1.60 lb/acre) or chopped sites (1.24 lb/acre).

Sodium concentrations were at about the same level as reported in 1981 and slightly lower than the values in 1982. The annual discharge weighted concentration on the sheared sites was 1.5 ppm compared to 1.9 ppm on the chopped sites and 1.4 ppm on the control sites (Table 52). There was no difference between treatments for either sodium concentrations or losses.

pH, Specific Conductivity and Turbidity

Pre-treatment-1980

During 1980, pH, specific conductivity and turbidity were taken for several of the storms. The pH was measured only on the May 15 storm event and averaged 5.4 for the 9 watersheds (Table 53). 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.

Table 53. 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.

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 54). There was no significant difference in pH between the three treatments. A slight elevation in pH on the two site prepared areas may have resulted from a higher cation concentration (Table 50). 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 February 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 54). 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 55). 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 55). 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

Table 54. 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.

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.

Post-treatment-1983

In the third year following treatment pH values were greater than the previous two years. Mean pH values were 6.5 on the sheared and chopped sites and 6.3 on the control sites (Table 56). Conductivity readings were similar for all treatments, with sheared and chopped sites recording 35 umhos/cm and the control 30 umhos/cm. Conductivity values ranged from 5 umhos/cm on the control site during the December 10 runoff event to 90 umhos/cm on the chopped site during the June 6 event. Turbidity values continued declining in 1983 on the sheared watersheds. There was no difference between the mean annual turbidity value of 47 NTU's on the sheared sites and 38 NTU's on the control sites. Mean turbidity on the chopped sites (16 NTU's) remained unchanged from the 1982 mean and was significantly lower than sheared and control values.

Table 55. 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
Apr 20	Control (1)	5.5	47	17
	Shear (3)	5.7	71	57
	Chop (3)	5.4	47	21
Apr 21	Control (2)	5.7	48	48
	Shear (3)	6.0	117	80
	Apr 24	Shear (2)	6.7	204
Apr 29	Shear (3)	6.2	198	96
	Chop (2)	5.6	51	25
May 13	Control (1)	5.4	34	67
	Shear (3)	6.3	94	66
	Chop (3)	6.5	94	18
May 17	Control (1)	6.0	47	42
	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 followed by the same letter are not significantly different ($P < .05$) according to Duncan's multiple range test.

Table 56. Mean pH, specific conductivity and turbidity the third year following treatment, 1983.

Storm Date	Treatment	pH	Specific Conductivity umhos/cm	Turbidity NTU
Jan 31	Shear (3)	6.6	31	49
	Chop (2)	6.7	39	11
Feb 2	Shear (3)	6.7	28	24
	Chop (3)	6.7	31	11
	Control (3)	6.7	32	26
Feb 9	Shear (2)	7.0	30	25
	Control (1)	7.0	32	27
Feb 20	Shear (1)	6.4	35	38
	Chop (1)	6.7	67	9
Mar 4	Shear (2)	6.8	34	35
	Chop (2)	6.8	46	14
	Control (1)	6.8	37	40
Mar 23	Shear (3)	6.4	29	28
	Chop (3)	6.5	32	15
	Control (2)	6.5	29	37
Mar 26	Shear (3)	6.5	29	28
	Chop (2)	6.6	37	11
	Control (1)	6.5	29	28
May 19	Shear (3)	6.1	39	60
	Chop (3)	5.9	38	17
May 21	Shear (3)	6.8	25	39
	Chop (3)	6.6	29	16
	Control (3)	6.6	29	44
Jun 6	Shear (2)	6.3	41	74
	Chop (1)	6.1	90	41
Dec 10	Shear (3)	6.1	57	120
	Chop (1)	5.9	30	24
	Control (1)	6.3	5	76
Mean - 1983	Shear	6.5 a*	35 a	47 a
	Chop	6.5 a	35 a	16 b
	Control	6.6 a	30 a	38 a

* Means for each treatment followed 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 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.

Less rainfall and revegetation of the treated watersheds, resulted in decreased runoff, sediment and nutrient losses in 1982. Water

yield decreased 66% on the sheared sites and 57% on the chopped sites during the second year following treatment. Differences between treatments narrowed as sediment and nutrient concentrations decreased.

Water yield in the third year following treatment increased slightly above 1982 levels. Sediment concentrations and losses continued to decrease, primarily on the sheared watersheds as the surface soil exposure decreased. Nutrient concentrations and losses for both sheared and chopped watersheds were approaching or meeting levels found on the control watersheds.

