TR- 124
1983

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Effect of Forest Site Preparation and Livestock Grazing on Stormflow and Water Quality in the South East

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ASSESSMENT OF STORMFLOW AND WATER QUALITY FROM GRAZED AND SITE PREPARED FOREST LAND IN THE SOUTHEAST

Interim Progress Report

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August 1983

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INTRODUCTION

The commercial forestlands of East Texas and Louisiana are the most water-efficient producing areas of the two states. Current and projected water shortages for Texas makes this water-rich area extremely important to future growth and development of Texas. However, little is known about the influence of intensive forest practices or livestock grazing on water quality, yield or site productivity in Texas. This is the only instrumented watershed study in Texas or Louisiana that is currently evaluating the influence of livestock grazing on water and the second study evaluating the impact of intensive forest practices on water.

This research is providing information that will enable forest managers, state and federal agencies to select livestock grazing and/or forest management practices that will maintain a productive forest environment and minimize off-site water quality impacts. It is imperative that if Texas in the next 30 years is: 1) to help meet the timber product demand that is projected to be placed on the Southeast, and 2) to meet the projected water shortages we need to understand the impact of intensive forest and livestock grazing practices on site productivity and water. This research is helping provide the basic information needed to manage Southeast forestlands for timber products, red meat and water.

The southern states are currently producing half of the nation's wood supply with large demands to increase timber production expected in the next 20 years. The challenge facing forestry in the South is in developing technology and management to meet this increased demand and maintain an acceptable forest environment in the face of increased taxes, rising labor, equipment and energy costs. The intensive forest management practices of harvesting and site preparation have been identified as causing potential declines in site production and as sources of nonpoint pollution. The Clean Water Act (PL 92-500 and PL 95-217) requires identification and control of silvicultural activities and livestock grazing which contribute to nonpoint source pollution. Implementation of "best management practices", either voluntary or mandatory, are the suggested means for maintaining water quality and site productivity.

Hydrologic impacts of livestock grazing result primarily from the interactions of climate, vegetation, soil, and intensity and duration of livestock use. Thus, grazing impacts will vary naturally from area to area due to the normal variability of these factors. Few studies have attempted to account for these natural variations. Documentation of the intensity and duration of livestock grazing has been poor or completely ignored in most studies.

In East Texas, the impact of livestock grazing on water quality has had no research effort. Most research regarding the impact of grazing upon water quality has been conducted outside the Southern Region and, more importantly, outside of the Gulf Coastal Plains. Because geology, soils , topography, climate, etc. are different, extensions of that research to the East Texas and Louisiana areas may be misleading.

OBJECTIVES

The objectives of this project are:

1) to develop baseline data on stormflow and water quality from stabilized forest sites (those which have been relatively undisturbed for a period of 15-20 years).

2) to assess the impact of clearcutting and mechanical site preparation on soil erosion, stormflow and water quality,

3) to assess the impact of livestock grazing and no grazing on soil erosion, stormflow and water quality.

PREVIOUS WORK

The long history of woodland overgrazing and poorly designed studies to evaluate proper livestock management has given the grazing animal a bad image in eastern forestry (Lee 1980; Johnson 1962; Adams 1975). Most of the studies conducted in eastern forests have evaluated the impacts of heavy, continuous grazing. Dissmeyer (1976), using his First Approximation of Suspended Sediment (FASS) method to evaluate soil loss on the southeast stated that in some areas, overgrazing of woodland is clearly the major source of sediment production.

Water Yield

Water yield from the undisturbed forest is regulated by the vegetation, soils, topography, and climate. Precipitation in the form of rain is the most common input for the humid region of the southeastern United States. Of the precipitation falling on a mature forested watershed, from 10 to 30 percent is intercepted by the forest canopy and lost as evaporation (Rogerson 1967). In most cases, the rain reaching the forest floor filters through the litter covered surface and infiltrates into the soil. Under certain circumstances of prolonged rainfall, where the soil becomes saturated, the infiltration rate is reduced and overland flow may occur. 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 or killed. In this study, the annual discharge increased up to 12.7 area-centimeters the first year following clear-cutting. Another study (Aubertin and Patric 1974) on the Fernow Experimental Forest found that clearcutting increased streamflow 20.3 area-centimeters during the first year following cutting. Rapid revegetation reduced the increase in streamflow to 6.4 area-centimeters by the second year.

Clearcutting followed by roller chopping, in the Georgia Piedmont, resulted in a first year water yield increase of 25.4 area-centimeters (Hewlett 1979). This represented an increase of 27 percent above pretreat-ment stormflow. The cumulative effects of forest operations more than doubled small stormflows and peaks, but were proportionally less influential on 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 50.8, 45.7, 50.8, and 7.6 area-centimeters, 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 defined as solid material both mineral and organic that has been eroded from its original source by water, wind, ice, or some other geologic agent and is being transported or has come to rest on the earth's surface (Soil Conservation Society of America 1970).

Erosion that occurs under natural environmental conditions of climate and vegetation, undisturbed by man, is called geological, natural, or normal erosion. Estimates of annual rates of geologic deposition in the United States range from less than 0.13 to 0.31 metric tons per hectare (Menard 1961; Smith and Stamey 1965). Erosion that is primarily a result of man's activities is called accelerated erosion (Soil Conservation Society of America 1970).

There are three basic types of erosion on forested watersheds. Surface erosion is 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, thin film flow, or concentrated surface runoff over the watersheds. Mass movement, such as landslides and slumps, is an important form of erosion in mountainous country. Channel cutting or the detachment and movement of material from a stream channel, may result in the movement of individual particles, as the grains of shifting sandbars, or in mass movement, as when a large part of an under cut bank may fall and be swept downstream in a flood. Sediment produced as a result of erosion may be deposited in places other than a stream.

Sediment concentrations in rivers of the United States range from 2,000 to 50,000 milligrams per liter (Glymph and Carson 1968). The amount of sediment moved by flowing water has been reported to average at least 3.6 billion metric tons per year, with about 0.9 billion metric tons reaching major streams (Freeman and Bennett 1969). Estimates ascribe about 30 percent of this country's sediment to geologic erosion and about 50 percent to erosion of agricultural lands (Wadleigh 1968). Experimental data from small undisturbed watersheds in the southeast indicate the sediment production may range from 136 to 0.9 kilograms per hectare-centimeter of stormflow (Rogerson 1971; Ursic 1975; Beasley 1977 and Douglass 1977). However, there is not data available for Texas or Louisiana conditions.

Harvesting and Site Preparation - Research data on the impacts of harvesting and site preparation for the South are sparse. However, a few studies are being conducted and some inferences can be drawn. 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 opens the soil up 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 reducing infiltration and increasing surface runoff (Edwards and Larson 1969). Removal of vegetation and litter also reduces resistance to overland flow and increases water velocity which in turn increases the carrying-power of runoff (Douglass 1975).

Beasley (1977) studied the impact of intensive site preparation treatments in the upper Coastal Plain of Mississippi. Three of the treatments compared were: 1) roller chopping and burning; 2) shearing, windrowing and burning; and 3) control, no logging, site preparation or other disturbance. After site preparation the treated watersheds were fertilized, limed, and sown with Mississippi Subterranean Clover and planted with loblolly pine seedlings.

Results showed that shearing and windrowing exposed the greatest percentage of mineral soil (57% compared to 37% for roller chopping) Table 1). Discharge weighted sediment yield was similar (0.3 to 0.4

metric tons/hectare-centimeter stormflow) for both of the treated watersheds, but was significantly higher than the control (0.07 metric tons/hectare-centimeter stormflow). Sediment yield was greatest during November, January, February, and March, the months with the greatest stormflow.

Table 1. Hydrologic and site data for two site prepared and one control watershed in northern Mississippi (Beasley 1979).

Treatment	Exposed Mineral Soil (%)	Sediment Yield (Metric tons/hectare)	Discharge Weighted Sediment Concentrations (Metric tons/ hectare-centimeter)
Control	--	.009	0.07
Chopped	37	2.497	0.32
Sheared and windrowed	37	2.837	0.36

Douglass (1977) evaluated three intensive site preparation treatments: 1) shearing with a KG blade; 2) shearing and disking; and 3) shearing, disking, fertilizing and grass seeding, in the North Carolina Piedmont. All treatments except the control were windrowed, burned and planted to loblolly pine. He found that one year after treatment, the shearing, disking and shearing treatment produced the largest sediment yield (0.34 and 0.39 metric tons/hectare-centimeter stormflow, respectively) (Table 2). The shearing, disking, fertilizer and grass seeding treatment reduced sediment by one-third (0.1133 metric tons/hectare-centimeter stormflow) but produced five times more sediment than the control (0.02266 metric tons/hectare-centimeter stormflow).

Table 2. Stormflow and sediment yield from site prepared watersheds, North Carolina Piedmont (Douglass 1977).

Treatment	Stormflow (hectare-centimeters)	Sediment Yield (Metric tons/ hectare)	Discharge Weighted Sediment Concentrations (Metric tons/ hectare-centimeter
Control		0.02	0.02
Shear and Disk		1.00	0.34
Shear		0.47	0.39
Shear, Disk, Fertilize Plant Grass		0.12	0.11

A paired watershed experiment on the southern piedmont of Georgia produced relatively low levels of sediment from the watershed site prepared by double-roller chopping. Sediment production was increased over the control watershed 36 kilograms/hectare-centimeter of stormflow by harvesting and 213 kilograms/hectare-centimeter of stormflow by roller chopping (Hewlett 1979).

Hunter and Miller (1976) studied soil erosion following site preparation and planting in East Texas. During the first year after treatment they observed no excessive erosion and concluded that some erosion and deposition occurred within this disturbed area, but little sediment moved off the watershed.

The variability in research data is a reflection of the broad range of factors that interact to determine what the impact of site preparation will be on erosion and increased sediment. Factors such as topography, soil characteristics, size of the cleared area, method of timber removal, natural revegetation, and methods of observation all play a role.

Livestock Grazing - Researchers outside the South Central region have measured erosion and sediment production resulting from livestock grazing at different stocking rates with several kinds of classes of livestock on a continuous or seasonal basis. Very few studies have investigated sediment production from grazing systems with some sequence of grazing and resting periods. Research data on the impact of livestock grazing for the South Central region are non-existent.

Renner (1936) found that the degree of erosion on the Boise River watershed was correlated with grazing intensity with low intensity having some effect on erosion. Dunford (1949) concluded that erosion from a pine (Pinus spp.) bunchgrass region of Colorado was not significantly changed by moderate grazing, but heavy grazing doubled the normal amount of erosion, compared to that from no grazing. On fescue (Festuca spp.) rangeland in Saskatchewan, Johnston (1962) found soil losses were not serious under light, moderate, or heavy rates of grazing.

Aldon and Garcia (1973) indicated that the Rio Puerco drainage in New Mexico was infamous for contributing only 8% of the water yield of the upper Rio Grande Basin, but almost half the sediment load. After years of continuous yearlong grazing, the watersheds were fenced to obtain 55% forage utilization with summer-deferred grazing. Under this grazing treatment, sediment production decreased from 1.9 to .6 metric tons/hectare. Buckhouse and Gifford (1976) found that grazing pinyon (Pinus edulis Engelm)-juniper (Juniperus spp. L.) sites in southeastern Utah caused no changes in sediment production.

McGinty et al. (1979) measured sediment losses from a simulated rainfall event of 210, 134 and 159 kilograms/hectare from a heavily stocked, continuously grazed treatment; a four-pasture, three-herd deferred-rotation treatment; and a 30-year-old livestock exclosure, respectively. Sediment production increased with decreasing soil depth of range sites.

Wood (1979) studied sediment production as influenced by livestock grazing in the Texas Rolling Plains. He found the midgrass interspace sediment production for the heavily stocked, continuously grazed treatment exceeded that of the deferred-rotation treatment and the exclosures. Likewise, sediment production for the grazed short duration treatment was larger than for the rested deferred-rotation treatments and exclosures.

Nutrients

Undisturbed forested watersheds are primary sources of high-quality water (Satterlund 1972; Corbett et al. 1975). Mineral and organic nutrients continually enter the forest soil by: 1) decomposition and weathering of mineral rock; 2) atmospheric inputs; and 3) biological inputs. Nutrients are continually lost from the soil in an undisturbed forest by: 1) natural soil erosion, 2) leaching of dissolved nutrients; 3) uptake into plants, 4) volatilization to the atmosphere by fire. This process results in a small outflow of nutrients from the forest to the sea. The amounts of nutrient 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; Corbett et al.

1975). The quantity of nutrients in streams evidently increases when the rate of decomposition of residues exceeds the uptake by vegetation and the exchange capacity of the soil (Rothacher and Lopushinsky 1974). The results from five small undisturbed watersheds of loblolly pine, planted to control erosion in northern Mississippi, showed that the annual inputs from rainfall and dry fallout of nitrate and ammonia nitrogen, inorganic phosphate, calcium, and potassium exceeded the losses as dissolved constituents in intermittent stormflows (Ursic 1974).

There is relatively little data available concerning nutrients in undisturbed forested watersheds in Texas. Examples used pertain mainly to areas outside the state. However, one environmental impact study does provide some insight into the nutrient status of East Texas forested areas. In the Blue Hills Nuclear Power Plant Experimental Study, by Inglis, Clark, Irby and Moehring (1976), data was collected concerning nutrients from three relatively undisturbed areas in East Texas. Nitrate-, nitrite-, ammonia-nitrogen, ortho-phosphate, total inorganic phosphate, sulfate, and chloride concentrations were studied in streams running through these areas. Nitrite-nitrogen values were very low at all stations ranging from 0.00 to 0.07 mg/liter with the majority being 0.00. Nitrate-nitrogen concentrations ranged from 0.00 to 1.00 mg/liter. The unusually high values at one sampling point were due to occasional fertilizer runoff. Concentrations of ammonia varied from 0.00 to 2.00 mg/liter. Orthophosphate concentrations ranged from a low of 0.03 to a high of 0.05 mg/liter. There was a tendency for higher values at stations with greater discharge. Total inorganic phosphates followed trends similar to those for orthophosphate. Concentrations varied from 4 to 7 mg/liter. Chloride concentrations were similar for all stream stations. Stream concentrations seemed to be connected to rainfall. Apparently, chloride was washed into the stream during times of higher discharge which made the concentrations per unit volume of water lower. When the discharge of the stream subsequently dissipated, the chloride concentrations per volume of water increased. Chloride concentrations ranged from 0.00 to 15 mg/liter, with the majority of samples between 5 and 10 mg/liter.

There have been many studies done concerning nutrient levels from forested watersheds outside Texas. Likens et al. (1970) reported pre-treatment maximum concentrations of nitrate-nitrogen to be 0.5 mg/liter at the Hubbard Brook Experimental Forest in New Hampshire. In a West Virginia study where a 10-20 meters wide buffer strip was left after harvesting, nitrate-nitrogen levels in streamwater following harvesting varied from 0.18 mg/liter to 0.49 mg/liter. Phosphate concentration increased while sulfate concentrations decreased. There were negligible changes in calcium, magnesium, sodium, potassium, iron, copper, zinc, manganese, and ammonium-nitrogen (Aubertin and Patric 1972). It seems apparent that even after harvesting if a buffer strip is left bordering a stream and the area is revegetated rapidly, nutrient concentrations are increased only slightly, if at all. Douglass and Swank (1975) also reported nitrate-nitrogen levels from undisturbed forested watersheds in North Carolina to be 0.002 to 0.013 mg/liter.

<u>Harvesting and Site Preparation</u> - There is little available data for the

southern United States on the impact clearcut harvesting and site preparation have on chemical water quality. However, a preliminary study (Hewlett 1979) on Georgia's southern piedmont found no evidence of large increases in dissolved mineral concentrations in a stream due to clearcutting or site preparation (Table 3). Although, annual water yield from the treated basin increased by about 60 percent for calcium, potassium, sodium and magnesium and by 100 percent for nitrate-nitrogen and phosphate. These increases are in line with similar studies conducted elsewhere (Corbett, Lynch and Sopper 1975).

Table 3. Dissolved mineral concentrations (as percent of control) in streamwater following clearcutting and site preparation in the southern piedmont of Georgia (Hewlett 1977).

Ions in Stream Water	Before Cutting 12/12/73 to 10/30/74	During Harvest and Roller-chopping 1/1/75 to 12/16/75
	- - - - - - - Percent of control	- - - - - - -
Nitrate Nitrogen	35	52
Total Phosphorus	29	89
Potassium	107	120
Sodium	88	73
Calcium	49	49
Magnesium	46	51

Nutrient losses are often closely tied to sediment losses. Several studies (Schreiber et al. 1976; Duffey et al. 1978) of undisturbed pine plantations have shown that, although yields are low, about one-half of the nitrogen and two-thirds of the phosphorus yields were associated with sediment. Thus, suggesting significant increases in N and P yields if forest management activities increase sediment yield.

Livestock Grazing - There exists virtually no published research concerning the impacts of livestock grazing on nutrient losses (Dixon et al. 1977).

Biolgical

The impact of livestock grazing on bacteria in waters is of concern. Buckhouse and Gifford (1976) studied the impact of livestock grazing on a southeastern Utah pinyon-juniper site which had been chained and windrowed. They found no change in fecal coliform due to livestock grazing. Stephenson and Street (1977) reported that typical rangeland cattle operations in Idaho will probably result in coliform bacterial pollution along various reaches of rangeland streams.