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 be wider. 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

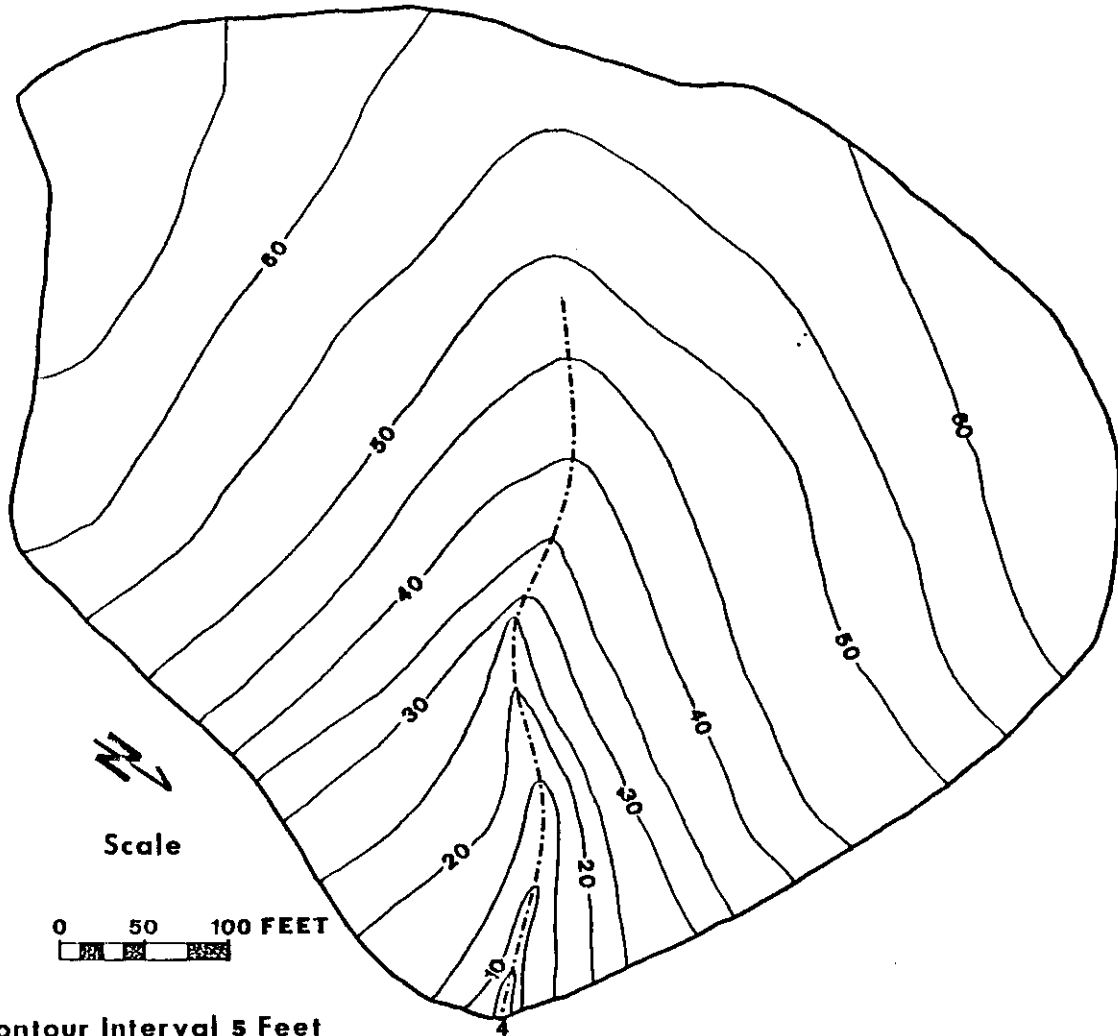
<u>Common Names</u>	<u>Trees</u>	<u>Scientific Names</u>
Pine		
Loblolly Pine		Pinus taeda
Shortleaf Pine		Pinus echinata
Oak		
Southern Red Oak		Quercus falcata
Blackjack Oak		Quercus marlandica
Post Oak		Quercus stellata
White Oak		Quercus alba
Water Oak		Quercus nigra
Hickory		
Mockernut Hickory		Carya tomentosa
Elm		
Winged Elm		Ulmus alata
Slippery Elm		Ulmus rubra
Sweetgum		Liquidambar styraciflua
Dogwood		Cornus florida
	<u>Shrubs and Vines</u>	
American Beautyberry		Callicarpa 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



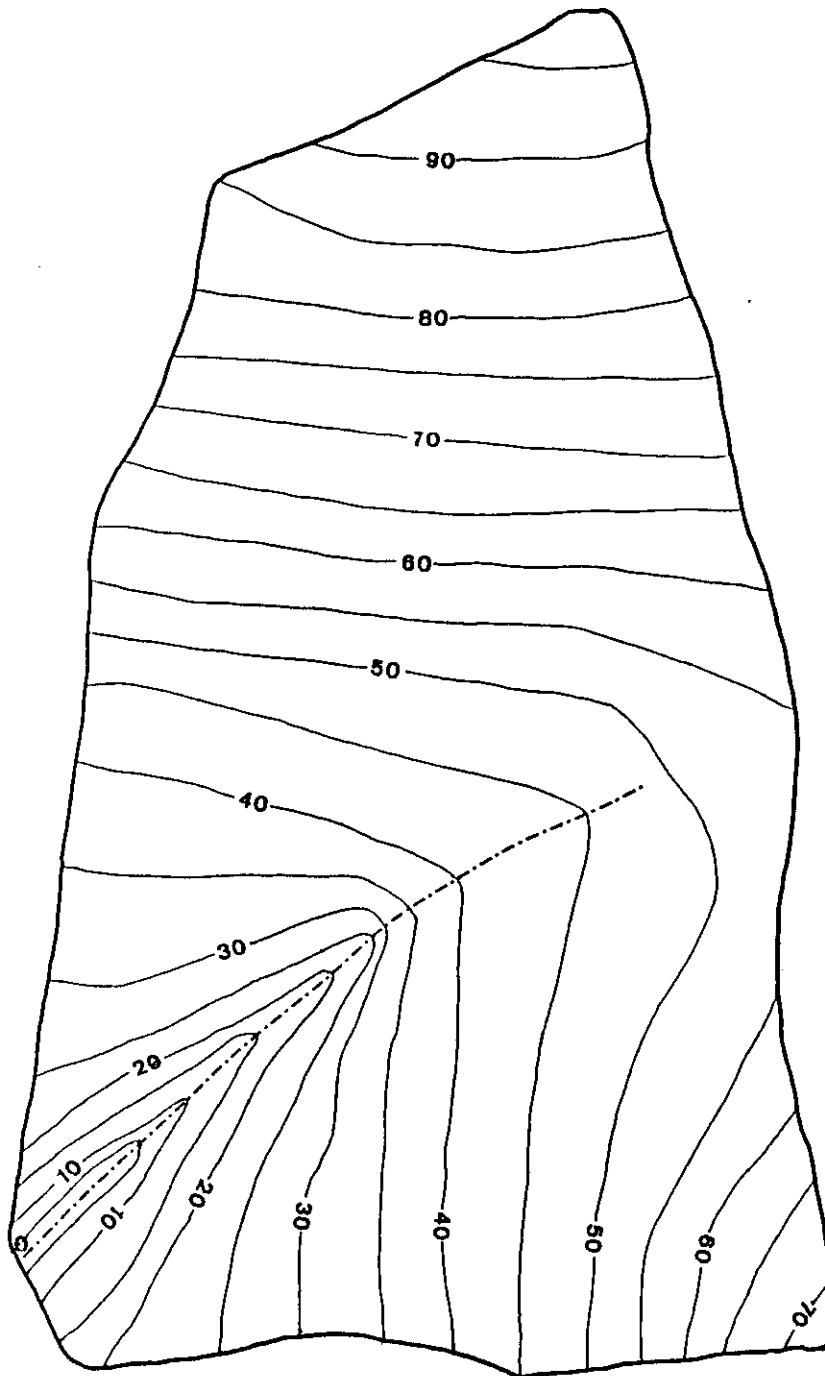
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Cherokee County Texas

EXPERIMENTAL WATERSHED

NUMBER 2

6.37 ACRES



Scale



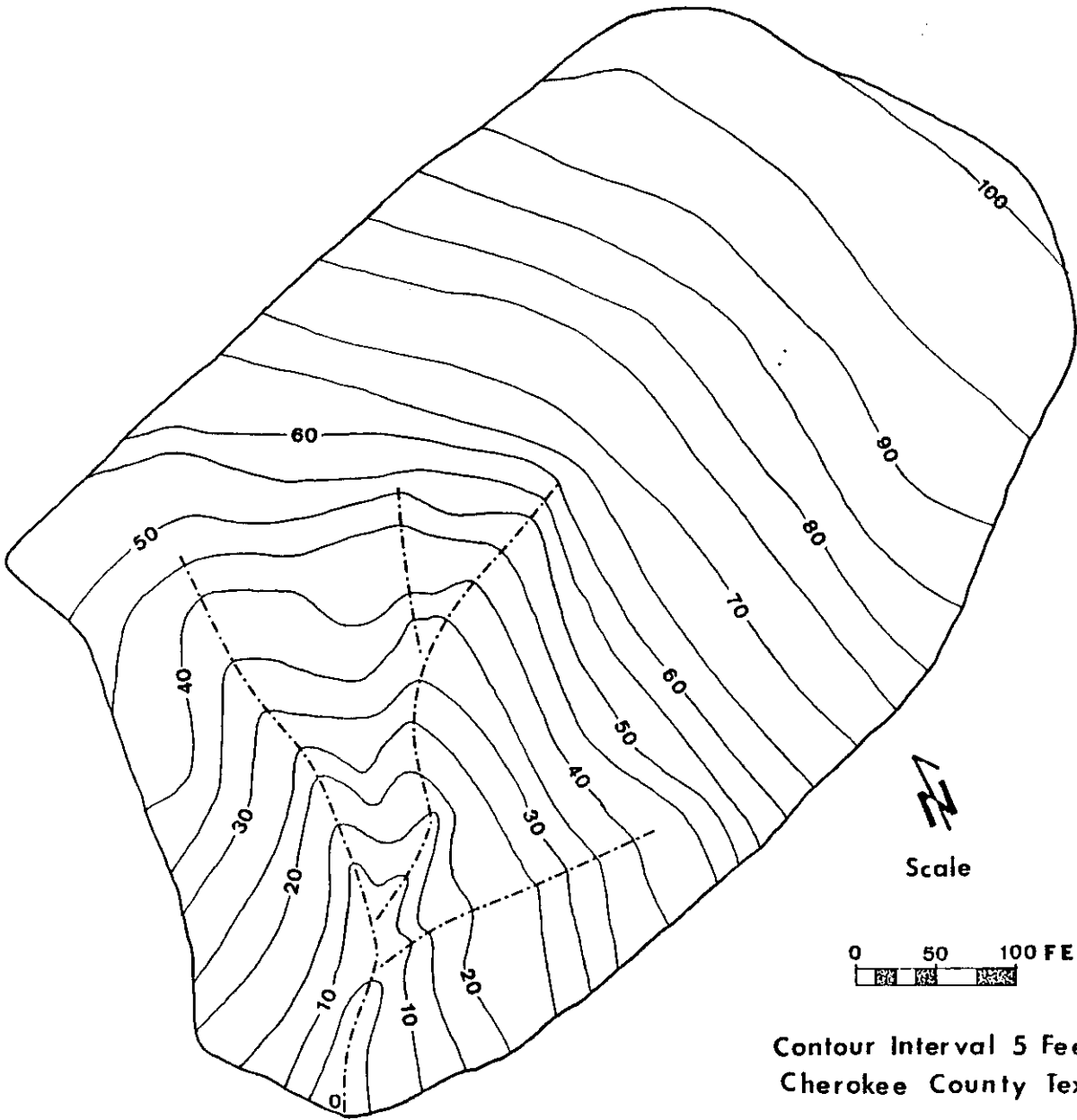
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Cherokee County Texas