Darling and Coltharp (1973) studied three mountain streams of the Bear River Range in northern Utah and found significant increases in total coliform, fecal coliform and fecal streptococcus counts at locations below areas grazed by cattle and sheep. Schillinger and Stuart (1976) reported that cattle grazing resulted in some bacteriological degradation of water quality in the Bozeman Creek Municipal Watershed, Montana.

Duran and Linn (1979) studied bacteriological quality of runoff water from pastureland in Nebraska. They found bacteriological counts in runoff from both grazed and ungrazed areas generally exceeded recommended water quality standards. Rainfall runoff from the grazed area contained 59 to

10 times more fecal coliforms than runoff from the ungrazed area. There was little difference in total coliforms between the two areas, but fecal streptococci counts were higher in runoff from the ungrazed area and reflected the contributions from wildlife.

Dissolved Oxygen/Organic Matter

Like temperature, dissolved oxygen is an element critical for the existence of a healthy stream environment. Dissolved oxygen concentrations in small forest streams help to determine the character and productivity of the aquatic ecosystem in that fish and other aquatic organisms are dependent on it for survival, growth and development. Forest practices can potentially reduce the concentration of dissolved oxygen present in the water below the lethal limit for some aquatic species. Such practices do this by increasing the amount of organic matter intering the stream, by increasing water temperature (USDA, Forest Service 1977), and in some cases, by the addition of high nitrogen and phosphorus concentrations which stimulate growth of organisms that use oxygen. Dissolved oxygen levels or the organic loading from undisturbed forests of Texas have not been documented; nor has it been documented for harvesting, site preparation, or livestock grazing.

Infiltration/Soil Bulk Density

Heavy livestock grazing has been reported to increase soil bulk density and lower infiltration rates (Table 4), compared to ungrazed areas. Stoeckeler (1959) reported infiltration rates of ungrazed oak woods to be 150

Table 4. Influence of livestock grazing and no grazing on selected watershed parameters of the eastern hardwood and pine forests.

Parameter	Ungrazed	Light grazing	Moderate grazing	Heavy grazing	Location	Reference
Bulk Density (g/cc)	1.09	1.51	-- [1/]	1.54 to 1.91	Pennsylvania	Alderfer and Robinson 1947
	0.92	--	--	1.15	New York	Chandler 1940
	0.51	--	0.92	--	Allegheny River Watershed	Trimble et al. 1951
	1.01	--	--	1.22	South Dakota	Read 1957
	1.32	--	1.39	1.41	Louisiana	Linnartz et al. 1966
Infiltration (cm/hr)	18.8	--	--	0.10	Oak Woods Wisconsin	Stoeckeler 1959
	27.9	--	--	3.1	Scotch Pine Plantation Wisconsin	Stoeckeler 1959
	4.6	--	3.1	2.0	Louisiana	Linnartz et al. 1966

1/ Data not reported.

times greater than adjacent heavily grazed woods. Duvall and Linnartz (1967) reported that infiltration rates of heavily grazed, moderately grazed and ungrazed longleaf pine/bluestem range was 2.0, 3.0 and 4.6 centimeters/hour, respectively. They also stated that compaction by livestock consistently reached the 38 centimeter depth. These findings are contrary to other studies that found grazing impacts were restricted to the surface 15 centimeters and are probably soil texture interactions. Alderfer and Robinson (1947) found soil compaction by cattle was limited to the surface 2.5 centimeters. Lull (1959) reviewed soil compaction on forests and concluded that trampling by livestock may compact the upper 15 centimeters of the soil, exerts pressure equivalent at least to those of heavy tractors, and reduces infiltration as much as logging equipment.

Abusive livestock grazing caused devastating effects on a hardwood watershed at the Coweeta Hydrologic Laboratory (Johnson 1962). Livestock browsing and trampling influenced the timing and quality of water. Storm water flowed to streams over the land surface rather than as subsurface flow. Turbidity was 30.5 mg/liter from the control watershed and 107.5 mg/liter from the grazed watershed. Grazing decreased soil porosity and infiltration rates (Table 5).

Johnson reports that utilization of understory trees 4.6 meters tall or less was so complete that in this size class practically all yellow-poplar, ash, black locust, oak, dogwood, sweet birch and sassafras have disappeared. Trees up to 6.4 centimeters in diameter were ridden down and tops eaten. Forage was so scarce that cattle required supplemental feeding to generate enough strength to range the area. The author contends that this grazing intensity was typical of grazed farm woodlands. The results of this study and other similar ones should not be used to evaluate the impact of proper livestock grazing in eastern forests.

Table 5. Changes in total porosity and infiltration rates of the soil caused by soil trampling expressed as a percent of the control fenced plot, Coweeta Hydrologic Laboratory (Johnson 1962).

	Cove hardwood	Oak hickory on slopes	Pine-oak on ridges
Total porosity			
0-5.1 centimeters	42 1/	15	6
5.1-10.2 centimeters	56 1/	12	6
Infiltration	91 1/	67 1/	--

1/Statistically significant from control.

Increased water temperature can be either beneficial or detrimental. For streams that are cooler than optimum, a moderate increase in temperature could increase productivity and have a beneficial effect on the aquatic environment. However, streams having temperatures that approach critical threshold limits during the summer months may be increased beyond these thresholds; the result could be detrimental to aquatic organisms.

Removal of shading vegetation as a result of timber harvesting or grazing increases stream temperatures because of increased exposure of solar radiation. The magnitude of the impact is a function of percentage of canopy removed, length of time of full exposure, streambed material, area exposed, discharge, and initial temperature. Stream temperature has not been documented for undisturbed forests of East Texas.

Increased stream temperatures that occur naturally or as a result of man's activities can affect fish populations in several ways, many of which are detrimental. For example, high temperature kills fish directly, decreases the dissolved oxygen concentration, increases the susceptibility of fish to disease by increasing bacteriological activity, affects the quantity of food available, and alters the feeding activities of fish (USDA, Forest Service 1977).

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 175,000 hectares of trees are harvested in East Texas each year (Blackburn et al. 1981) (Table 6). Of these hectares, 95,362 are clearcut, 63,031 are selectively harvested by the seed tree and shelterwood system. Harvesting activities are carried out through most of the year, but about 66 percent occur between march and August.

Tree length harvesting is characteristic of the East Texas area. Using this method, trees are normally felled and limbed with chain saws and then dragged to a central landing by means of wheeled skidders. Once the tree length material has been moved to a central landing, it is loaded onto trucks and removed.

Table 6. Estimated hectares of sawtimber and pulpwood sized material annually receiving a final harvest cut on forest land in East Texas by regeneration system (Blackburn et al. 1981).

Regeneration system	Sawtimber	Pulpwood	Total	Percentage of total
Clearcut	54,242	23,757	78,000	55
Selection*	30,323	21,394	51,555	36
Seed Tree	5,831	1,332	7,163	5
Shelterwood	4,892	1,265	6,157	4
Total	95,288	47,748	143,037	

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

Of the forest land receiving a final harvest cut each year, about 70,653 hectares receive some form of site preparation prior to reestablishment of a new forest (Blackburn et al. 1981) (Table 7). Mechanical means alone, or in combination with prescribed burning are the most frequently used methods.

Table 7. Estimated hectares of East Texas forest land receiving a site preparation treatment annually (Blackburn et al. 1981).

Site preparation technique	Forestland
Mechanical	40,636
Prescribed burning	13,419
Herbicide	3,734
Total	57,789*

* Actual area treated is less due to overlapping activities.

The following mechanical site preparation activities are employed on East Texas managed forest lands: 1) shearing; 2) raking; 3) windrowing; 4) burning windrows; 5) chopping; 6) disking; and 7) bedding. These activities may be employed singly or in various combinations. Shearing and windrowing are the most commonly used site preparation techniques. Chopping ranks second in usage among mechanical means. Bedding and disking are only used on poorly drained soils of southeast Texas.

STUDY SITE DESCRIPTION

The five experimental watersheds are located about 56 kilometers east of Lufkin on the Angelina National Forest in western San Augustine County (Figure 1). The study area is characterized by gentle rolling topography intersected with numerous drainages. Slopes range from 1 to 8%. Overstory vegetation is predominantly loblolly, longleaf, shortleaf, red oak and sweetgum. The study area is located in the northern part of the Yegua geologic formation. The Yegua formation in this area is mainly acid stratified sandstone and shale with some areas underlaid by variable amounts of siltstone. The soils have loamy surfaces with mainly clayey subsoils. The soils have been mapped as the Cuthbert or Kirvin Series.

The Cuthbert series consists of moderately deep, loamy, moderately slowly permeable soils on uplands. These soils formed in acid, stratified loamy and clayey sediments. The A1 horizon is dark brown, brown, very dark gray, dark grayish brown, grayish brown, or pale brown. The A2 hori-

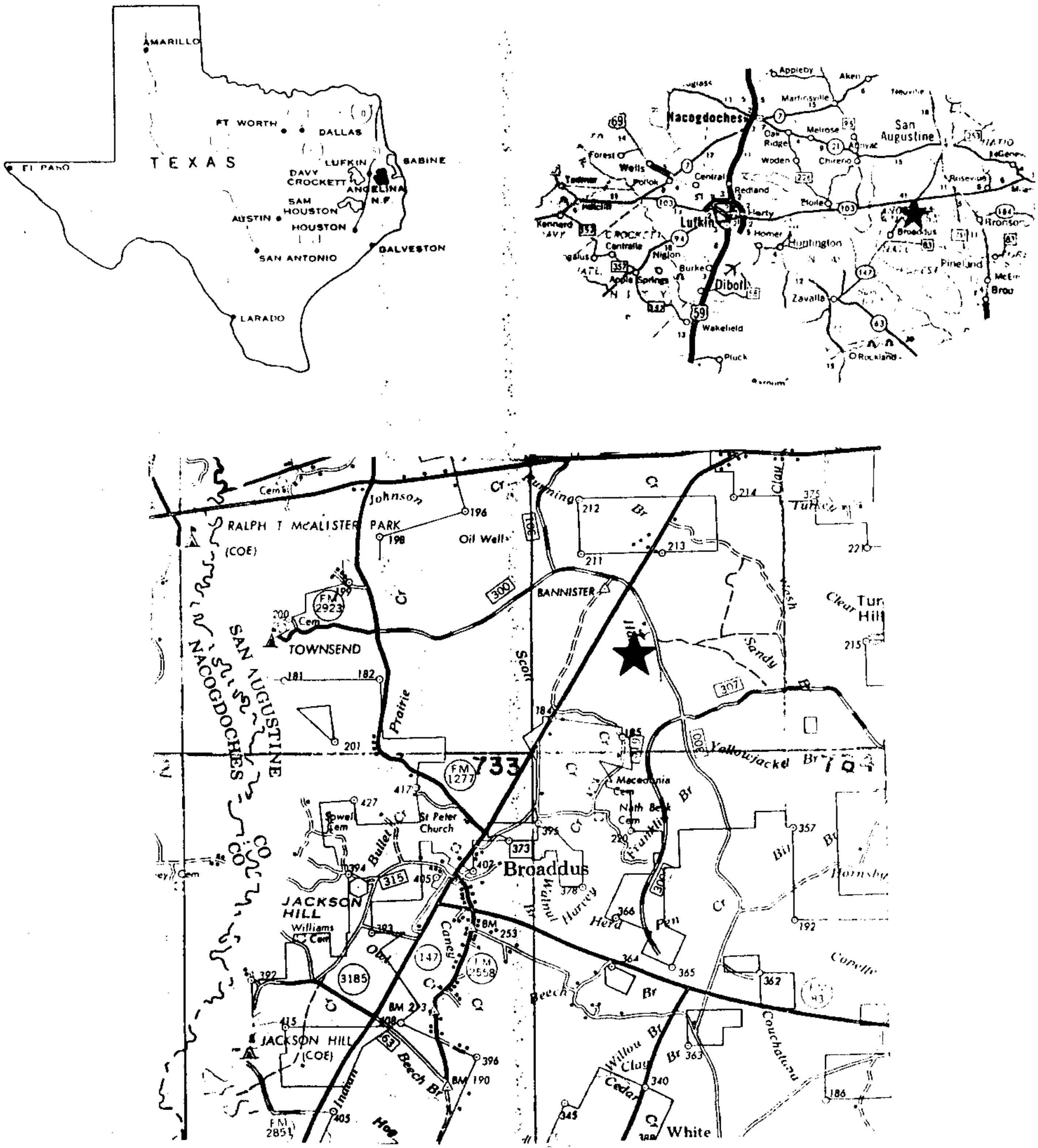

Figure 1. Study site location, 6.4 kilometers northeast of Broaddus, Texas, in the Angelina National Forest.

zon is brown, light brown, pale brown, yellowish brown, or light yellowish brown. Reaction ranges from very strongly acid to slightly acid. The Bt horizon is dark reddish brown, reddish brown, dark red, red, or yellowish red. Some pedons have a few to common yellowish or brownish mottles in the lower part. Grayish or brownish horizontally oriented weathered shale fragments or strata are in the lower part of most pedons. Reaction ranges from extremely acid to strongly acid. The B3&C or B3 horizon has reddish, brownish or yellowish colors and is stratified or mottled with these and grayish colors. The degree of weathering is variable and some pedons have B3 horizons with only a few visible parent material fragments. It is sandy clay loam, fine sandy loam or clay loam with or without weathered sandstone and shaly materials. Reaction ranges from extremely acid to strongly acid. The C horizon is stratified weakly consolidated sandstone and shale. The loamy materials and sandstone are reddish, yellowish and brownish and the shaly materials are mainly grayish. The amount of sandstone or shaly materials is variable and either may be absent in some pedons. Roots penetrate the materials but are concentrated along fractures. Most pedons have clay flows along some vertical fractures. The reaction is extremely acid or very strongly acid.

The Kirvin series consists of deep, loamy, moderately slowly permeable soils on uplands. These soils formed in weakly consolidated loamy and shaly materials. Slopes range from 1 to 5 percent. The A1 horizon is dark brown, brown, grayish brown, dark grayish brown or very dark grayish brown. The A2 horizon is brown, pale brown, light yellowish brown, yellowish brown or light brown. In some pedons ironstone pebbles make up as much as 10 percent of the A horizon. Reaction ranges from strongly acid to slightly acid. The Bt horizon is red, dark red, or yellowish red. Yellowish or brownish mottles range from none to common. Grayish platy shale fragments are in the lower Bt horizon of most pedons. Texture is clay or sandy clay loam. Reaction ranges from extremely acid to strongly acid. The C horizon is reddish, yellowish or brownish soft sandstone and is stratified with mainly grayish shaly material. The amount of sandstone or shaly materials is variable. Roots penetrate the materials, but are concentrated along fractures. Most pedons have clay flows along some vertical fractures. The reaction is extremely acid or very strongly acid.

The Cuthbert and Kirvin soil series are found extensively throughout East 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.

EXPERIMENTAL DESIGN

Small Watersheds

Five instrumented first order watersheds (<4.9 hectares) are being used to evaluate state-of-the-art silviculture and grazing practices, which involves a calibrated watershed approach. Calibration relationships have been developed over the past three years between four watersheds and one control (Figure 2). Four of the watersheds are scheduled for clearcutting in 1983 and the fifth one will remain as an untreated control. Two clearcut watersheds will receive a grazing treatment, and will be fenced with a large enough buffer to enable an adequate livestock number

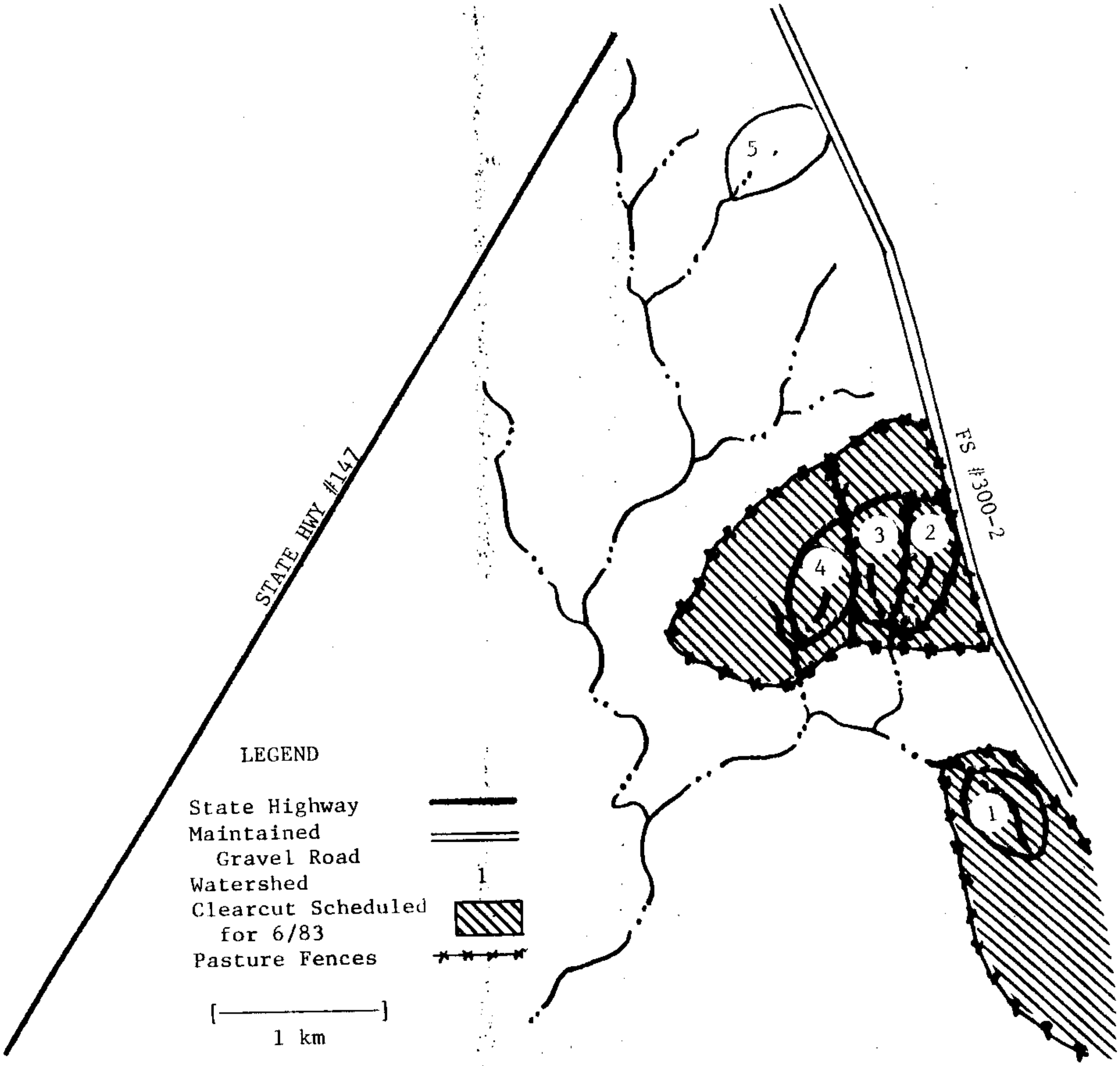

Figure 2. Detail of the study site showing locations of experimental watersheds, Angelina National Forest, Texas.

to graze each watershed. The untreated watershed and two clearcut watersheds will be protected from livestock grazing either by non-use of the large pasture or fence.