EXPERIMENTAL WATERSHED

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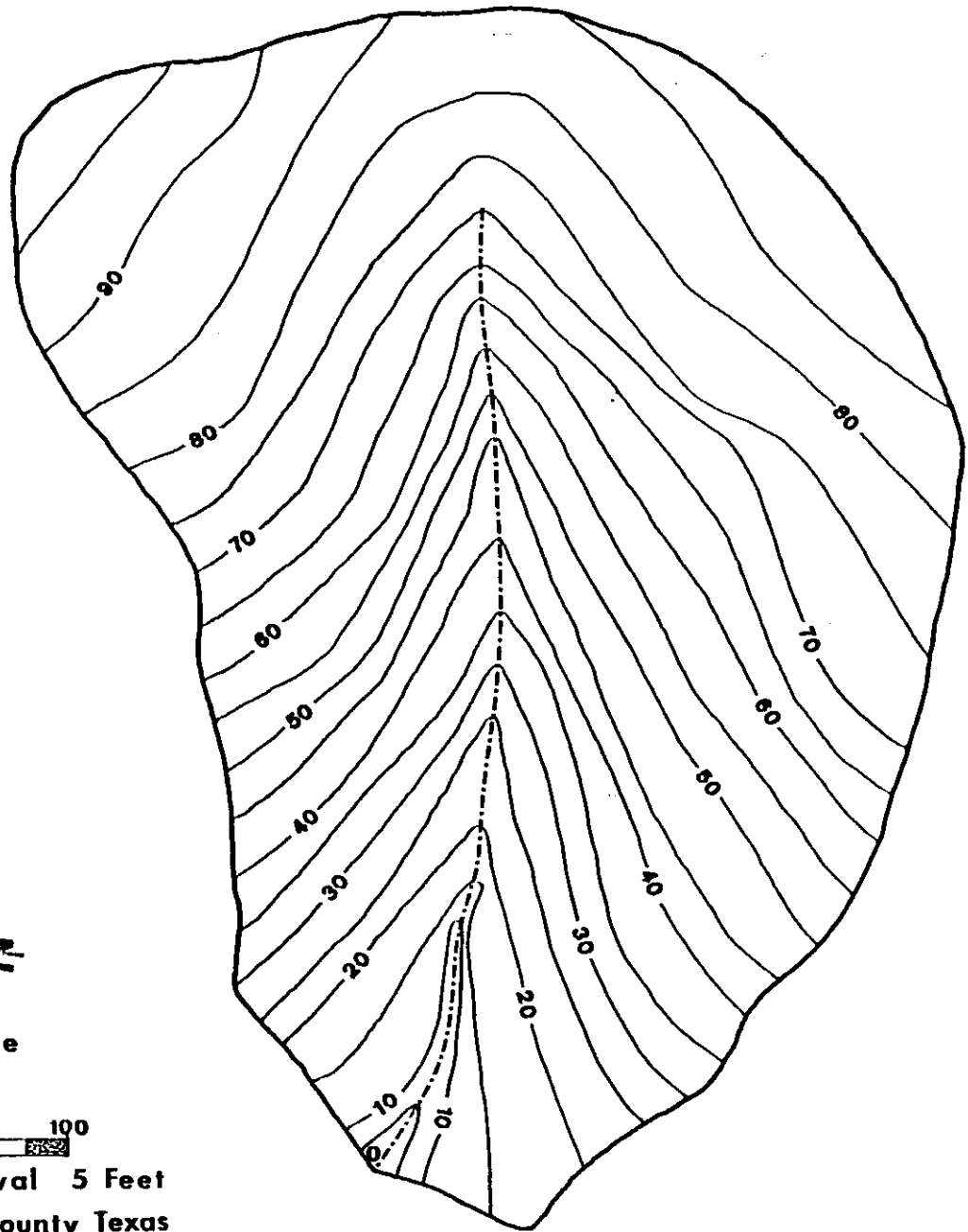
6.52 ACRES