One clearcut of approximately 35 hectares will be in conjunction with watershed number 1 (Figure 2). The second clearcut of approximately 40 hectares will be associated with watersheds 2, 3, and 4. Watershed 2 and a small buffer area will be site prepared by roller chopping and watersheds 1, 3 and 4 and associated clearcut areas will be prepared by shearing and windrowing. Mechanical site preparation will follow the harvesting and should be completed in time for machine planting in early winter. All silviculture practices will be performed by or under the direction of the Angelina Ranger District. All silviculture practices will follow the "best state-of-the-art methods" and Forest Service policy.

Livestock are scheduled to graze the two pastures during the spring, summer and fall (9 months) each year with a winter deferrment (3 months). The following grazing treatments are proposed: 1) the large pasture associated with watershed 1 will be moderately stocked (40-50% utilization of key species), continuously grazed for 9 months; 2) watershed 4 and adjacent area will be grazed under a short duration grazing system, stocked at the 1/3 higher rate than the moderately stocked pasture. This pasture represents one pasture of an 8 pasture system. The grazing period will be 5 to 7 days with a 40 to 56 day rest period depending on forage availability, quality and plant physiological stages.

Rainfall Simulation

The hydrologic impacts of grazing in the sawtimber and sapling silvicultural managed stands in Texas and Louisiana will be evaluated using a small plot rainfall simulator. A split-plot analysis of variance and Duncan's multiple range test (Steele and Torrie 1960) will be used to test for treatment differences for both the Kisatchie and Angelina studies by sample date. On the Kisatchie Forest, the hydrologic impacts of a one-herd four-pasture deferred rotation grazing system and no grazing will be evaluated each with two silvicultural practices (intensive silviculture and no silviculture). For each sample date the evaluation will require 48 sample plots when six replications and two subsamples are employed (1 grazing system X 2 grazing treatments X 2 silvicultural practices X 6 replications or blocks X 2 subsamples).

The Angelina study will evaluate a switch back grazing system and no grazing each with two silviculture practices, (intensive silviculture and no silviculture). For each sample date the evaluation will require 40 sample plots when five replications and two subsamples are employed.

The two grazing treatments and two silvicultural treatments will be evaluated on adjacent areas to the watersheds using the rainfall simulator. The design will be completely randomized analysis of variance (Steele and Torrie 1960) with four treatments and eight subplots per treatment per sample date. Treatment means will be separated using Duncan's new multiple range test.

STATISTICAL ANALYSIS

Small Watersheds

Accepted regression and covariance analysis techniques (Ursic and Popham 1967; Wilm 1943, 1949) based on individual storm data was used in developing pretreatment calibration and will be used in evaluating post-treatment differences. Simple and multiple regression and factor analysis will be used to explore relationships among site variables and water yield and water quality.

Rainfall Simulation

Data was subjected to three types of statistical analysis: 1) skewness and kurtosis tests on each variable to determine the normality of data (Snedecor and Cochran 1971), 2) analysis of variance and Duncan's Multiple range test of terminal rates of infiltration and sediment production for each treatment (Steel and Torrie 1960), and 3) stepwise multiple regression and correlation analysis to determine the important parameters influencing infiltration and sediment production (Draper and Smith 1966).

MEASUREMENT AND ANALYSIS

Small Watersheds

The following measurements are being made on each experimental watershed:

Water

Precipitation - Precipitation was measured in Forest Service type rain gauges located in a network on each site to provide a minimum of one gauge for every 5 acres. Intensities are obtained from recording raingauges (Belfort weighing bucket type). Atmospheric deposition both wet and dry fall are collected by a sampler similar to that described by Volchok and Graveson (1975).

Water Yield - Timing, rates, and volumes of runoff are measured with .9-meter H-flumes equipped with FW-1 type water level recorders. Approach sections are 3.6 meters long. Output included runoff volume in cubic m/sec and area centimeters, flow duration, peak discharges, and timing of flow.

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 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 10-centimeter PVC water pipe. The sample is collected in a chemically inert container. Volume of sampled water is measured and collected for laboratory analysis the day following the runoff event.

Each watershed is equipped with ISCO (Model 2100) 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 provided data on sediment and nutrient concentrations at discrete time intervals throughout the storm hydrograph.

Bedload was collected in an 8 cm by 173 cm by 23 cm 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 through 0.45 micron Millipore filters, then oven drying and weighing. Sediment is expressed in terms of milligrams per liter (mg/liter). Bedload samples are dried and weighed to determine the bed-load loss.

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

Ortho-phosphate and total phosphate are both analyzed unfiltered because of their association with sediments. Ortho-phosphate was determined using the ascorbic acid reduction method (APHA et al. 1976). Total phosphate includes ortho-P, condensed phosphates and organic phosphates. Samples are first digested using the persulfate digestion method, with the total P concentrations determined by the ascorbic acid reduction method (APHA et al. 1976).

Calcium, magnesium, potassium and sodium concentrations are filtered through 0.45u Millipore filters, and analyzed using an Instrumentation Laboratory 457 Atomic Absorption Spectrophotometer (Soters and Stux 1979).

Data are expressed as a concentration (mg/liter) by storm event. Conductivity and pH are spot checked during some runoff events.

Soil Properties

Soil Bulk Density - Bulk density determinations of the 0 to 7.62 centimeter depth zone using the core sampler are made at approximately 20 locations in each watershed prior to treatment.

Soil Moisture - Thirty depth moisture gauge access tubes are installed on watershed 5. Ten additional access tubes will be located on the other four watersheds along two transect lines from the watershed divide to the channel after treatments are completed. Percent soil moisture is determined using a Troxler Model 1255 depth moisture gauge.

Vegetation and Surface Condition

Pretreatment overstory, intermediate and understory vegetation, surface conditions, above ground biomass for each watershed has been determined under a separate contract with Dr. Smeins. A study plan outlining the procedures of a detailed study to follow the vegetation changes and disturbances caused by treatment will be developed by 1984.

Infiltration Study

Infiltration

A rainfall simulator similar to the one described by Meyer and Harman (1979) is used in this study. Runoff plots are 1 m^2 and are prewet with a sprinkler system to remove antecedent moisture differences. After the plots are prewet they are covered with plastic to maintain uniform surface moisture conditions. When the plots are at or near field capacity (approximately 24 hrs. later), the simulator is used to determine infiltration rates. Simulated rainfall is applied at a rate of 13 centimeters per hour for 0.50 hours. Runoff is collected and measured by weight at 5 minute intervals.

Sediment Production

Upon termination of the rainfall period a one-liter subsample is taken from thoroughly mixed runoff. Sediment production is determined by filtering the subsample through a #1 Whatman filter paper and weighing the oven-dried filter. This sediment loss is converted to kilograms per hectare loss for each plot.

Water Chemistry

Upon termination of the simulated rainfall period three thoroughly agitated whirl-pac subsamples are collected. All subsamples are placed on ice. One subsample is treated with nitric acid for later analysis of potassium, calcium and magnesium on an Atomic Absorption Spectrophotometer (Instrumentation Laboratories 457), according to Standard Methods, 14th edition. The second subsample is frozen at the end of the day for later analysis of nitrate nitrogen, total and ortho-phosphate content on a Technicon Autoanalyzer, according to Standard Methods, 14th edition. The third subsample at the end of the day is analyzed for total and fecal coliform bacteria using the multiple-triple fermentation method listed on page 662 of Standard Methods, 14th edition.

Cover and Standing Crop

The percentage ground cover by grass and forb foliage, mulch and bare ground are determined by ocular estimates on each runoff plot from a gridded sampling quadrat. Grass, forbs and standing dead material are clipped to a 2 cm stubble height and mulch is hand-collected from each runoff plot. The herbaceous material is dried at 60°C and weighed.

Soils

Soil moisture content and bulk density are measured at depth of 0 to 5 cm on areas adjacent to each runoff plot just prior to each simulated rainfall event. Soil moisture is determined by the gravimetric method and soil bulk density by the core method (Black 1965).

A soil sample is collected from the 0 to 10 cm depth within each runoff plot after each simulated rainfall event and analyzed for texture by the hydrometer method (Bouyoucos 1962) and organic matter by the Walkley and Black method (1934).

RESULTS AND DISCUSSION

Small Watersheds

Precipitation

1981 - Precipitation recorded for 1981 totaled 122.23 cm and was 13.04 cm above the normal (NOAA 1981) (Table 8). Precipitation was greater than normal for March, May, June, July, August, September and October. Unfortunately, most of the above normal precipitation came during late spring and summer when soil moisture was low. Generally, during 1981 the rainfall events were too small and/or too infrequent to cause runoff. Runoff is generally low during late spring and summer because of high evapotranspiration and low antecedent soil moisture.

1982 - Total precipitation for 1982 totaled 166.14 cm (Table 9), 56.95 cm above normal. Precipitation during nine months in 1982 was greater than normal. October and December precipitation was almost three times the long term normal and April, June and November almost two times the normal precipitation (NOAA 1982).

Runoff

Runoff from small watersheds was dependent on several factors: 1) antecedent soil moisture conditions, 2) rainfall amount, intensity and duration, and 3) watershed condition - size, shape, slope, vegetation,

Table 8. Precipitation (cm) for forest watersheds, Angelina National Forest, Texas, 1981.*

DATE	RAINFALL	TOTAL	NORMAL
Jan 6	1.98		
19	3.81	5.79	9.27
Feb 1	3.81		
6	1.40		
10	1.30		
22	.71	7.21	9.25
Mar 1	1.96		
4	3.76		
8	.36		
14	.25		
22	.71		
29	5.21	12.24	8.84
Apr 2	.15		
5	.66		
21	1.40		
23	1.96	4.17	11.51
May 1	3.19		
5	3.18		
9	1.55		
10	.69		
14	1.30		
16	3.35		
31	2.87	15.77	12.93
Jun 1	.15		
3	4.06		
4	1.19		
5	7.14		
11	1.12		
13	2.92		
24	.33		
26	1.83	18.75	8.23
Jul 2	.74		
5	4.19		
6	.84		
7	.36		
Jul 10	1.12		
11	2.01		
27	.86	10.11	7.24
Aug 6	1.57		
12	.91		
21	3.96		
26	2.06		
27	.38	8.89	6.43
Sep 1	9.96		
2	.91		
3	1.88		
4	.66		
13	1.45		
14	.88	15.16	8.23
Oct 5	.18		
7	3.68		
8	2.49		
9	2.67		
14	.99		
16	.36		
17	1.07		
23	.41		
25	.13		
30	2.67		
31	.97	15.60	7.54
Nov 8	3.66		
30	1.17	4.83	9.47
Dec 6	.53		
13	.43		
14	.84		
17	.30		
20	.38		
30	1.22	3.71	10.26
TOTAL		122.23	109.19

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

Table 9. Precipitation (cm) for forest watersheds, Angelina National Forest, Texas, 1982.*

DATE	RAINFALL	TOTAL	NORMAL	DATE	RAINFALL	TOTAL	NORMAL
Jan 1	1.55			Jun 28	6.02		
2	1.02			30	.25	15.65	8.23
11	1.75						
13	1.04			Jul 21	.99		
21	1.37			23	1.14		
22	.18			25	2.77		
31	2.97	9.88	9.27	26	2.72	7.62	7.24
Feb 2	.99			Aug 7	2.01		
5	1.30			10	1.73	3.74	6.43
8	1.07						
26	2.46	5.82	9.25	Sep 3	.84		
				14	1.07		
Mar 6	.84			16	2.31	4.22	8.23
21	1.65						
24	.30			Oct 6-7	2.64		
27	2.72			8	1.93		
30	3.23	8.74	8.84	9-10	9.55		
				12	8.15		
Apr 1	.10			20	.76		
2	.86			29	2.90	25.93	7.54
10	.94						
17	6.91			Nov 2	3.78		
19	.76			11	.20		
20	7.06			16	4.39		
21	2.18			18	.71		
24	.84			22	.36		
26	3.15			26-27	6.27		
28	.36	23.16	11.51	30	1.27	16.99	9.47
May 1	2.08			Dec 2-3	4.98		
6	2.64			9-10	2.72		
13	7.21			18	5.97		
17	3.00			22	.41		
24	.58	15.52	12.93	24	1.37		
				25	5.23		
Jun 6	2.39			26	4.85		
20	3.28			30	1.24		
21	2.90			31	2.11	28.88	10.26
25	.81						
				TOTAL		166.14	109.19

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

ground cover, and soil type.

1981 - The only rainfall event that produced runoff from the watersheds occurred on June 5. The largest volume of runoff was from watershed 3 (.546 area-centimeters) followed by watershed 2, watershed 5, watershed 4 and watershed 1. The peak discharge rate was also greatest from watersheds 3 and 2 and lowest from watersheds 4 and 1 (Table 10). Runoff as a percent of precipitation averaged 4.0% for this storm.

1982 - During the first three months of 1982 no runoff was recorded from the watersheds (Table 10). Four runoff events occurred during April with runoff recorded from all five watersheds. The first storm occurred on the 17th, after receiving 6.91 cm of rain, and runoff values in area-centimeters ranged from .224 for watershed 3 to .053 for watershed 4. Runoff as a percent of precipitation averaged 2.1% for all five watersheds. Three days later, on the 20th, it rained 7.06 cm. This storm was the largest during April and generated the greatest runoff. Runoff ranged from 2.568 cm for watershed 3 to 0.627 cm for watershed 4. Runoff as a percent of precipitation averaged 18.5%. The following day (21st) it rained 2.18 cm, and because of the high soil moisture conditions, runoff occurred from all five watersheds. Runoff varied from .716 cm on watershed 3 to .140 for watershed 4. Runoff as a percent of precipitation averaged 21.1%. On April 26 another rainfall event (3.15 cm) generated runoff from all five watersheds. The greatest runoff occurred from watershed 5 (.810 cm), with watershed 4 having the least (.378 cm).

Table 10. Precipitation and runoff by watershed for runoff producing storms, Angelina National Forest, Texas, 1981-1982.

Storm Date	Watershed	Precipitation area cm	Runoff	Runoff as a % of Precipitation %	Peak rate of Discharge cms
1981					
Jun 5	1	7.14	.094	1.3	.007
	2		.455	6.4	.016
	3		.546	7.6	.018
	4		.150	2.1	.009
	5		.183	2.6	.011
1982					
Apr 17	1	6.91	.119	1.7	.003
	2		.150	2.2	.010
	3		.224	3.2	.014
	4		.053	0.8	.008
	5		.170	2.5	.021
Apr 20	1	7.06	1.478	20.9	.021
	2		1.113	15.8	.023
	3		2.568	36.4	.034
	4		.627	8.9	.016
	5		.752	10.6	.024
Apr 21	1	2.18	.737	33.7	.007
	2		.419	19.2	.003
	3		.716	32.8	.006
	4		.140	6.4	.002
	5		.297	13.6	.002
Apr 26	1	3.15	.406	12.9	.011
	2		.429	13.6	.012
	3		.658	20.9	.031
	4		.378	12.0	.027
	5		.810	25.7	.071
May 1	3	2.08	.036	1.7	.001
	5		.376	18.0	.017
May 6	3	2.64	.008	0.3	<.001
	5		.076	2.9	.001

Table 10. Continued.

Storm Date	Watershed	Precipitation area cm	Runoff	Runoff as a % of Precipitation %	Peak rate of Discharge cms
May 13	1	7.21	1.232	17.1	.026
	2		1.890	26.2	.051
	3		1.890	26.2	.051
	4		1.298	18.0	.070
	5		1.372	19.0	.079
May 17	1	3.00	.018	0.6	<.001
	2		.089	3.0	.001
	3		.249	8.3	.001
	4		.168	5.6	.005
	5		.635	21.2	.031
Jun 29	3	6.02	.015	0.3	.001
	5		.020	0.3	.002
Oct 9	5	9.55	.030	0.3	.002
Oct 12	1	8.15	.257	3.1	.015
	2		.018	0.2	.002
	3		.107	1.3	.009
	4		.094	1.2	.010
	5		.274	3.4	.019
Nov 27	1	6.27	.569	9.1	.016
	2		.719	11.5	.008
	3		1.044	16.6	.022
	4		.333	5.3	.019
	5		.279	4.5	.012
Dec 3	1	4.98	.973	19.5	.024
	2		.881	17.7	.017
	3		1.443	29.0	.024
	4		.813	16.3	.021
	5		2.022	40.6	.030
Dec 10	1	2.72	.124	4.6	.001
	3		.284	10.5	.003
	4		.104	3.8	.002
	5		.142	5.2	.002
Dec 13	1	5.97	3.015	50.5	.090
	2		2.271	38.0	.064
	3		5.504	62.6	.115

Table 10. Continued.

Storm Date	Watershed	Precipitation area cm	Runoff area cm	Runoff as a % of Precipitation %	Peak rate of Discharge cms
Dec 13	4	5.97	2.337	39.1	.067
	5		1.839	30.8	.063
Dec 25	1	5.23	2.924	55.9	.085
	2		2.421	46.3	.056
	3		3.188	60.9	.074
	4		2.365	45.2	.053
	5		2.123	40.6	.048
Dec 26	1	4.85	2.576	53.1	.044
	2		2.438	50.3	.033
	3		3.630	74.8	.049
	4		2.629	54.2	.043
	5		2.715	56.0	.045
Dec 30	1	1.24	.066	5.3	.001
	3		.170	13.7	.001
	4		.094	7.6	.001
	5		.094	7.6	.001
Dec 31	1	2.11	.172	31.3	.010
	2		.663	31.4	.009
	3		1.207	57.2	.014
	4		.678	32.2	.012
	5		.846	40.1	.020

Four runoff events also occurred during May. The first two events occurred on May 1 and 6 following 2.08 and 2.64 cm of rain. However, runoff occurred only from watersheds 3 and 5. On May 13, after a 7.21 cm rainfall event runoff occurred form all five watersheds. This was the largest storm during May, and created 82% of the month's runoff. Runoff as a percent of precipitation averaged 21.3%. Four days later, on May 17, it rained 3.0 cm and again created runoff on all 5 watersheds. The greatest runoff occurred from watershed 5 (.635 cm) and the least from watershed 1 (.018 cm). This storm decreased in amount of precipitation from watershed 5 to 1, with 5 having twice as much rain as watershed 1.

The only runoff event during June occurred on the 29th and created stormflow on watersheds 3, 4 and 5. The runoff values ranged from .015 cm (WS 3) to .020 cm (WS 5). Although the precipitation for the month was nearly twice the normal average, there was only one runoff event. This was due to high evapotranspiration during late spring and summer.

Due to low precipitation and high evapotranspiration during July, August, and September no runoff event occurred.

October had two runoff events. The first runoff event in October occurred on the 9th. However, the 9.55 cm low intensity rain storm occurred over two days with low soil antecedent moisture content and runoff occurred only from watershed 5 (.030 cm). Two days later however, a 8.15 cm rain storm generated runoff from all five watersheds. Runoff was 1.8% of precipitation.

One runoff event occurred during November on the 27th after a 6.27

cm rainfall event. This storm occurred over a two day period and had fairly low rainfall intensities which accounted for the low volume of runoff.

Seven runoff events occurred during December, but water quality samples were collected from six. It rained more during December than any other month. The first runoff event occurred on December 3 after a 4.98 cm rain storm. Runoff from the five watersheds averaged 24.6% of the precipitation. The second runoff event occurred on December 10 after a 2.72 cm rainfall but only watersheds 1, 3, 4, and 5 recorded runoff. The greatest runoff occurred from watershed 3 (.284 cm) and the least from watershed 4 (.104 cm). Three days later, on December 13, a 5.97 cm storm produced runoff from all five watersheds. Runoff averaged 44.2% of precipitation. A 5.23 cm rain storm on December 25 produced runoff from all five watersheds. Again, watershed 3 recorded the greatest runoff (3.188 cm) and watershed 5 the least (2.123 cm). Runoff as a percentage of precipitation averaged 49.8%. The following day, December 25, 4.85 cm rain storm on the saturated soils produced runoff from all five watersheds. This storm created the greatest runoff for all storms during 1981 and 1982. Runoff from watershed 3 (3.630 cm) was the greatest and from watershed 2 the least, (2.438 cm). Runoff averaged 57.7% of precipitation. A low intensity storm (1.24 cm) on December 30 produced little runoff. The following day a 2.11 cm storm, because of the saturated soil condition, produced runoff from all five watersheds. Runoff averaged 38.4% of the precipitation.

The most runoff during 1982 occurred from watershed 3 followed by watershed 1, 5, 2, and then 4 (Table 12). Watershed 5 had the greatest runoff from the smaller storms (<3 cm), but more runoff occurred from watershed 3 from the larger storms (>3 cm). Watershed 5 appeared to be the most responsive to all rainfall events.

As outlined in the study plan this project involves a calibrated watershed approach. Calibration relationships have been developed between four watersheds and one control, watershed 5. Regression correlation coefficients (r) have been determined comparing watershed 5 to 1, 2, 3, and 4 which are .83, .85, .87 and .92, respectively. These high values indicate there is a relationship between these watersheds to watershed 5.

Sediment

1981 - Mean sediment concentration in runoff and total sediment loss were 217.8 mg/l and 4 kg/ha from the five watersheds (Table 12). Only one runoff event occurred in 1981 and the large sediment concentration from watershed 4 was probably due to contamination from flume construction.

1982 - Sediment concentrations for 1982 ranged from 0.1 to 714.8 mg/l from the watersheds (Table 11). Mean discharge weighted suspended sediment concentration was 41.5 mg/l (Table 12) and mean sediment loss from the five watersheds was 63.3 kg/ha. No measurable bedload occurred in 1982.

Total sediment loss (kg/ha) during 1982 averaged 63.3 kg/ha for the five watersheds. The values ranged from 0.1 kg/ha to 24.6 kg/ha

Table 11. Runoff and sediment concentrations and losses by watershed and event, Angelina National Forest, Texas, 1981-1982.

Storm Date	Watershed	Runoff (cm)	Suspended Sediment Concentration (mg/l)	Suspended Sediment loss (kg/ha)
1981				
Jun 5	1	.094	*	*
	2	.455	50.9	2.3
	3	.546	49.3	2.7
	4	.150	879.5	13.1
	5	.183	109.1	2.0
1982				
Apr 17	1	.119	*	*
	2	.150	73.3	1.1
	3	.224	62.2	1.4
	4	.053	*	*
	5	.170	66.0	1.1
Apr 20	1	1.480	38.0	5.6
	2	1.113	54.0	6.0
	3	2.568	52.7	13.5
	4	.627	54.2	3.4
	5	.752	86.8	6.5
Apr 21	1	.737	41.8	3.0
	2	.419	54.2	2.3
	3	.716	46.7	3.3
	4	.140	52.0	.7
	5	.297	47.0	1.4
Apr 26	1	.406	*	*
	2	.429	3.3	.1
	3	.658	4.1	.3
	4	.378	50.4	1.9
	5	.258	12.3	.9
May 1	3	.036	*	*
	5	.376	161.3	6.1
May 6	3	.010	*	*
	5	.076	*	*

Table 11. Continued.

Storm Date	Watershed	Runoff (cm)	Suspended Sediment Concentration (mg/l)	Suspended Sediment loss (kg/ha)
May 13	1	1.232	0.1	0.1
	2	1.890	58.4	11.0
	3	1.890	0.1	0.2
	4	1.298	66.0	8.5
	5	1.372	111.3	15.3
May 17	1	.018	*	*
	2	.089	*	*
	3	.249	464.0	11.5
	4	.168	227.8	3.8
	5	.635	85.7	5.4
Jun 29	3	.015	*	*
	5	.020	*	*
Oct 9	5	.030	*	*
Oct 12	1	.257	511.6	13.1
	2	.018	*	*
	3	.107	*	*
	4	.094	42.2	0.3
	5	.274	714.8	19.6
Nov 27	1	.569	39.1	2.2
	2	.719	36.8	2.6
	3	1.044	68.4	7.1
	4	.333	26.2	.8
	5	.279	120.0	3.3
Dec 2	1	.973	28.8	2.7
	2	.881	26.1	2.3
	3	1.443	20.0	2.9
	4	.813	22.9	1.9
	5	2.022	42.8	8.6
Dec 9	1	.124	*	*
	3	.284	*	*
	4	.104	*	*
	5	.142	*	*
Dec 13	1	3.015	10.0	3.0
	2	2.271	17.3	3.9

Table 11. Continued.

Storm Date	Watershed	Runoff (cm)	Suspended Sediment Concentration (mg/l)	Suspended Sediment loss (kg/ha)
Dec 13	3	3.739	27.3	10.2
	4	2.150	32.8	7.6
	5	1.839	40.0	7.3
Dec 25	1	2.924	16.3	4.8
	2	2.421	22.1	5.3
	3	3.188	45.4	14.4
	4	2.365	20.8	4.9
	5	2.123	32.7	6.9
Dec 26	1	2.576	18.5	4.8
	2	2.438	25.9	6.3
	3	3.630	33.0	11.9
	4	2.629	23.1	6.1
	5	2.715	19.3	5.2
Dec 30	1	.066	*	*
	3	.170	*	*
	4	.094	*	*
	5	.094	*	*
Dec 31	1	.660	16.0	1.1
	2	.663	30.4	2.0
	3	1.207	204.0	24.6
	4	.678	21.7	1.4
	5	.846	30.6	2.6

* Insufficient runoff to collect sample.

Table 12. Annual runoff and sediment loss and mean annual sediment concentration by watershed, Angelina National Forest, Texas, 1981-1982.

Watershed	Runoff (cm)		Suspended Concentration (mg/l)**		Sediment loss (kg/ha)	
	1981	1982	1981	1982	1981	1982
1	0.094	15.1	*	28.0	*	40.3
2	0.455	13.5	50.9	32.2	2.3	43.0
3	0.546	21.2	49.3	49.3	2.7	101.2
4	0.150	12.1	879.5	35.1	13.1	41.6
5	0.183	14.8	109.1	62.7	2.0	90.4
Mean	0.286	15.3	217.8	41.5	4.0	63.3

* No sample collected.
** Discharge weighted.

(Table 11). Approximately 90% of the sediment export values were below 10 kg/ha/event. The greatest sediment loss occurred from watershed 3 and 5 and the smallest loss from watersheds 1, 2 and 4 (Table 12). Sediment losses were generally the result of channel erosion.

Beasley (1979) observed in Northern Mississippi sediment yields from undisturbed forests of 124.9 kg/ha/yr and 22.3 kg/ha/yr. Douglas and Goodwin (1980) found sediment yields were 17.8 kg/ha/yr from North Carolina Piedmont undisturbed forests. Loehr (1974) noted annual sediment yields from undisturbed forest, mechanical site prepared forest, pasture and cropland of 800, 11,000, 8,000 and 100,000 kg/ha/yr, respectively.

Nutrients - Nitrogen

1981 - Nitrogen concentration levels were generally low for the one runoff event (Table 13). These concentrations were similar to data obtained from undisturbed forest watersheds in Georgia, Mississippi and Texas. But one runoff event cannot effectively be compared to other studies.

1982 - Mean discharge weighted nitrate concentration for the year was 10 ug/l (Table 14). The concentrations ranged from less than detectable to 610 ug/l with nitrate concentration of approximately 70% of the event being below 10 ug/l and 7% of the event above 100 ug/l (Table 13). Watershed 1 lost the most nitrates because of extremely high concentrations (610 ug/l) in one event. The mean nitrate loss for 1982 was 0.015 kg/ha (Table 14).

Table 13. Nitrogen concentrations and losses by watershed and event, Angelina National Forest, Texas, 1981-1982.

Storm Date & WS	Nitrate ug/l	Nitrate kg/ha	Nitrite ug/l	Nitrite kg/ha	Ammonia ug/l	Ammonia kg/ha	Total filtered ug/l	Total filtered kg/ha	Total unfiltered ug/l	Total unfiltered kg/ha
1981										
Jun 5										
2	1	<.0001	6	.0003	48	.0022	944	.0428	580	.0263
3	12	.0007	4	.0002	81	.0044	1020	.0556	800	.0436
4	13	.0002	10	.0001	94	.0014	969	.0145	2138	.0320
5	9	.0002	6	.0001	145	.0021	847	.0155	987	.0180
1982										
Apr 17										
2	6	<.0001	3	<.0001	<24	.0003	762	.0113	526	.0078
3	9	.0002	4	<.0001	36	.0008	1158	.0258	778	.0173
5	13	.0002	13	.0002	409	.0069	1229	.0208	1246	.0211
Apr 20										
1	40	.0058	2	.0002	25	.0037	514	.0758	1234	.1820
2	4	.0047	2	.0002	89	.0099	737	.0818	955	.1060
3	26	.0067	3	.0007	39	.0099	575	.1473	912	.2336
4	<2	.0001	4	.0002	<24	.0015	614	.0384	859	.0537
5	19	.0014	2	.0001	61	.0046	563	.0422	864	.0648
Apr 21										
1	9	.0007	5	.0003	53	.0035	924	.0679	885	.0650
2	6	.0002	4	.0001	27	.0011	791	.0331	785	.0328
3	4	.0003	3	.0002	<24	.0017	480	.0343	473	.0338
4	5	<.0001	4	<.0001	25	.0003	1122	.0156	762	.0106
5	7	.0002	6	<.0001	<24	.0007	906	.0002	670	.0021
Apr 26										
2	65	.0027	2	.0001	377	.0161	836	.0358	738	.0316
3	59	.0038	3	<.0001	166	.0109	525	.0344	591	.0388
4	39	.0014	2	.0007	60	.0022	431	.0163	646	.0244
5	103	.0083	2	.0001	41	.0033	675	.0545	702	.0568
May 1										
5	32	.0012	8	.0003	119	.0044	637	.0238	830	.0311
May 13										
1	<2	.0002	3	.0003	28	.0034	630	.0774	831	.1021
2	12	.0022	2	.0003	116	.0218	376	.0709	553	.1043

Table 13. Continued.

Storm Date & WS	Nitrate		Nitrite		Ammonia		Total filtered		Total unfiltered	
	ug/l	kg/ha	ug/l	kg/ha	ug/l	kg/ha	ug/l	kg/ha	ug/l	kg/ha
May 13										
3	<2	.0003	3	.0005	91	.0171	619	.1167	877	.1653
4	14	.0018	3	.0003	82	.0162	783	.1014	1005	.1301
5	19	.0026	2	.0002	51	.0069	368	.0503	583	.0797
May 17										
3	300	.0074	2	<.0001	50	.0012	661	.0164	819	.0203
4	20	.0003	3	<.0001	38	.0006	651	.0109	875	.0146
5	12	.0156	2	.0001	62	.0239	539	.0341	707	.0448
Oct 12										
1	610	.0156	18	.0004	935	.0239	2781	.0711	2661	.0681
4	9	<.0001	2	<.0001	51	.0004	500	.0046	683	.0064
5	112	.0031	54	.0014	1810	.0495	3243	.0887	3000	.0821
Nov 27										
1	21	.0011	2	.0001	97	.0055	733	.0416	683	.0387
2	6	.0004	<2	<.0001	78	.0055	583	.0418	497	.0356
3	7	.0007	<2	.0001	97	.0101	583	.0605	836	.0868
4	7	.0002	<2	<.0001	60	.0019	533	.0176	497	.0165
5	41	.0011	2	<.0001	94	.0026	633	.0176	931	.0259
Dec 2										
1	4	.0003	<2	<.0001	53	.0051	599	.0581	766	.0743
2	<2	<.0001	<2	<.0001	39	.0034	589	.0515	559	.0491
3	<2	<.0001	<2	.0001	35	.0050	466	.0670	476	.0685
4	<2	<.0001	<2	<.0001	<24	.0018	546	.0442	579	.0469
5	<2	.0001	<2	.0002	25	.0050	433	.0873	488	.0984
Dec 13										
1	<2	<.0001	<2	.0003	37	.0111	500	.1504	455	.1368
2	<2	.0002	<2	.0002	37	.0083	416	.0941	497	.1124
3	<2	.0004	<2	.0003	<24	.0085	483	.1801	703	.2622
4	<2	<.0001	<2	.0004	<24	.0044	143	.0333	658	.1534
5	<2	<.0001	<2	.0003	35	.0064	333	.0611	497	.0911
Dec 25										
1	<2	.0001	2	.0005	78	.0227	400	.1166	517	.1508
2	<2	<.0001	2	.0004	39	.0094	400	.0966	559	.1350
3	<2	.0001	<2	.0003	35	.0111	366	.1164	463	.1472
4	<2	<.0001	2	.0004	<24	.0054	460	.1085	559	.1319
5	<2	<.0001	<2	.0002	<24	.0040	366	.0775	476	.1008

Table 13. Continued.