EXPERIMENTAL WATERSHED

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6.58 ACRES



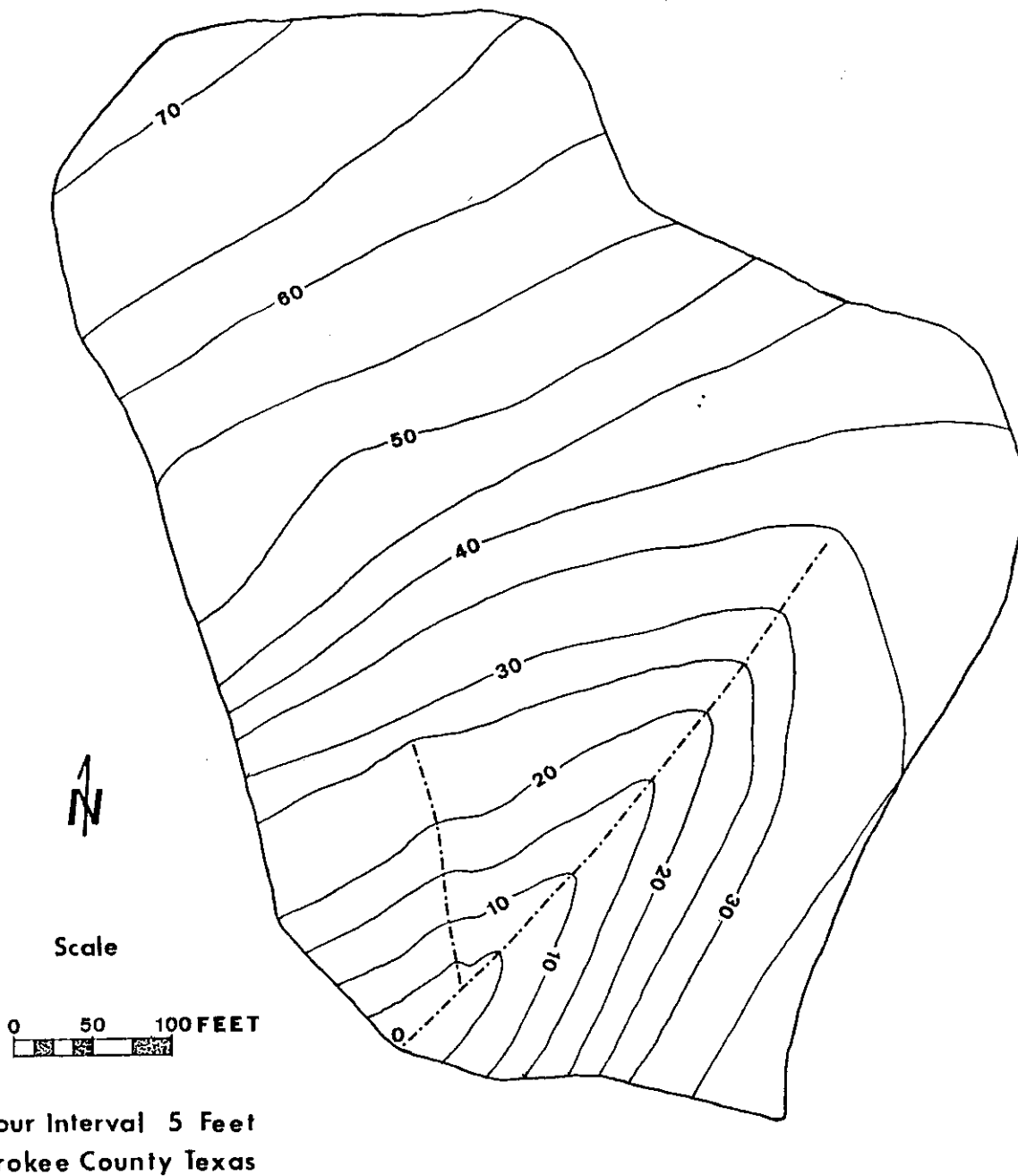
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Cherokee County Texas