Storm Date & WS	Nitrate ug/l	Nitrate kg/ha	Nitrite ug/l	Nitrite kg/ha	Ammonia ug/l	Ammonia kg/ha	Total filtered ug/l	Total filtered kg/ha	Total unfiltered ug/l	Total unfiltered kg/ha
Dec 26										
1	<2	<.0001	2	.0005	<24	.0098	393	.1009	455	.1169
2	4	.0009	2	.0004	<24	.0040	460	.1119	322	.0783
3	<2	.0003	2	.0007	39	.0141	466	.1686	559	.2023
4	<2	.0001	2	.0005	39	.0102	533	.1398	641	.1681
5	<2	.0001	<2	.0002	39	.0105	340	.0921	442	.1143
Dec 31										
1	<2	<.0001	<2	<.0001	58	.0038	356	.0234	645	.0425
2	<2	<.0001	2	.0001	44	.0029	444	.0293	876	.0579
3	2	.0002	<2	.0001	44	.0052	489	.0588	715	.6860
4	<2	.0001	<2	<.0001	73	.0049	356	.0240	632	.0427
5	2	.0001	<2	<.0001	58	.0048	529	.0446	552	.0466

Table 14. Annual nitrogen loss and mean concentration by watershed, Angelina National Forest, Texas, 1982.

WS	Nitrate ug/l*	Nitrate kg/ha	Nitrite ug/l*	Nitrite kg/ha	Ammonia ug/l*	Ammonia kg/ha	Total filtered ug/l*	Total filtered kg/ha	Total unfiltered ug/l*	Total unfiltered kg/ha
1	16.9	.0243	2.1	.0031	61.0	.0878	544.7	.7836	679.4	.9775
2	5.7	.0076	1.8	.0023	62.3	.0837	492.8	.6584	562.2	.7511
3	10.2	.0209	1.8	.0036	46.8	.0960	500.8	1.0268	664.6	1.3627
4	3.7	.0043	2.1	.0024	37.8	.0447	469.2	.5551	675.8	.7996
5	13.6	.0194	2.8	.0041	80.0	.1141	490.2	.6954	605.0	.8601
Mean	10.0	.0153	2.1	.0031	57.6	.0853	499.5	.7439	637.4	.9502

* Discharge weighted.

Nitrite concentrations and losses in runoff were lower than nitrates during 1982 (Table 13). The mean discharge weighted concentration was 2.1 ug/l (Table 14). Concentrations ranged from less than detectable to 54 ug/l with 90% of the runoff event below 5 ug/l. Watershed 5 lost the greatest nitrites. Mean nitrite loss for 1982 was 0.0031 kg/ha (Table 14).

Ammonia concentrations were greater than nitrate concentrations. The mean discharge weighted concentration was 57.6 ug/l (Table 14). These values ranged from less than detectable to 1810 ug/l. The 1810 ug/l is probably due to contamination by either insects or other foreign objects. The October 12 runoff sample from watershed 5 was generally higher in nutrients than the other storms or watersheds. Approximately 60% of the ammonia concentrations were less than 50 ug/l with approximately 13% greater than 100 ug/l. Most ammonia concentrations were low and corresponded to concentrations from undisturbed forest watersheds near Alto, Texas (DeHaven, et al. 1983). Watershed 5 lost the greatest ammonia which was due primarily to one storm with extremely high cnocentrations. Ammonia concentration was lowest from watershed 4 primarily because of the smallest amount of runoff. Annual ammonia loss in runoff was 0.0853 kg/ha.

Total nitrogen concentration (filtered) ranged form 143 ug/l to 3243 ug/l where unfiltered nitrogen concentrations ranged from 322 ug/l to 3000 ug/l (Table 13).

Schreiber et al. (1976) in northern Mississippi found nitrate losses of .31 kg/ha/yr and ammonium losses of 3.3 kg/ha/yr. Aubertin and Patric (1974) found in West Virginia nitrate losses of .6 kg/ha/yr and ammonium losses of .8 kg/ha/yr. Hewlett (1979) observed in Georgia nitrate concentrations of 90 ug/l.

Loeher (1974) noted annual total nitrogen losses for forests or cropland of 13 kg/ha/yr.

Nutrients - Phosphorus

1981 - Total and ortho phosphate concentrations averaged 391 and 28 ug/l respectively for the five watersheds. Concentrations for total and ortho ranged from a low of less than detectable to a high of 1242 (WS 1) and 100 (WS 4), respectively (Table 15).

1982 - The mean discharge weighted ortho-phosphate concentration was 10.9 ug/l (Table 16). Concentrations ranged from undetectable to 527 ug/l (WS 1 on 12 October). Approximately 67% of ortho-P concentrations were below 10 ug/l, and 4% were above 100 ug/l. Annual ortho-P loss was .0157 kg/ha. Total phosphorus concentrations ranged from undetectable to 1810 ug/l (WS 1 on 12 October). Concentration of the October 12th runoff event was greater than other events. Approximately 76% of the concentrations were below 50 ug/l, while 13% of the concentrations were above 100 ug/l. Annual total phosphorus loss was .0605 kg/ha.

Aubertin and Patric (1974) in undisturbed forests in West Virginia

Table 15. Phosphorus concentrations and losses by watershed and event, Angelina National Forest, Texas, 1981-1982.

Storm Date	Watershed	Ortho-P ug/l	Ortho-P kg/ha	Total P ug/l	Total P kg/ha
1981					
Jun 5	2	<3	<.0001	43	.0025
	3	<3	.0001	45	.0025
	4	100	.0015	1242	.0186
	5	9	.0002	235	.0043
1982					
Apr 17	2	4	<.0001	43	.0006
	3	24	.0005	90	.0020
	5	42	.0007	118	.0020
Apr 20	1	10	.0014	64	.0094
	2	3	.0003	45	.0049
	3	12	.0031	60	.0153
	4	77	.0048	114	.0071
	5	18	.0013	69	.0051
Apr 21	1	<3	.0002	47	.0034
	2	<3	.0001	23	.0009
	3	<3	.0002	25	.0017
	4	<3	<.0001	45	.0006
	5	<3	<.0001	46	.0013
Apr 26	2	13	.0005	50	.0021
	3	13	.0008	19	.0012
	4	15	.0005	97	.0036
	5	8	.0006	32	.0025
May 1	5	80	.0030	147	.0055
May 13	1	5	.0006	21	.0025
	2	13	.0024	46	.0086
	3	7	.0013	22	.0041
	4	14	.0018	61	.0079
	5	19	.0020	102	.0139
May 17	3	33	.0008	157	.0038
	4	17	.0002	102	.0017
	5	10	.0006	67	.0042

Table 15. Continued.

Storm Date	Watershed	Ortho-P ug/l	Ortho-P kg/ha	Total P ug/l	Total P kg/ha
Oct 12	1	517	.0134	1810	.0463
	4	16	.0001	84	.0007
	5	319	.0087	868	.0237
Nov 27	1	300	.0016	82	.0046
	2	13	.0009	46	.0032
	3	17	.0016	37	.0038
	4	9	.0002	30	.0009
	5	10	.0002	40	.0011
Dec 2	1	6	.0005	22	.0021
	2	3	.0002	22	.0019
	3	3	.0004	20	.0028
	4	3	.0002	24	.0019
	5	<3	.0005	30	.0060
Dec 13	1	3	.0009	23	.0069
	2	24	.0053	32	.0072
	3	3	.0012	<20	.0055
	4	4	.0010	25	.0058
	5	3	.0006	<20	.0027
Dec 25	1	4	.0012	22	.0064
	2	4	.0009	<20	.0036
	3	3	.0010	20	.0063
	4	4	.0010	26	.0061
	5	3	.0006	26	.0055
Dec 26	1	3	.0007	<20	.0046
	2	<3	.0003	<20	.0041
	3	3	.0011	<20	.0061
	4	4	.0011	20	.0052
	5	3	.0008	<20	.0032
Dec 31	1	<3	.0001	<20	.0006
	2	6	.0003	41	.0027
	3	4	.0004	<20	.0012
	4	4	.0002	<20	.0005
	5	4	.0003	<20	.0006

Table 16. Annual total and ortho-phosphorus loss and mean concentration by watershed, Angelina National Forest, Texas, 1982.

Watershed	Ortho-P		Total P	
	ug/l*	kg/ha	ug/l*	kg/ha
1	14.7	.0211	60.6	.0872
2	8.9	.0118	30.2	.0403
3	6.3	.0129	26.6	.0545
4	9.9	.0116	35.9	.0425
5	14.8	.0210	54.0	.0779
Mean	10.9	.0157	41.5	.0605

* Discharge weighted.

found total phosphorus losses of 0.03 kg/ha/yr while Schreiber et al. (1976) observed in Northern Mississippi phosphorus losses of 0.04 kg/ha/yr. Hewlett (1979) found a total phosphorus concentration of 620 ug/l in Georgia. Loehr (1974) noted annual total phosphorus losses for forests and cropland of .99 and 2.7 kg/ha, respectively.

Nutrients - Calcium, Magnesium, Potassium, and Sodium

1981 - Calcium, magnesium, potassium and sodium concentrations for 1981 averaged 1.7, .7, 4.5, 3.9 mg/l, respectively, (Table 17). Runoff from watershed 5 had the greatest concentrations of all elements.

1982 - Sodium concentrations (2.8 mg/l) were greater than other elements. Mean concentrations of calcium and magnesium were the same, 0.9 kg/ha/yr (Table 18). Sodium annual loss was 4.2 kg/ha/yr and potassium 2.6 kg/ha/yr. Calcium and magnesium annual losses were both 1.4 kg/ha/yr, (Table 18).

Calcium concentrations during the year ranged from 0.3 mg/l from watershed 2 and 4 for 31 December storm to 9.4 mg/l on watershed 5 for the 12 October storm (Table 17). Eighty-three percent of calcium concentrations were below 1.5 mg/l. Magnesium concentrations ranged from 0.6 mg/l on watershed 2 for the 17 April storm, to 2.5 mg/l on watershed 1 during the 12 October storm. Only 2% of the storms runoff were above 1.5 mg/l.

Table 17. Calcium, Magnesium, Potassium and Sodium concentrations and losses by watershed and event, Angelina National Forest, Texas, 1981-1982.

Storm Date	Watershed	Calcium mg/l	Calcium kg/ha	Magnesium mg/l	Magnesium kg/ha	Potassium mg/l	Potassium kg/ha	Sodium mg/l	Sodium kg/ha
1981									
Jun 6	2	1.3	.059	0.8	.035	3.7	.166	2.6	.115
	3	1.2	.065	0.6	.034	2.4	.129	2.0	.106
	4	*	*	*	*	*	*	*	*
	5	2.6	.047	0.8	.015	7.4	.134	12.4	.226
1982									
Apr 17	2	0.7	.010	0.6	.009	2.5	.037	5.9	.087
	3	1.2	.027	1.2	.025	3.1	.069	18.8	.419
	5	1.8	.030	1.0	.016	2.6	.044	13.9	.235
Apr 20	1	1.9	.274	1.2	.181	2.4	.358	3.7	.542
	2	0.7	.078	0.7	.079	1.9	.215	4.3	.472
	3	0.7	.184	1.1	.279	2.2	.553	3.6	.930
	4	1.4	.085	1.1	.070	1.9	.119	9.8	.615
	5	0.9	.071	0.9	.069	1.6	.120	2.0	.146
Apr 21	1	1.6	.111	1.3	.097	2.4	.175	1.7	.123
	2	0.8	.035	0.8	.031	1.8	.073	4.4	.178
	3	1.0	.070	1.0	.069	1.9	.134	4.4	.313
	4	0.7	.009	1.2	.017	1.9	.026	1.8	.024
	5	0.8	.024	1.0	<.001	1.6	.018	1.6	.018
Apr 26	2	0.9	.036	0.8	.035	1.6	.069	3.3	.140
	3	1.2	.079	1.0	.064	1.9	.124	3.5	.232
	4	1.1	.042	1.1	.041	1.8	.068	2.2	.081
	5	1.2	.140	0.9	.075	1.4	.115	1.7	.136
May 1	5	1.5	.057	0.9	.034	1.5	.056	2.5	.094
May 13	1	1.6	.192	1.1	.130	1.6	.191	1.7	.202
	2	0.8	.145	0.8	.145	1.4	.267	3.0	.573
	3	1.0	.184	0.9	.173	1.5	.284	2.4	.450
	4	0.8	.108	1.1	.141	1.4	.187	1.6	.202
	5	1.1	.149	0.8	.113	1.8	.244	2.6	.350
May 17	3	2.3	.058	1.3	.032	2.7	.066	4.9	.121
	4	1.3	.022	1.2	.019	1.8	.029	3.2	.054
	5	0.9	.060	0.8	.052	1.2	.077	2.4	.155

Table 17. Continued.

Storm Date	Watershed	Calcium mg/l	Calcium kg/ha	Magnesium mg/l	Magnesium kg/ha	Potassium mg/l	Potassium kg/ha	Sodium mg/l	Sodium kg/ha
Oct 12	1	4.1	.105	2.5	.063	5.9	.15§	3.6	.091
	4	1.7	.015	0.7	.006	1.6	.015	8.5	.079
	5	9.4	.225	1.3	.036	7.7	.204	8.8	.239
Nov 27	1	1.2	.069	0.9	.048	1.0	.056	2.0	.111
	2	2.0	.146	1.4	.098	2.7	.192	3.9	.279
	3	0.7	.075	1.2	.123	1.5	.158	4.7	.486
	4	1.4	.044	1.3	.043	1.7	.057	1.9	.062
	5	2.2	.061	1.0	.028	2.2	.062	3.5	.098
Dec 2	1	2.2	.213	1.4	.139	2.1	.201	2.4	.233
	2	1.4	.118	1.2	.104	2.5	.216	3.4	.295
	3	1.0	.136	1.2	.175	2.7	.388	4.0	.574
	4	1.1	.092	1.4	.111	2.2	.178	2.8	.228
	5	1.0	.191	1.2	.234	2.0	.403	2.9	.581
Dec 13	1	1.1	.342	0.9	.279	1.8	.526	1.8	.544
	2	0.7	.158	0.9	.194	1.7	.389	2.6	.590
	3	0.8	.294	0.9	.335	2.0	.742	2.5	.936
	4	0.7	.153	0.8	.195	1.8	.424	2.5	.582
	5	0.6	.115	0.9	.168	1.6	.289	2.2	.403
Dec 25	1	0.9	.271	0.8	.245	2.0	.583	1.8	.519
	2	0.8	.181	0.9	.212	1.6	.396	2.2	.519
	4	0.7	.213	0.9	.289	1.8	.582	2.8	.887
	4	0.6	.148	0.9	.202	1.4	.318	2.2	.526
	5	0.6	.125	0.9	.199	1.3	.266	2.3	.489
Dec 26	1	0.8	.210	0.7	.190	1.3	.328	2.3	.598
	2	0.5	.111	0.8	.187	1.3	.318	3.1	.744
	3	0.5	.184	0.8	.289	1.5	.535	3.0	.100
	4	0.5	.131	0.8	.204	1.1	.285	2.2	.571
	5	0.5	.132	0.7	.197	1.1	.300	2.3	.633
Dec 31	1	0.6	.040	0.7	.048	1.0	.068	2.5	.166
	2	0.3	.021	0.8	.052	1.2	.078	3.5	.230
	3	0.4	.049	0.8	.099	1.2	.146	3.9	.465
	4	0.3	.020	0.7	.047	0.9	.062	3.0	.200
	5	0.4	.033	0.8	.066	0.7	.056	2.7	.228

* Data not available.

Table 18. Annual calcium, magnesium, potassium and sodium loss and mean concentration by watershed, Angelina National Forest, Texas, 1982.

Watershed	Calcium mg/l	Calcium kg/ha	Magnesium mg/l	Magnesium kg/ha	Potassium mg/l	Potassium kg/ha	Sodium mg/l	Sodium kg/ha
1	1.3	1.8	1.0	1.4	1.8	2.6	2.2	3.1
2	0.8	1.0	0.9	1.2	1.7	2.3	3.1	4.1
3	0.8	1.6	1.0	2.0	1.8	3.8	3.4	6.9
4	0.7	0.9	0.9	1.1	1.5	1.8	2.7	3.2
5	1.0	1.5	0.9	1.3	1.6	2.3	2.7	3.8
Mean	0.9	1.4	0.9	1.4	1.7	2.6	2.8	4.2

Potassium concentrations for 1982 ranged from 0.7 mg/l for watershed 5 during the 31 December storm, to 7.7 mg/l for watershed 5 during the 12 October runoff event. Approximately 70% of the runoff events were below 2 mg/l of potassium. Sodium concentrations were greater than the other elements, and were fairly consistent between runoff events. The concentrations varied from 1.6 mg/l from watershed 5 and watershed 4 to 18.8 mg/l from watershed 3.

The concentrations of the elements were similar to, or lower than concentrations reported by DeHaven et al. 1983 for Alto, Texas watersheds. The highly weathered, acidic, sandy soils in East Texas and the Southeastern United States are generally deficient in nutrients. Sodium does not strongly adhere to soil colloids and thus is easily exchanged. Because of this it was easily brought into solution by runoff water. Likewise, potassium does not strongly adhere to soil colloids and can be leached in coarse textured, highly weathered soils. Both sodium and potassium have only one valence charge while calcium and magnesium have two valence charges, thus, calcium and magnesium more strongly adhere to soil colloids and are less likely to be exchanged.

Hewlett (1979) observed calcium, magnesium and potassium concentrations in Georgia which were 4.6, 2.1 and 1.3 mg/l, respectively. Aubertin and Patric (1974) found calcium, magnesium and potassium losses were 4.3, 2.4, and 3.1 kg/ha/yr in West Virginia. Schreiber et al. (1976) in northern Mississippi found calcium, magnesium and potassium losses to be 6.2, 3.0 and 3.3 kg/ha/yr, respectively.

Coliform Bacteria

1981 - Bacteria measurements were not taken during this period.

1982 - Bacteria counts were determined for runoff events that occurred during the Fall and Winter of 1982. Bacteria counts varied greatly between runoff events. Total coliform (TC) ranged from 0 to >1000/100 ml, and fecal coliform (FC) ranged from 0 to 562/100 ml (Table 19). Total coliform bacteria variation was greater between both storms and watersheds than fecal bacteria. In general, coliform bacteria were less for the larger runoff events than the smaller events.

These results are similar to results from other studies. Robbins et al. (1972) reported fecal coliform counts from ungrazed watersheds in North Carolina of 10,000 per 100 ml. Doty and Hookans (1974) analyzed water from three pristine watersheds in northern Utah and found total and fecal coliforms ranged to maxima of 570 and 183 per 100 ml, respectively. Kunkle (1970) analyzed runoff from a Vermont watershed and found total and fecal coliform counts that ranged to maxima of 16,000 and 1,000 per 100 ml, respectively.

Coliform bacteria are present in the intestinal tracts of warm blooded animals and are excreted in large numbers in fecal waste. These bacteria are not usually pathogenic and generally do not multiply outside the intestines but are found with intestinal pathogens which affect man and other mammals. Therefore, their presence indicates that intestinal waste products have reached a stream. Water containing coliform concentrations greater than one colony per 100 ml are not acceptable for domestic use

Table 19. Coliform Bacteria counts/100 mls. runoff from storms occurring during 1982.

Storm Date	Watershed	Total	Fecal
Oct 12	1	364	0
	4	266	10
	5	780	0
Nov 27	1	0	124
	2	0	194
	3	0	350
	4	0	30
	5	0	10
Dec 2	1	2	208
	2	>1000	562
	3	96	352
	4	38	182
	5	0	206
Dec 13	1	32	38
	2	20	138
	3	0	184
	4	4	66
	5	4	28
Dec 25	1	>1000	155
	2	>1000	257
	3	>1000	405
	4	>1000	193
	5	>1000	166
Dec 26	1	76	42
	2	0	176
	3	0	208
	4	0	28
	5	0	110
Dec 31	1	0	6
	2	0	30
	3	416	14
	4	124	30
	5	340	32

(U.S. Environmental Protection Agency 1975). The recommended standard for primary contact recreation is 200 fecal coliform colonies per 100 ml. The watersheds averaged 137 fecal coliform/100 ml which is below the recommended standard and is suitable for primary contact recreation.

pH, and Specific Conductivity

1981 - pH measurements for 1981 averaged 5.5 for the watersheds (Table 20). Specific conductivity averaged 50 umhos/cm (Table 20).

1982 - Mean pH measurements averaged 5.3 for the watersheds, with watersheds 1 and 5 having the highest readings and watersheds 3 and 4 having the lowest (Table 20). Specific conductivity averaged 35.6 umhos/cm for the watersheds, with watershed 5 having the highest number and watershed 1 having the lowest (Table 20).

Table 20. Mean pH and specific conductivity by watershed, Angelina National Forest, Texas, 1981-1982.

Watershed	pH		Specific Conductivity umhos/cm	
	1981	1982	1981	1982
1	*	5.5	*	28.8
2	5.3	5.3	40	34.8
3	5.4	5.2	40	37.6
4	5.2	5.2	75	37.3
5	5.7	5.5	47	39.7
Mean	5.4	5.3	50	35.6

* Insufficient runoff to collect sample.

Louisiana Infiltration Study

The study area was sampled twice during 1982. The first measurements were made in June to characterize the areas prior to grazing exclusion. The areas samples were: 1) Pre No Silviculture No Graze, (P-NSNG), 2) No Silviculture With Graze (NSWG), 3) Pre Seedtree No Graze (P-STNG), and 4) Seedtree With Graze (STWG). Areas where exclosures were to be built were sampled, although they were being grazed and were labeled Pre No Silviculture No Graze and Pre Seedtree No graze to be able to characterize those areas.

The second sample date was in September, 3 mo. after livestock had been excluded. The treatments that were sampled were 1) No Silviculture No Graze (NSNG), 2) No Silviculture With Graze (NSWG), 3) Seedtree No Graze (STNG) and 4) Seedtree With Graze (STWG).

Infiltration

Statistical analysis of the June infiltration data showed no difference between treatments (Table 21, Fig. 3).

Analysis of the September infiltration data showed NSNG significantly greater than NSWG but was similar to both seedtree treatments (Table 22, Fig. 4). All the other treatments were not significantly different from each other.

Infiltration rates of the seedtree areas were similar, indicating little treatment difference due to grazing, while the no silviculture treatments indicated an impact of grazing. This indicates that areas

Table 21. Mean infiltration rate after 30 min, sediment production, vegetation, and soil data for the June 1982 sampling period, Kisatchie National Forest, Louisiana.

Parameter	TREATMENT			
	P-NSNG	NSWG	P-STNG	STWG
Infiltration (cm/hr)	4.77a	4.84a	4.02a	4.76a
Sediment (kg/ha)	48.2a	60.1a	51.1a	65.4a
Grass (kg/ha)	650	723	706	959
Forbs (kg/ha)	184	192	402	271
Litter (kg/ha)	6848	6890	3829	3100
Woody (kg/ha)	59	44	0	0
Texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Organic Matter %	3.4	4.2	4.6	4.8
Bulk Density				
0-5 (g/cc)	1.31	1.38	1.43	1.41
5-10 (g/cc)	1.49	1.39	1.51	1.48

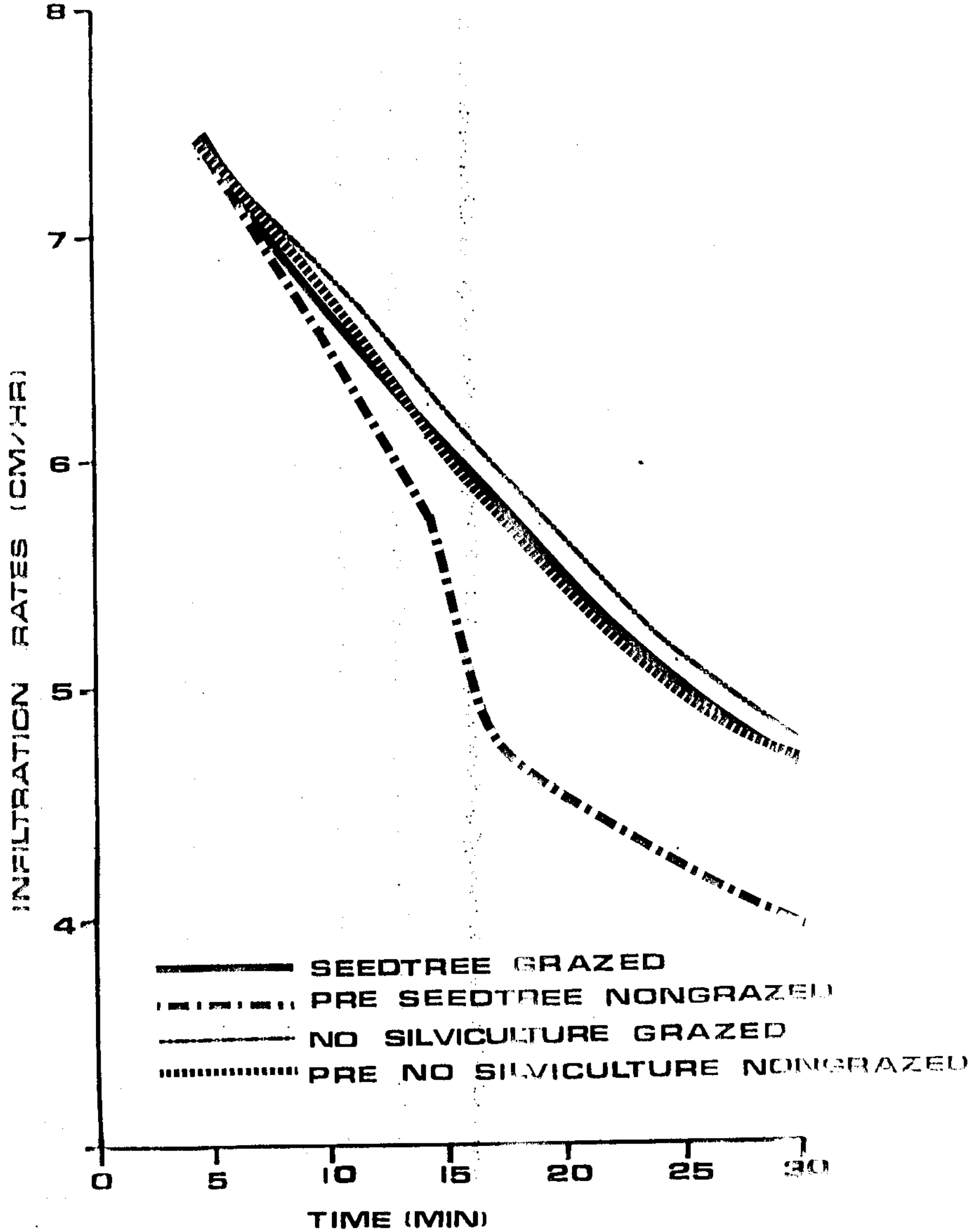

Figure 3. Mean infiltration curves for the various treatments, Kisatchie National Forest, Louisiana, June 1982.

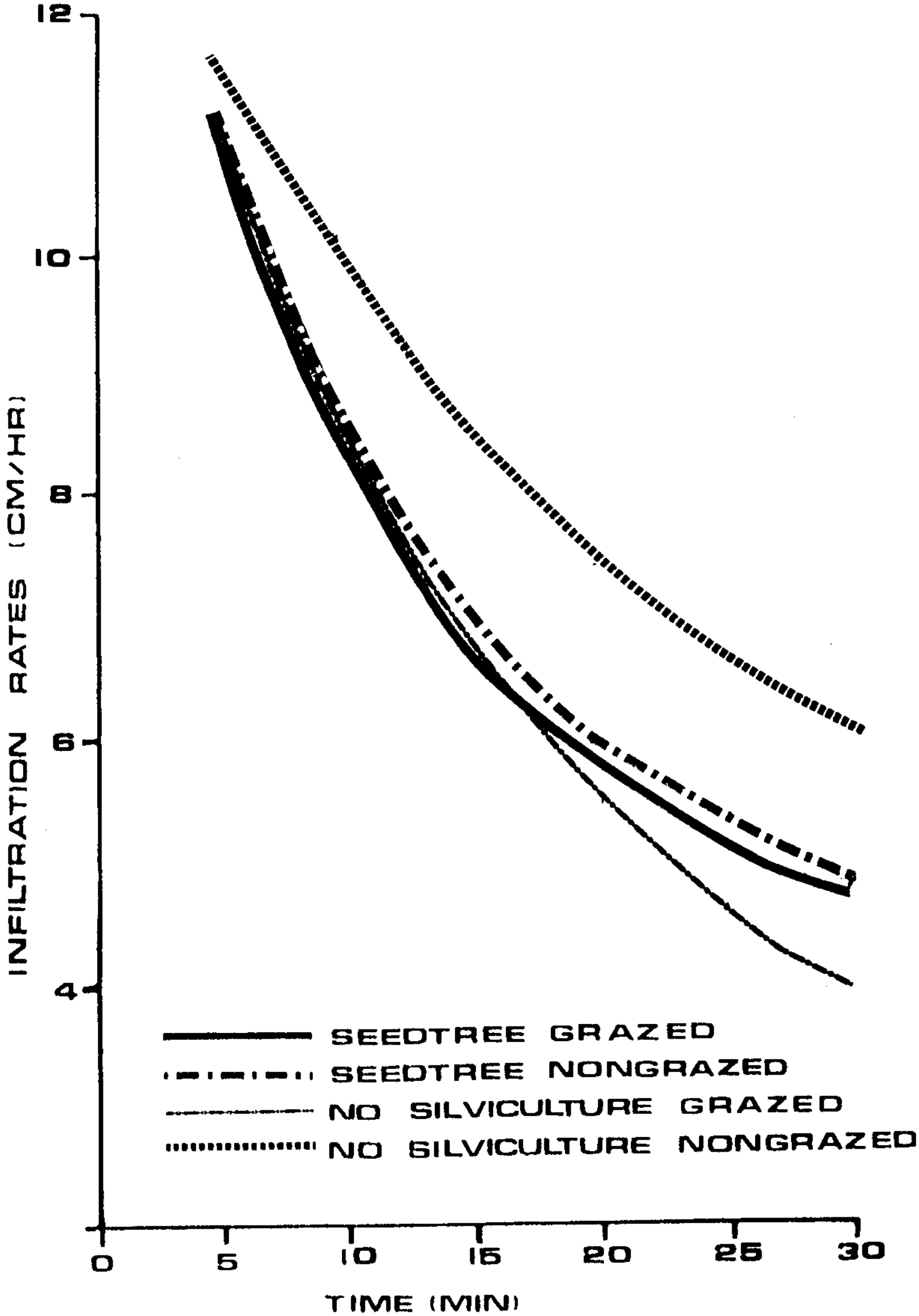

Figure 4. Mean infiltration curves for the various treatments, Kisatchie National Forest, Louisiana, September 1982.

already disturbed by silvicultural practices had a smaller grazing impact than an area not disturbed by silvicultural practices.

Sediment

Sediment production for the June and September sample periods was not significantly different between treatments (Table 21, 22).

Vegetation Production

Grass production for the June sample period differed little between treatments (Table 21). However, the seedtree area had a slightly higher grass produciton. The seedtree areas also had a greater amount of forbs than the no silviculture areas. This was probably due to the disturbance associated with logging. Litter was twice as great on the no silviculture areas than on the seedtree area. There were few woody plants in the no silviculture areas and no woody plants in the seedtree areas.

Grass production at the September sample period showed no major differences between the no silviculture and the seedtree areas (Table 22). However, within each major treatment area (no silviculture, seedtree) the grazed areas had less grass. Forb production on the seedtree areas was greater than on no silviculture areas (Table 22). The no silviculture areas had a much higher amount of litter than the seedtree sites (Table 22). There was very little difference in the amount of woody plants in the treatments (Table 22).

Table 22. Mean infiltration rate after 30 min, sediment production, vegetation and soil data from the September 1982 sampling period, Kisatchie National Forest, Louisiana.

Parameter	TREATMENT				
	NSNG	NSWG	STNG	STWG	Control*
Infiltration (cm/hr)	6.23a	3.86b	4.82ab	4.73ab	
Sediment (kg/hr)	228.0a	598.3a	329.7a	480.1a	
Grass (kg/ha)	1663	1050	1510	1305	
Forb (kg/ha)	228	223	396	376	
Litter (kg/ha)	7803	7003	4047	4926	
Woody (kg/ha)	36	56	19	12	
Texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	
Organic Matter %	3.5	3.9	4.4	3.7	
NO_3 (ug/l)	5.1	10.7	9.0	8.7	4.5
NH_4 (ug/l)	194	327	71	74	101
Total N (ug/l)	1105	1699	753	1384	182
Ortho P (ug/l)	59	74	52	59	37
Total P (ug/l)	416	431	342	436	84
Bacteria					
Total (#/100ml)	1.8	11.0	0	0	
Fecal (#/100ml)	1.6	0.3	0	2.7	
pH	4.5	4.9	4.4	4.9	
CA (mg/l)	2.40	2.99	2.58	3.21	18.9
Mg (mg/l)	2.26	2.35	2.17	2.40	2.2
K (mg/l)	5.29	4.95	6.05	5.78	2.7
Na (mg/l)	45.40	46.58	46.70	47.52	44.3
Bulk Density					
0-5 (g/cc)	1.32	1.35	1.34	1.33	
5-10 (g/cc)	1.36	1.35	1.36	1.37	

* Nutrient concentrations of the water used for the rainfall application.

Aggregate Stability

Aggregate stability was not determined because the aggregates were too tightly aggregated for the slake method and too weakly aggregated for the wet sieve method.

Texture

Texture for the plots in both sample periods was sandy loam (Table 21, 22).

Organic Matter

Percent organic matter for the June sample period did not differ much between treatments (Table 21). The percent organic matter during the September sample period was very similar for all treatments (Table 22).

Bulk Density

Bulk density for the June sample period (0-5 cm depth) ranged from 1.31 to 1.43 g/cc with the seedtree areas having the greatest bulk density. Bulk density at the 5-10 cm depth was similar for all treatments (Table 21). The bulk densities for the September sample period were similar for both the 0-5 and 5-10 cm depths and treatments (Table 22).

Nutrients

Nutrients were analyzed only for the September sampling period. No major differences in nutrients could be found between treatments (Table 22).

Broaddus Infiltration Study

The Broaddus study areas were sampled during July, 1982. Five sites were sampled which correspond to pastures of proposed grazing system (Figure 5). This sampling period is to characterize these areas before treatment.

Infiltration

There was no major difference between sites. Site 1 had the highest infiltration rate (7.01 cm/hr), followed by 4 (6.84 cm/hr), 3 (6.52 cm/hr), 2 (6.30 cm/hr) and 5 (5.87 cm/hr) (Table 23) (Figure 6).