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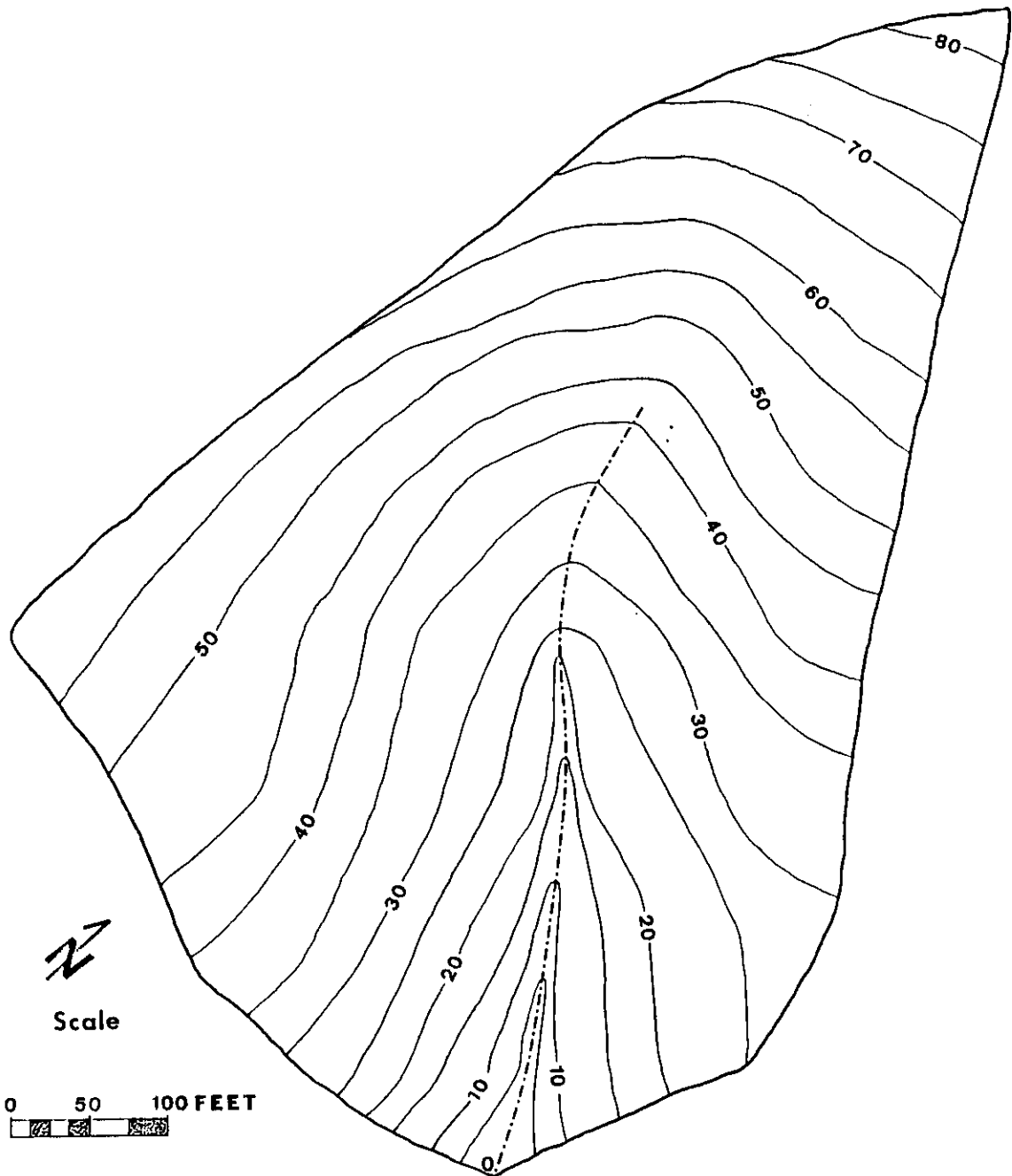
NUMBER 5 6.70 ACRES