Sediment

Study site 3 had the greatest sediment production (125.39 kg/ha), twice site 2 (65.45 kg/ha) and 5 (60.14 kg/ha). Sediment production was lowest for site 1 (51.91 kg/ha) and site 4 (33.41 kg/ha) (Table 23).

Vegetation Production

There was little difference in grass production between plots 1 through 3, but sites 4 and 5 were greater due to the thinning that had recently occurred. Site 1 had the most forbs while site 3 had none (Table 23). There was very little variation in litter for the sites except for site 3 which had only one half the litter accumulation of the other sites (Table 23).

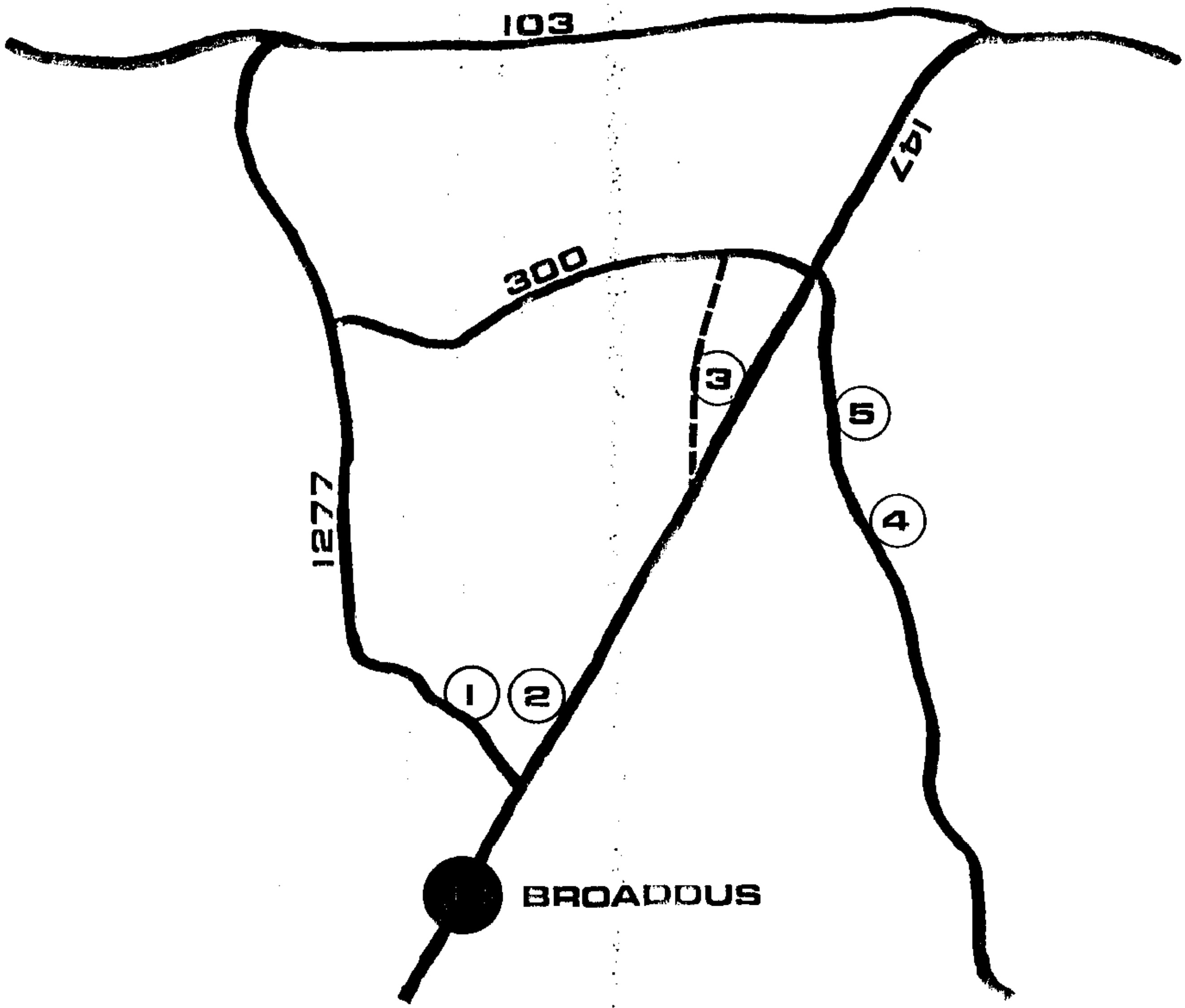

Figure 5. Detail of the study site showing locations of the five infiltration sites, Angelina National Forest, Texas.

Table 23. Mean infiltration rate after 30 min, sediment production, vegetation and soil data for the July 1982 sampling period, Angelina National Forest, Texas.

Parameter	SITE 1	2	3	4	5
Infiltration (cm/hr)	7.01	6.30	6.52	6.84	5.87
Sediment (kg/ha)	51.9	65.5	125.4	33.4	60.1
Grass (kg/ah	178	171	194	304	575
Forb (kg/ha)	233	130	0	104	60
Litter (kg/ha)	11041	12809	5269	11212	10232
Woody (kg/ha)	19	269	180	307	179
Bulk Density					
0-5 (g/cc)	1.03	1.15	1.13	1.12	1.18
5-10 (g/cc)	1.18	1.41	1.38	1.21	1.24
Texture	Loam	Loam	Sandy Laom	Sandy Loam	Sandy Loam
Organic Matter %	5.0	5.8	3.4	3.7	3.4

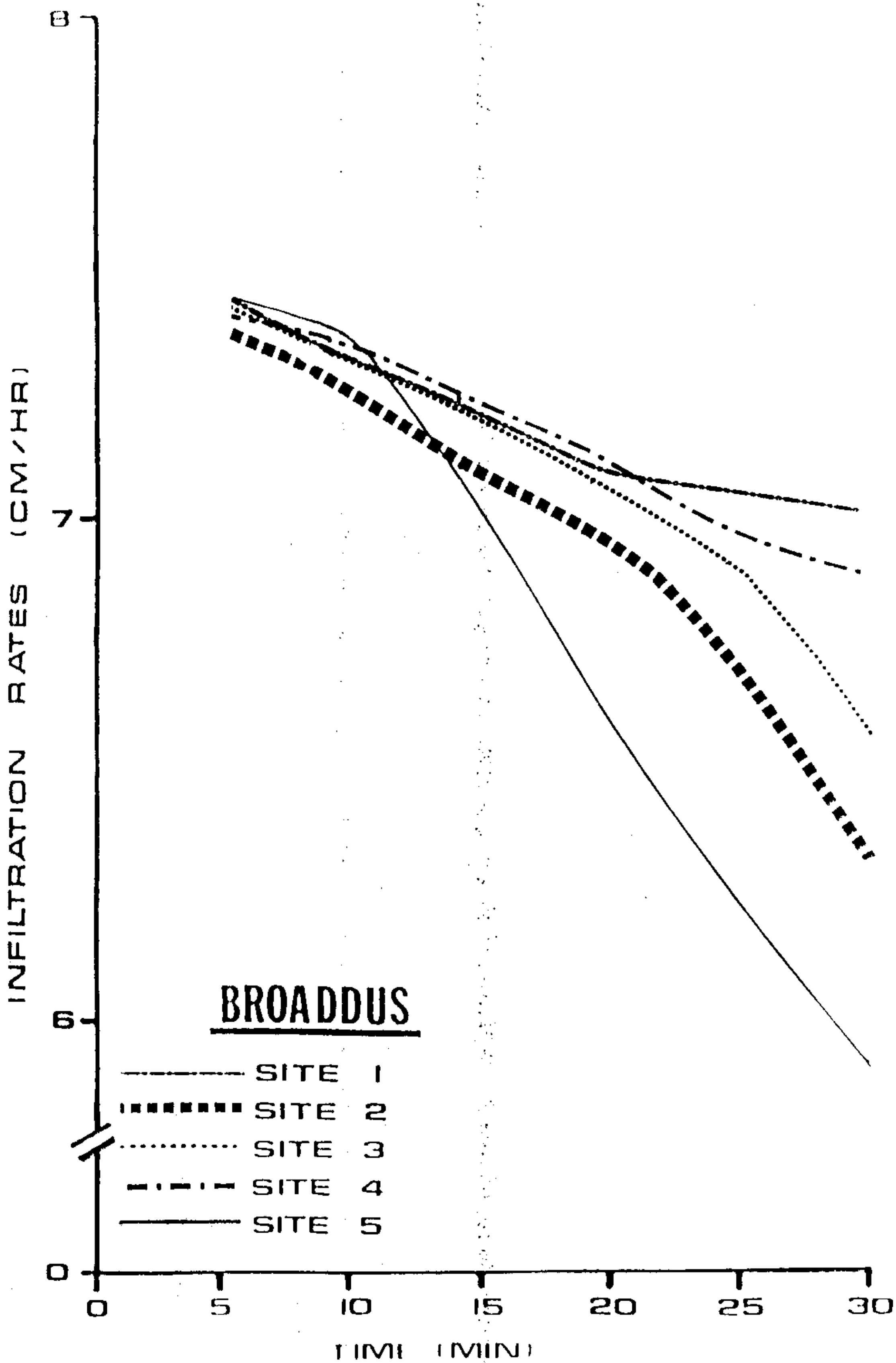

Figure 6. Mean infiltration curves for the five study sites, Angelina National Forest, Texas, July 1982.

Bulk Density

Bulk density (0-5 cm and 5-10 cm depth) varied little between sites.

Texture

Sites 1 and 2 have a loam surface soil texture and sites 3, 4 and 5 have a sandy loam surface (Table 23).

Organic Matter

The percent organic matter was greater for sites 1 and 2 than sites 3, 4 and 5 (Table 23).

Aggregate Stability

Aggregate stability was not determined because they were too tightly aggregated for the slake method and too weakly aggregated for the wet sieve method.

Prescribed Burning Study

Prescribed burning is an accepted timber management technique in the southern pine forest region. Burning may impact forest soil production potential by accelerating erosion, decreasing infiltration and water holding capacity, and reducing drainage water quality. Therefore it is important that modification in forest soil properties brought about by prescribed burning be known. In 1982 a study was initiated to determine the effects of 20 years of prescribed fire on the hydrological and chemical properties of southern forest soils. The study area is located in an ungrazed 100 ha stand of longleaf pine/pinehill bluestem on the Palustris Experimental Forest, 54 km south of Alexandria, Louisiana. The predominant soil type is a Ruston fine sandy loam on slopes of 1-3 percent.

Burning treatments have been applied biennially since 1962 during three seasons, winter, spring, and summer (Grelen 1967). The 900 m^2 plots were last burned in 1982. Simulated rainfall was applied at 12.6 cm/h for a duration of 45 minutes to determine infiltration rate, sediment production, and runoff water quality.

Infiltration Rates

Following the 1982 burning period, average infiltration rates were determined for each seasonal treatment and the unburned control. Average infiltration rates after 45 minutes for winter burning treatments were different when compared to control plots (Figure 7). After 10 months

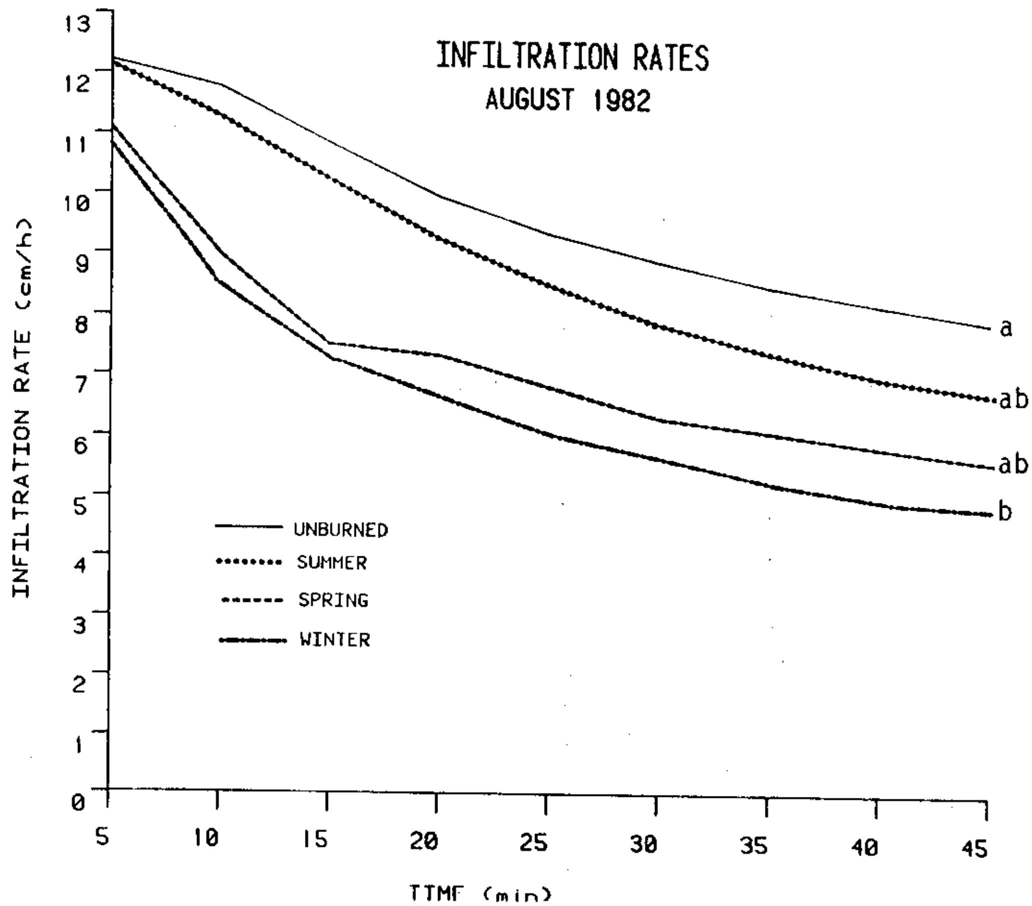

Figure 7. Mean infiltration rates immediately following fire treatments. Mean infiltration rates after 45 minutes not followed by the same letter are significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

of no burning, these differences were insignificant (Figure 8).

Sediment Production

August 1982 runoff from rainfall simulation plots contained significantly greater suspended sediment from winter (1451.2 kg/ha) burns than from the unburned (45.6 kg/ha) control (Table 24). Within 10 months these treatment differences were insignificant (Table 25).

Nutrients - Nitrogen and Phosphorus

Fertility loss from the forest ecosystem results from volatilization, leaching, and erosion. Burning may accelerate these losses or increase short-term availability through nutrient release. Runoff water samples were tested for total nitrogen, nitrate plus nitrite, and ortho-phosphate.

Concentration of unfiltered total nitrogen reflects nitrogen in solution as well as suspended solid organic material and mineral sediment. Total nitrogen loss from the unburned control was greater than from the 1982 burning treatment (Table 24). Similarly, in June 1983 runoff concentrations of unfiltered total N were greater from the unburned plots (Table 25) than from the winter or spring burns but only slightly less than the summer burn. Both the unburned control and summer burns contained greater amounts of organic material on the plot surface.

The greatest loss of filtered total nitrogen still occurred from the unburned control. This relationship is maintained following 1982 burning (Table 24) as well as 10 months later (Table 25).

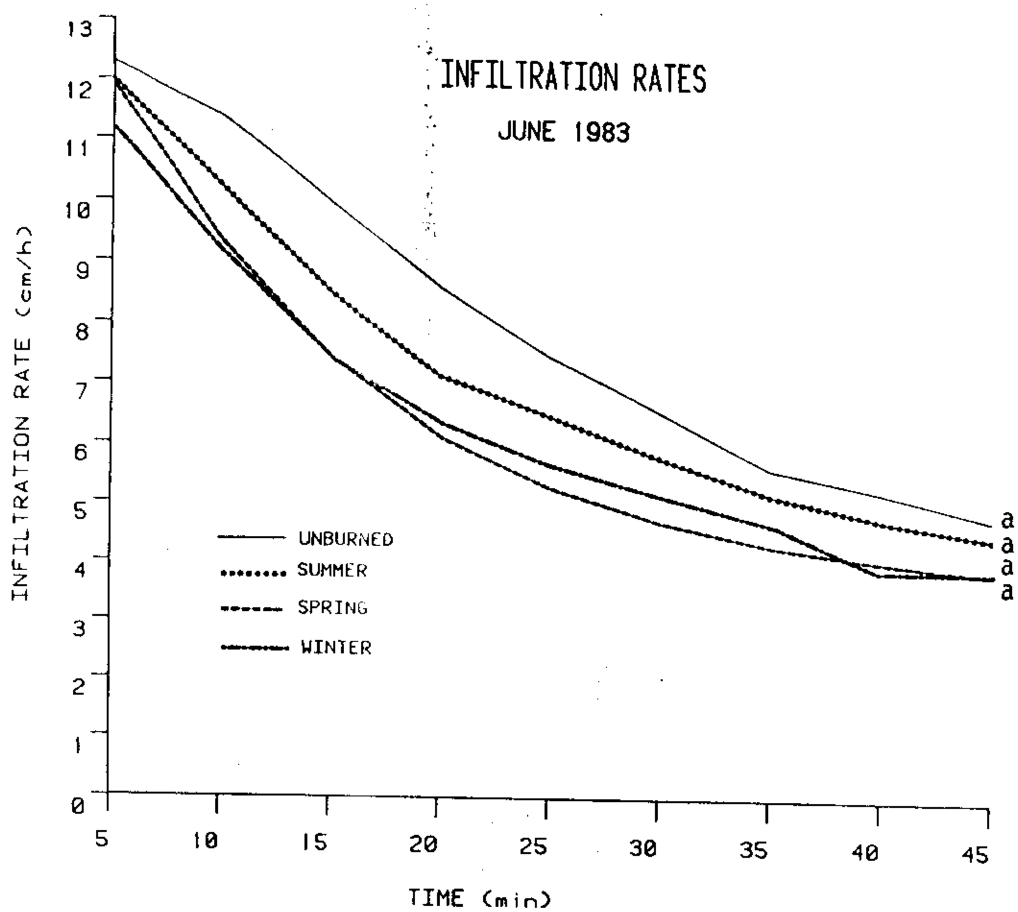

Figure 8. Mean infiltration rates 10 months following fire treatments. Mean infiltration rates after 45 minutes not followed by the same letter are significantly different according to Fisher's protected LSD test ($\alpha = 0.05$).

Table 24. Mean values for sediment production and nutrient removal from rainfall simulation plots, Palustris Experimental Forest, Louisiana, August 1982. Means not followed by the same letter are significant (α = 0.05) according to Fisher's unprotected LSD test.

Burning Treatment	Sediment (kg/ha)	Unfiltered Total N (ug/l)	Filtered Total N (ug/l)	Nitrate + Nitrite (ug/l)	Ortho-Phosphate (ug/l)
Winter	1451.2a	2396.7	380.2	14.6	319.9
Spring	1271.8ab	3425.7	346.1	10.2	373.3
Summer	878.8ab	4439.4	312.5	13.3	356.9
Unburned	451.6b	4882.6	551.8	23.9	239.1
Application Water	--	52.2	42.2	6.9	362.0

Table 25. Mean values for sediment production and nutrient removal from rainfall simulation plots, Palustris Experimental Forest, Louisiana, June 1983. Means not followed by the same letter are significant (α = 0.05) according to Fisher's unprotected LSD test.

Burning Treatment	Sediment (kg/ha)	Unfiltered Total N (ug/l)	Filtered Total N (ug/l)	Nitrate + Nitrite (ug/l)	Ortho-Phosphate (ug/l)
Winter	175.7a	833.5	281.6	14.8	290.6
Spring	150.4a	1328.0	252.9	17.9	298.6
Summer	175.2a	1516.7	285.6	19.1	292.4
Unburned	151.6a	1452.2	491.2	17.0	236.6
Application Water	--	65.9	73.2	17.9	394.3

Unfiltered concentration of ortho-phosphate, the mobile form of inorganic phosphorus (Table 24) for the August 1982 application water (362.0 ug/l) was similar to the August 1982 values for winter (319.9 ug/l), spring (373.3 ug/l), and summer (356.9 ug/l). The unburned control plots effectively filtered the phosphorus from the application water. By June 1983 concentrations in runoff from all plots were lower than the concentration of the application water (Table 25).

Nutrients - Calcium, Magnesium, Potassium, Sodium

Water samples are currently being tested for Ca, Mg, K, and Na. However, this data was not available at the time of publication.

Summary

In summary, increased raindrop impact on bare soil resulting from prescribed fire decreased infiltration rates and elevated suspended sediment of burning treatments versus unburned control plots. After 10 months these differences were insignificant. No significant nutrient losses have been detected.

Tension Lysimeters

In addition to the rainfall simulation, each burning treatment replication containes two tension lysimeters to capture nutrients lost in leaching water. Presently, soil water is being collected from two depths, 15 cm and 40 cm. These samples are being analyzed for the movement of nitrogen, phosphorus, and the major cations through the soil solution.

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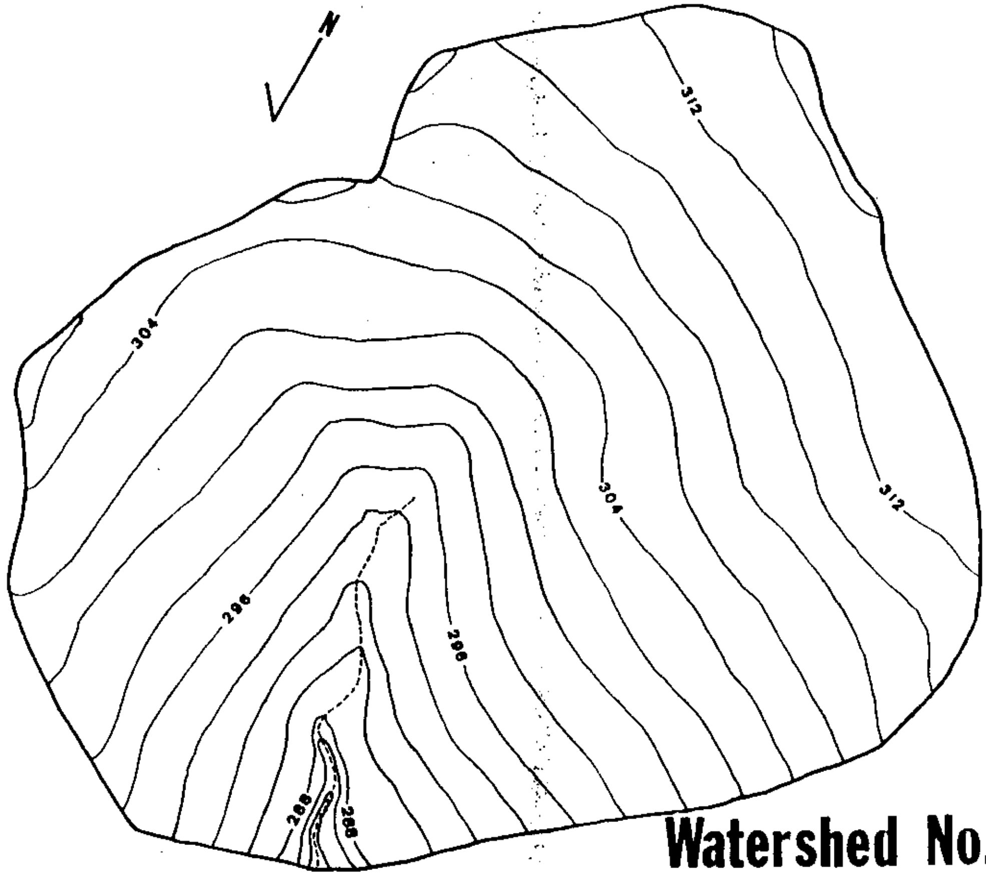
APPENDIX:

Watershed Maps



Watershed No. 1

LEGEND

Watershed Boundary ———

Contour Interval 2 feet ———

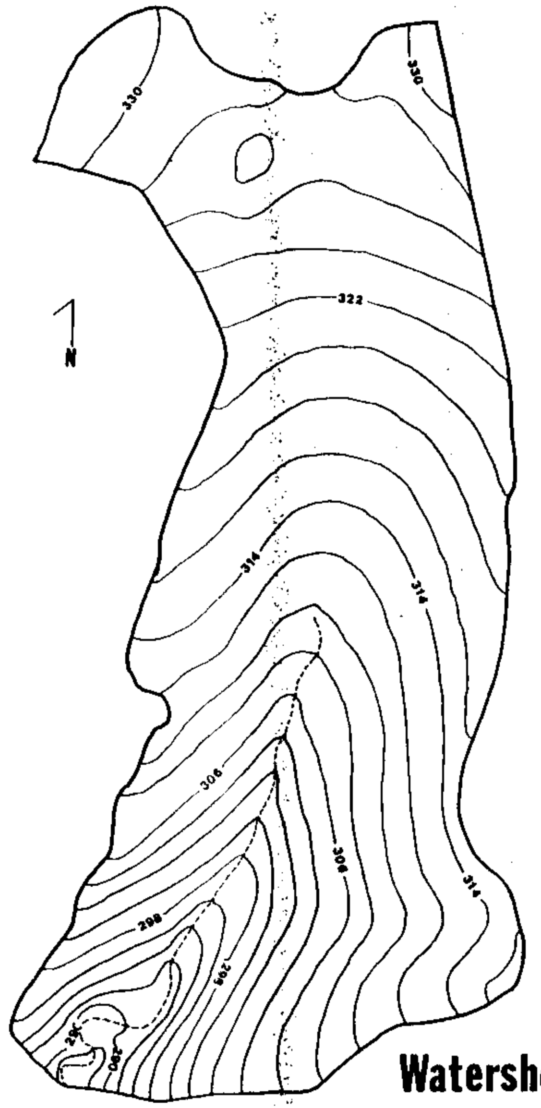
Channel - - - - - - - -

SCALE

0 100 200 feet

Angelina National Forest

San Augustine County, Texas



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LEGEND

Watershed Boundary ———

Contour Interval 2 feet ———

Channel ---------

SCALE

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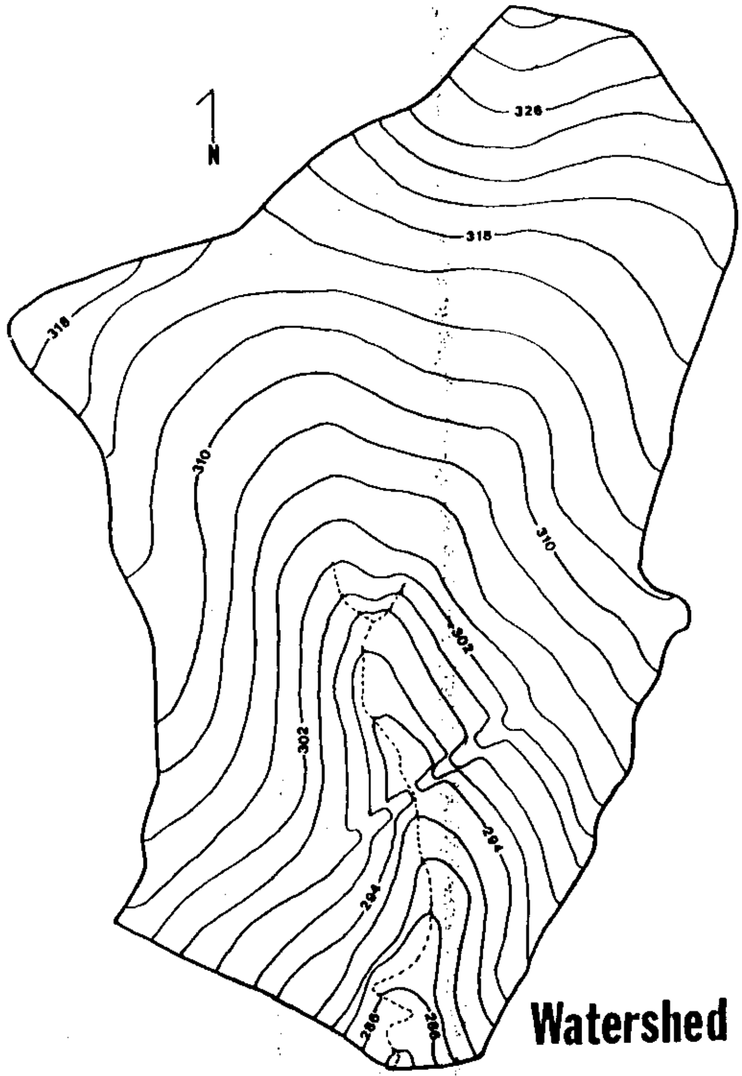
Angelina National Forest

San Augustine County, Texas



Watershed No.3

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Watershed Boundary ————

Contour Interval 2 feet ————

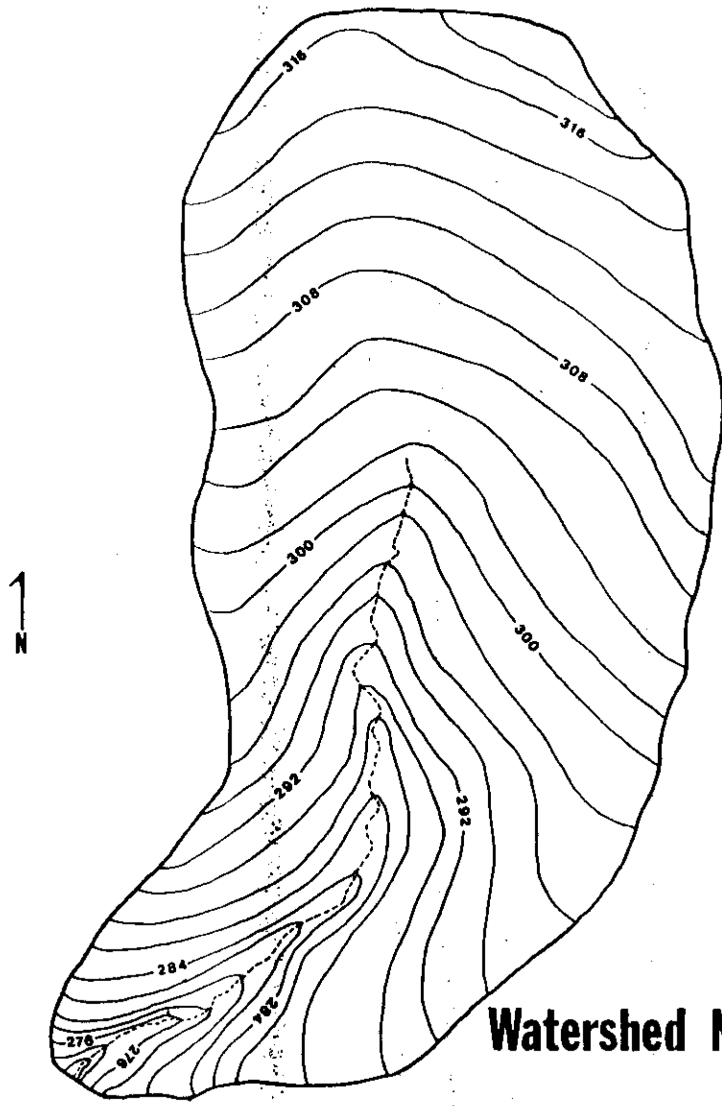
Channel ------------

SCALE

0 100 200 feet

Angelina National Forest

San Augustine County, Texas



Watershed No. 4

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Watershed Boundary ————

Contour Interval 2 feet ————

Channel - - - - - - -

SCALE

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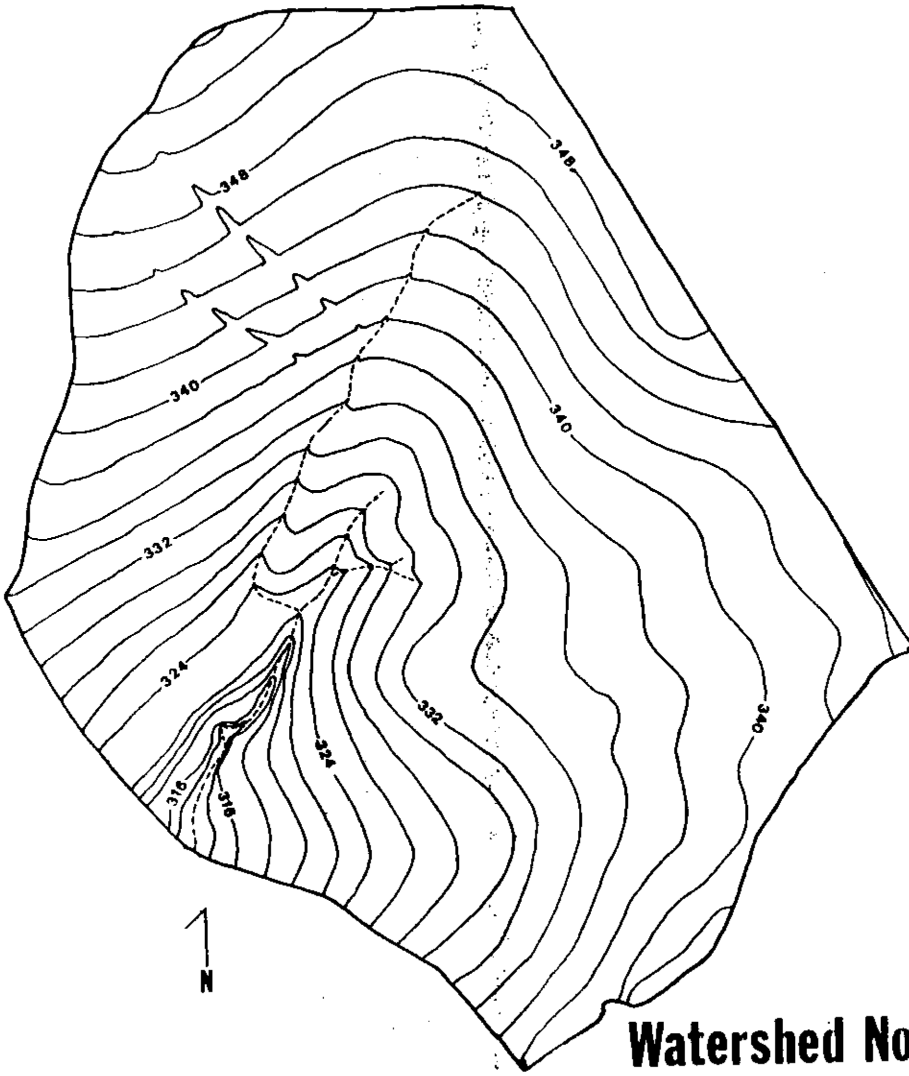
Angelina National Forest

San Augustine County, Texas



Watershed No. 5

LEGEND

Watershed Boundary ————

Contour Interval 2 feet ————

Channel - - - - - - - - -

SCALE

0 100 200 feet

Angelina National Forest

San Augustine County, Texas