EXPERIMENTAL WATERSHED

NUMBER 6

6.58 ACRES

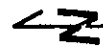
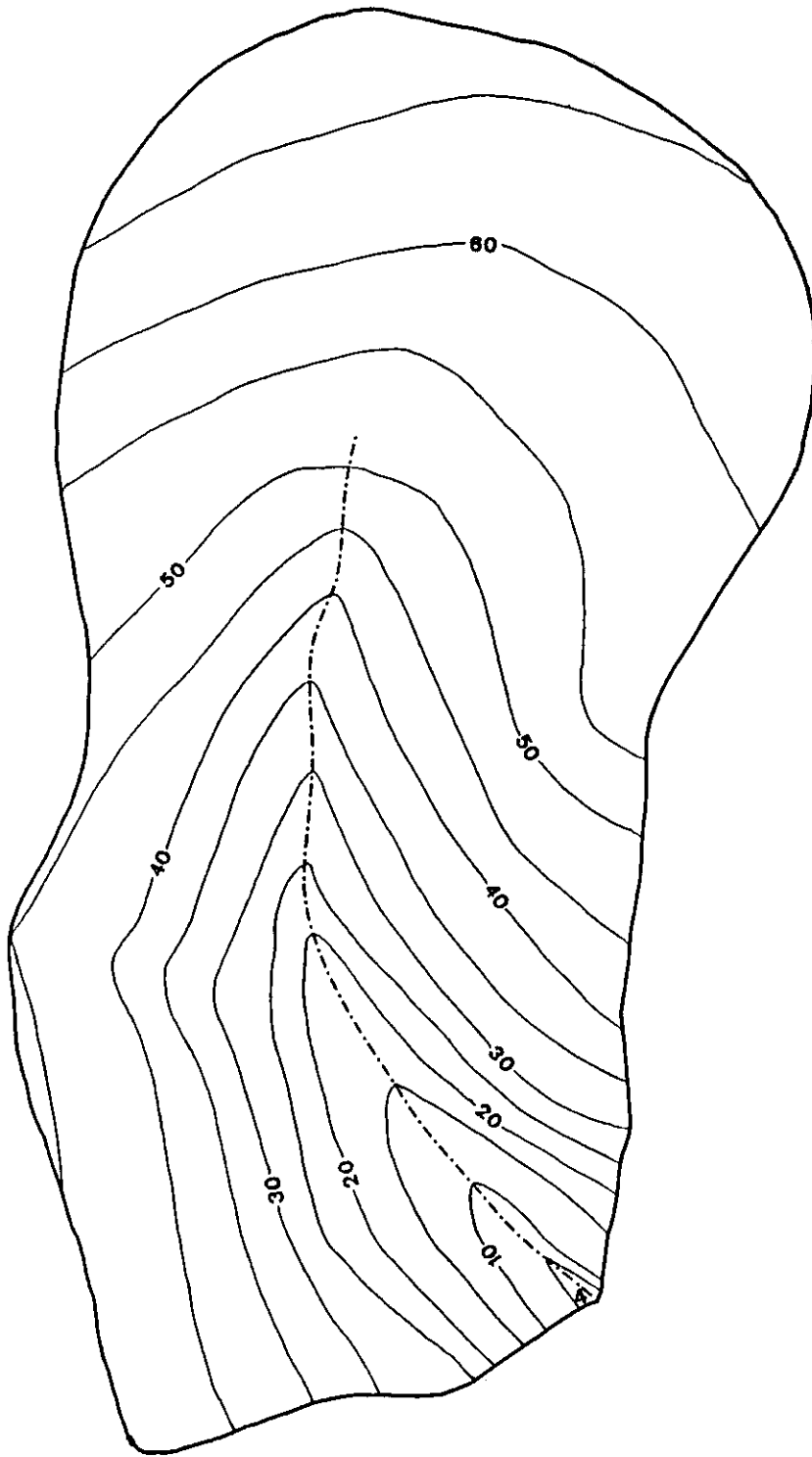


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EXPERIMENTAL WATERSHED

NUMBER 7

6.78 ACRES



Scale



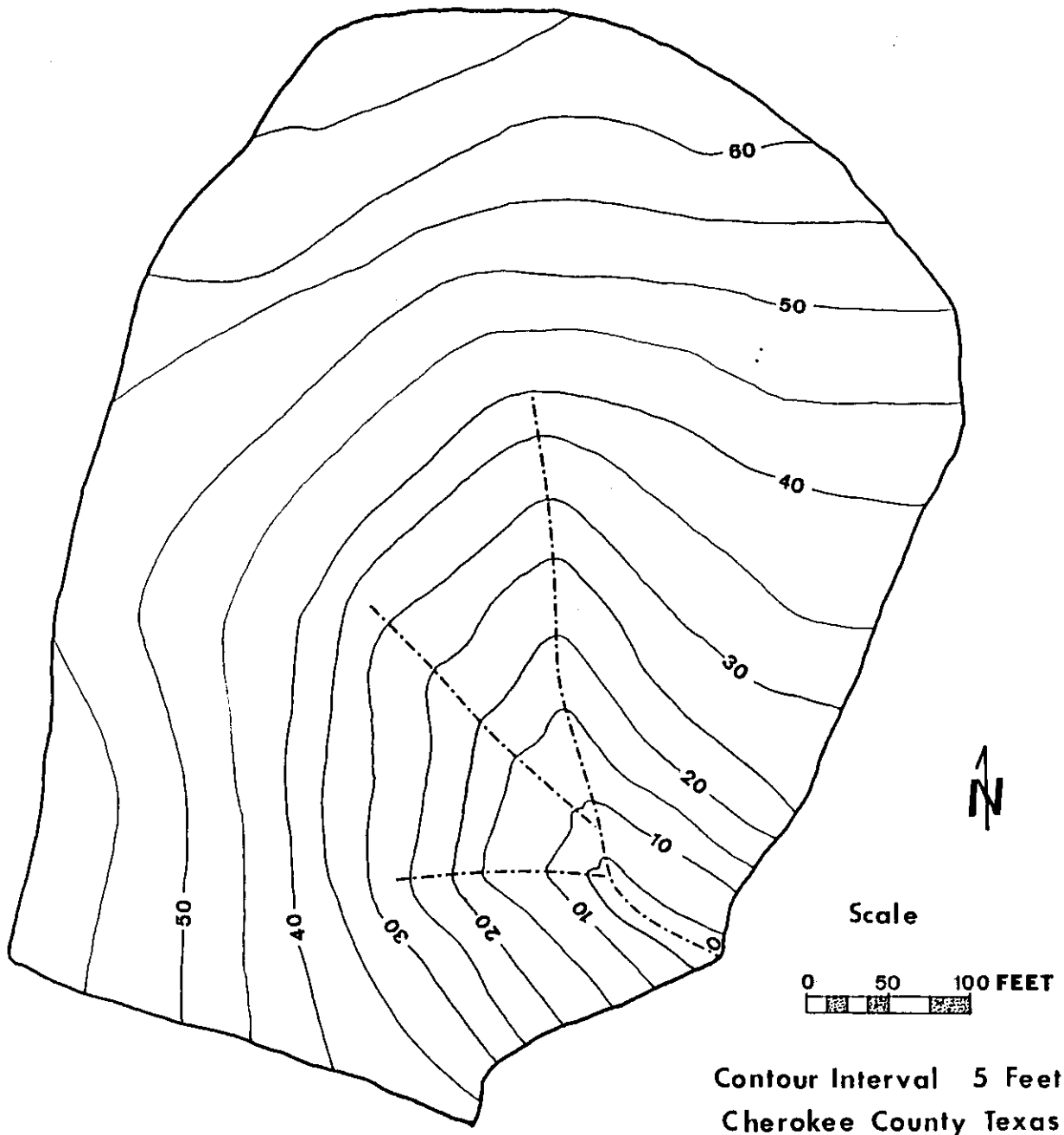
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Cherokee County Texas

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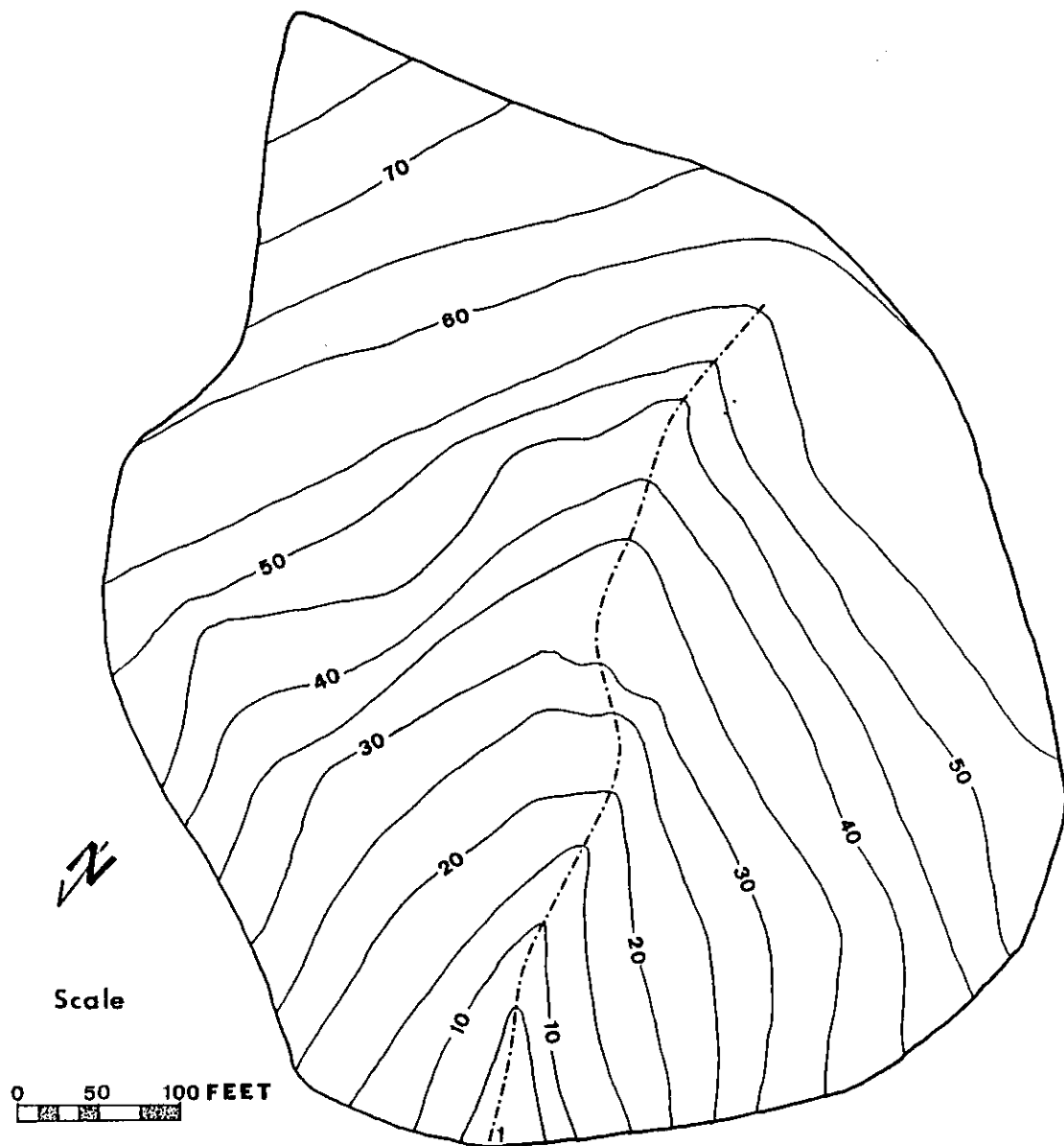
6.46 ACRES



EXPERIMENTAL WATERSHED

NUMBER 9

6.76 ACRES



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Cherokee County Texas